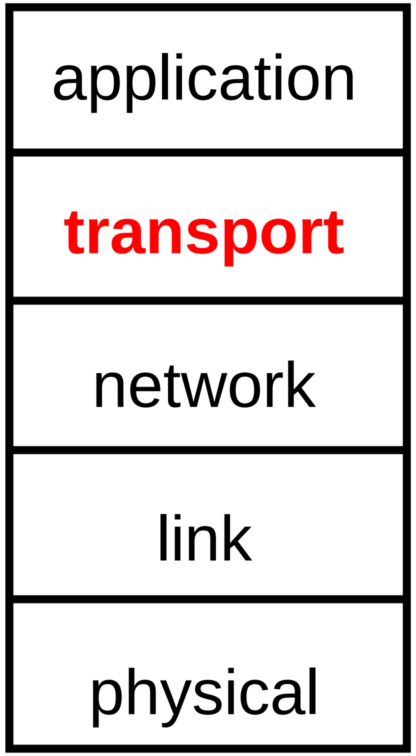
6. Transport layer and network layer

- transport layer
  - transport-layer services
  - multiplexing and demultiplexing
  - connectionless transport: UDP
  - connection-oriented transport: TCP
- network layer – data plane
  - overview of network layer
  - what’s inside a router
  - Internet Protocol (IP)
  - generalized forwarding and Software-Defined Networking (SDN)

- *application:* supporting network applications
  - FTP, SMTP, HTTP
- *transport:* process-process data transfer
  - TCP, UDP
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- *physical:* bits “on the wire”



5-layer Internet protocol stack

- transport layer provides communication services directly to the application processes running on different end systems
- extends the network layer’s delivery service between two end systems
- What are the principles? How to implement them in protocol**s**?
- connectionless transport protocol - User Datagram Protocol (UDP)
- reliable communication - Transmission Control Protocol (TCP)

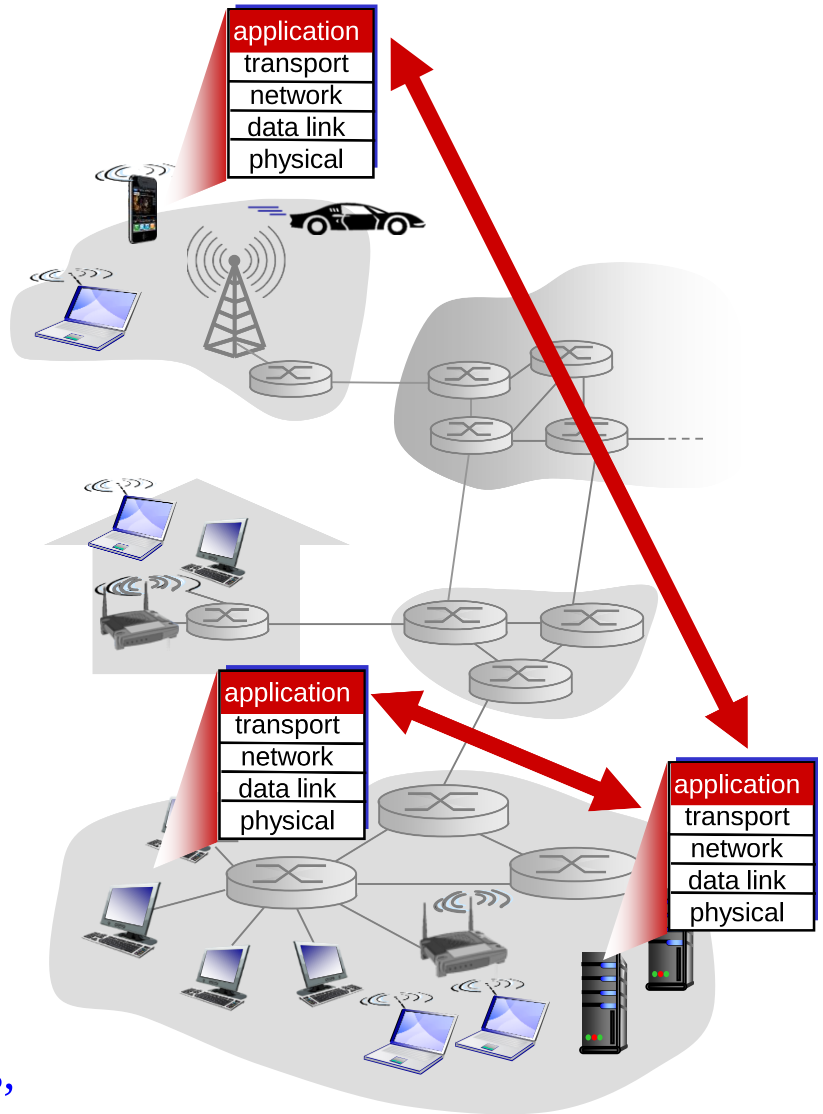
6.1 Transport-layer services

write programs that:

- run on (different) *end systems*
- communicate over network
- e.g., web server software communicates with browser software

no need to write software for network-core devices

- network-core devices do not run user applications
- applications on end systems allows for rapid app development, propagation



Transport-layer protocols are implemented in the end systems, not in the network routers *process:* program running within a host

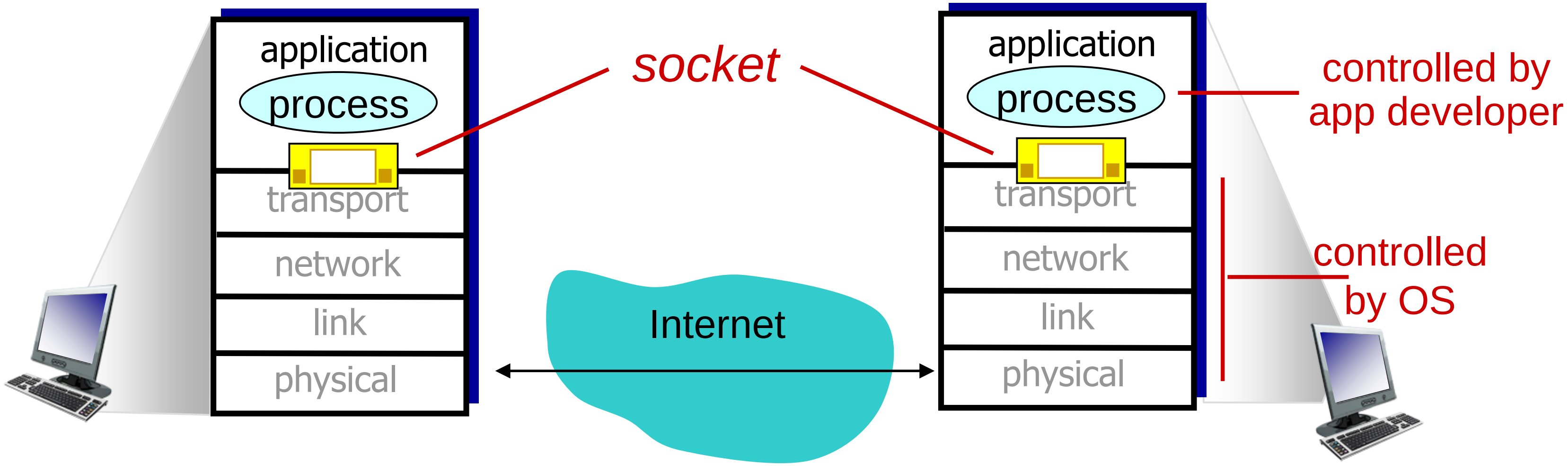
- within same host, two processes communicate using inter-process communication (defined by OS)
- processes in different hosts communicate by exchanging messages

clients, servers

client process: process that initiates communication

server process: process that waits to be contacted

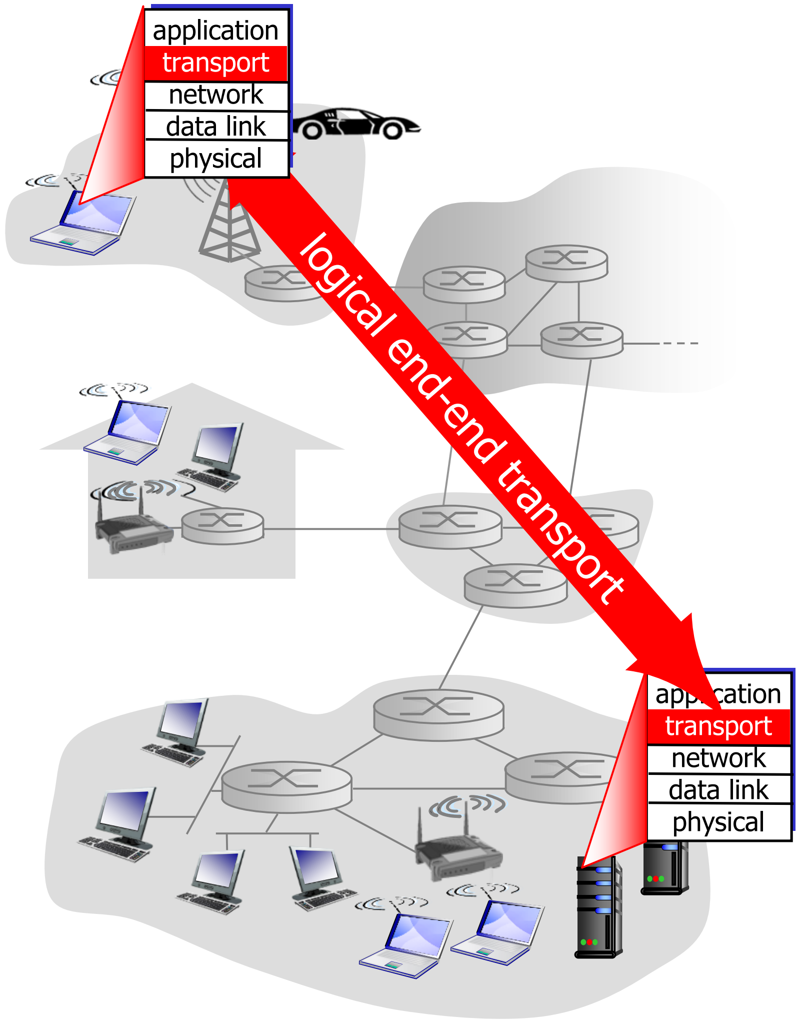
- process sends/receives messages to/from its socket
- socket analogous to door
  - sending process shoves message out door
  - sending process relies on transport infrastructure on other side of door to deliver message to socket at receiving process



- to receive messages, process must have *identifier*
- host device has unique 32-bit IP address
- *Q:* does IP address of host on which process runs suffice for identifying the process?
  - *A:* no, *many* processes can be running on the same host

- *identifier* includes both IP address and port numbers associated with process on host.
- example port numbers:
  - HTTP server: 80
  - mail server: 25
- to send HTTP message to gaia.cs.umass.edu web server:
  - IP address: 128.119.245.12
  - port number: 80

- provide *logical communication* between app processes running on different hosts
- transport protocols run in end systems
  - sender side: breaks app messages into *segments*, passes to network layer
  - receiver side: reassembles segments into messages, passes to app layer
- more than one transport protocol available to apps
  - Internet: TCP and UDP

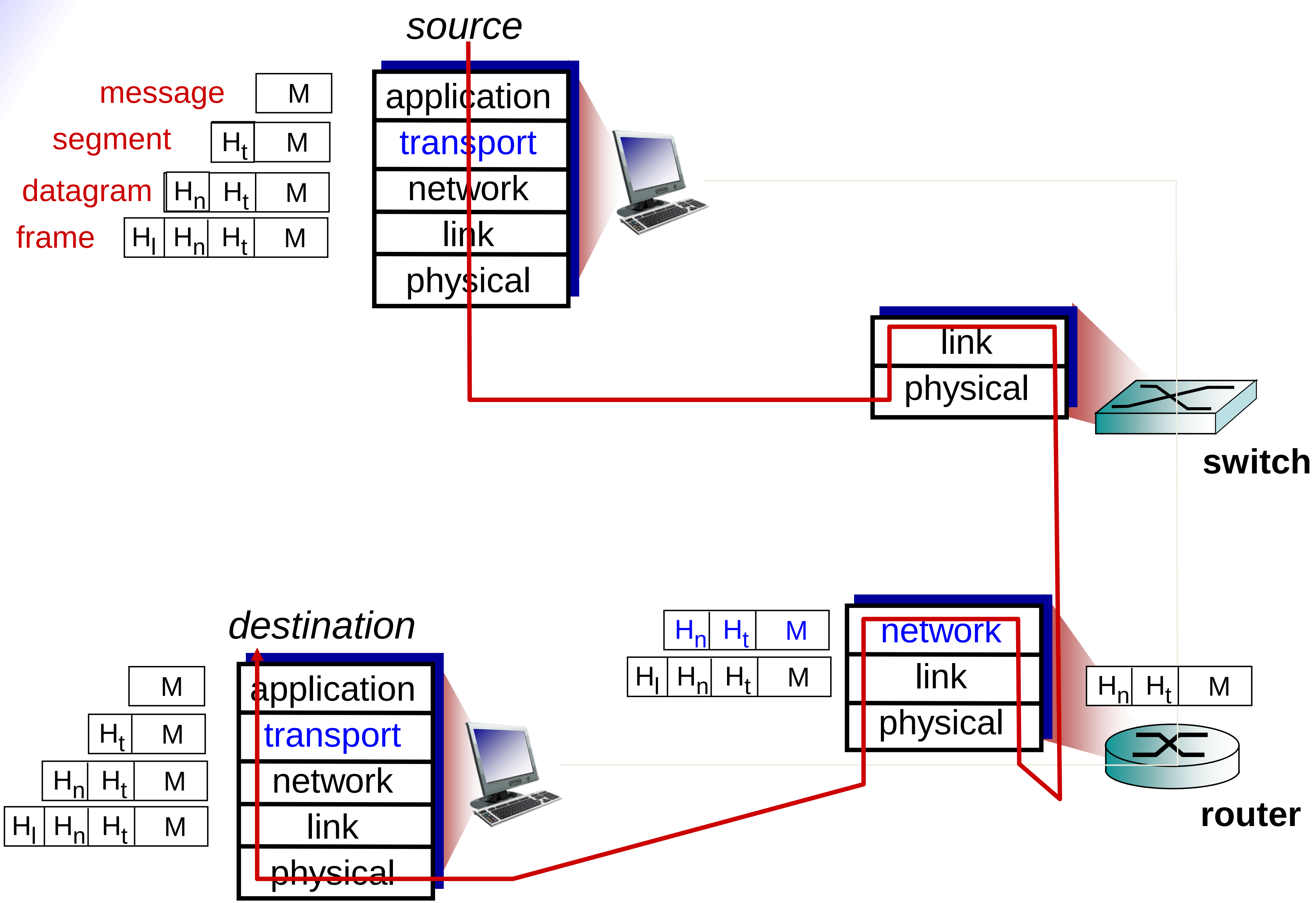


- sender – application process sends messages to transport layer
- transport layer converts messages into transport-layer packets (segments) with addition of transport-layer header
- transport layer passes segment to network layer
- network layer converts segment into network-layer packet (datagram) with the addition of network-layer field
- datagram is sent to the destination

- network routers act only on network-layer field of the datagram

- receiver – network layer extracts the transport-layer segment from datagram, passes the segment up to the transport layer

- transport layer processes the received segment, passes the data/messages to the receiving application process


source
message
segment
datagram
frame
M
Ht M
Hn Ht M
Hl Hn Ht M
application
transport
network
link
physical
link
physical
switch
destination
application
transport
network
link
physical
M
Ht M
Hn Ht M
Hl Hn Ht M
network
link
physical
Hn Ht M
Hl Hn Ht M
Hn Ht M
router

Transport vs. network layer

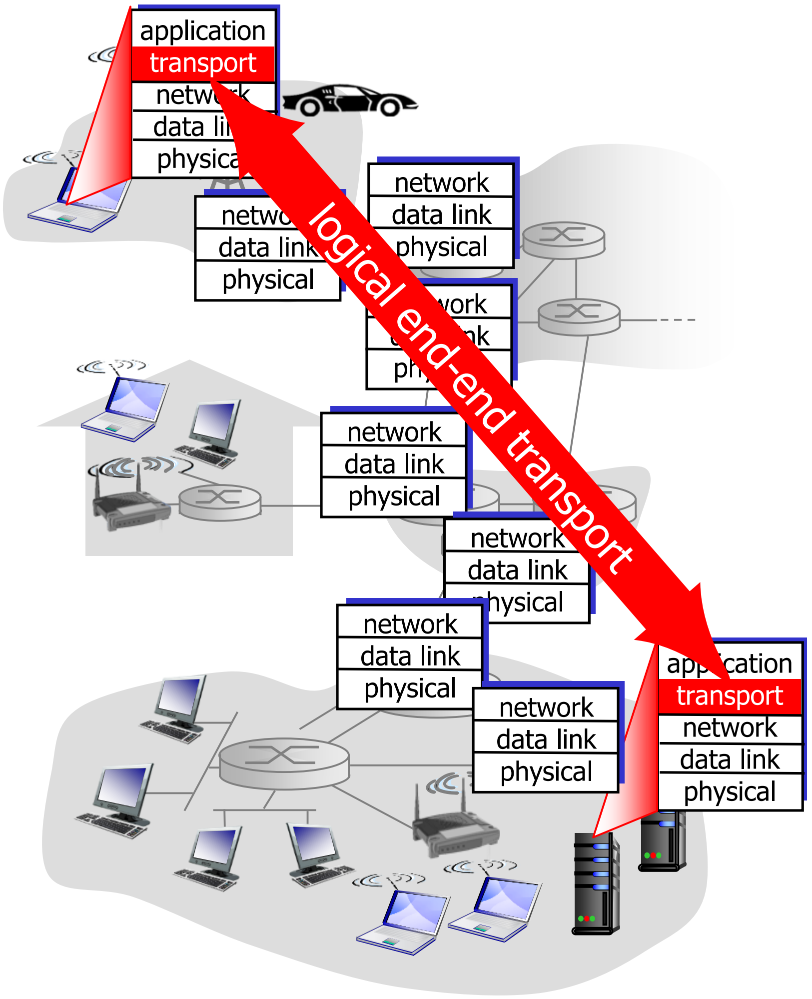
- *network layer:* logical communication between hosts
- *transport layer:* logical communication between processes
  - relies on, enhances, network layer services

household analogy:

12 kids in Ann's house sending letters to 12 kids in Bill's house:

- hosts = houses
- processes = kids
- app messages = letters in envelopes
- transport protocol = Ann and Bill who demux to in-house siblings
- network-layer protocol = postal service

- reliable, in-order delivery (TCP)
  - flow control
  - congestion control
  - connection setup
- unreliable, unordered delivery: UDP
  - no-frills extension of "best-effort" Internet Protocol (IP) – network-layer protocol
- services not available:
  - delay guarantees
  - bandwidth guarantees



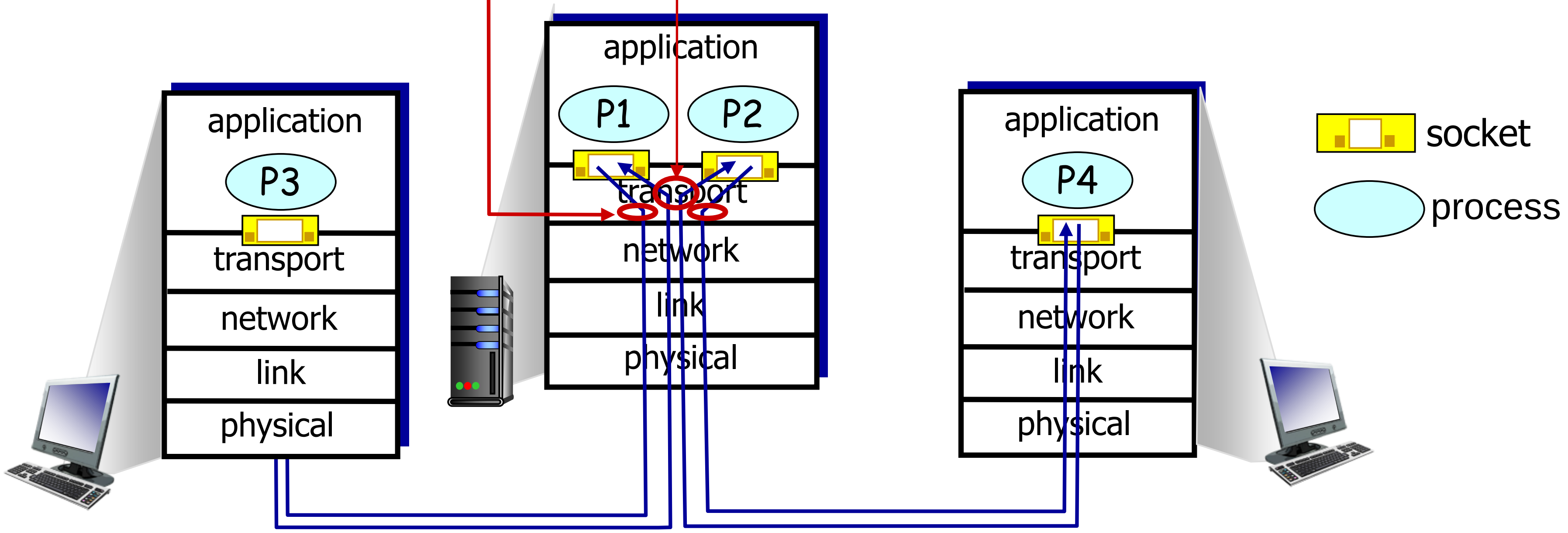
6.2 Multiplexing and demultiplexing

multiplexing at sender:

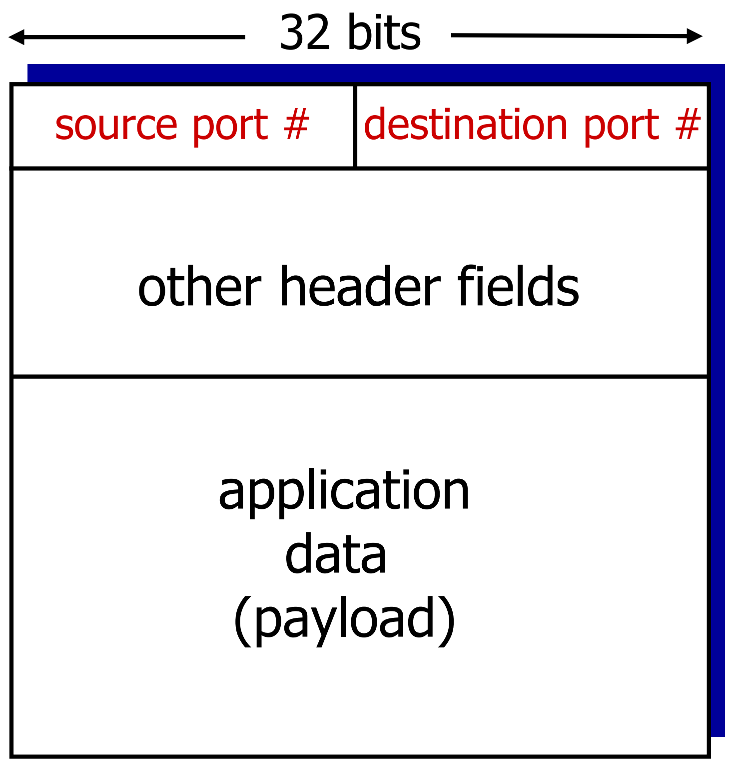
handle data from multiple sockets, add transport header (later used for demultiplexing)

demultiplexing at receiver:

use header info to deliver received segments to correct socket



- host receives IP datagrams
  - each datagram has source IP address, destination IP address
  - each datagram carries one 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

Destination port number is 16-bit (0 – 65535). 0-1023 are well-known port numbers (restricted). For instance, HTTP port number is 80.

- *note:* created socket has host-local port #:

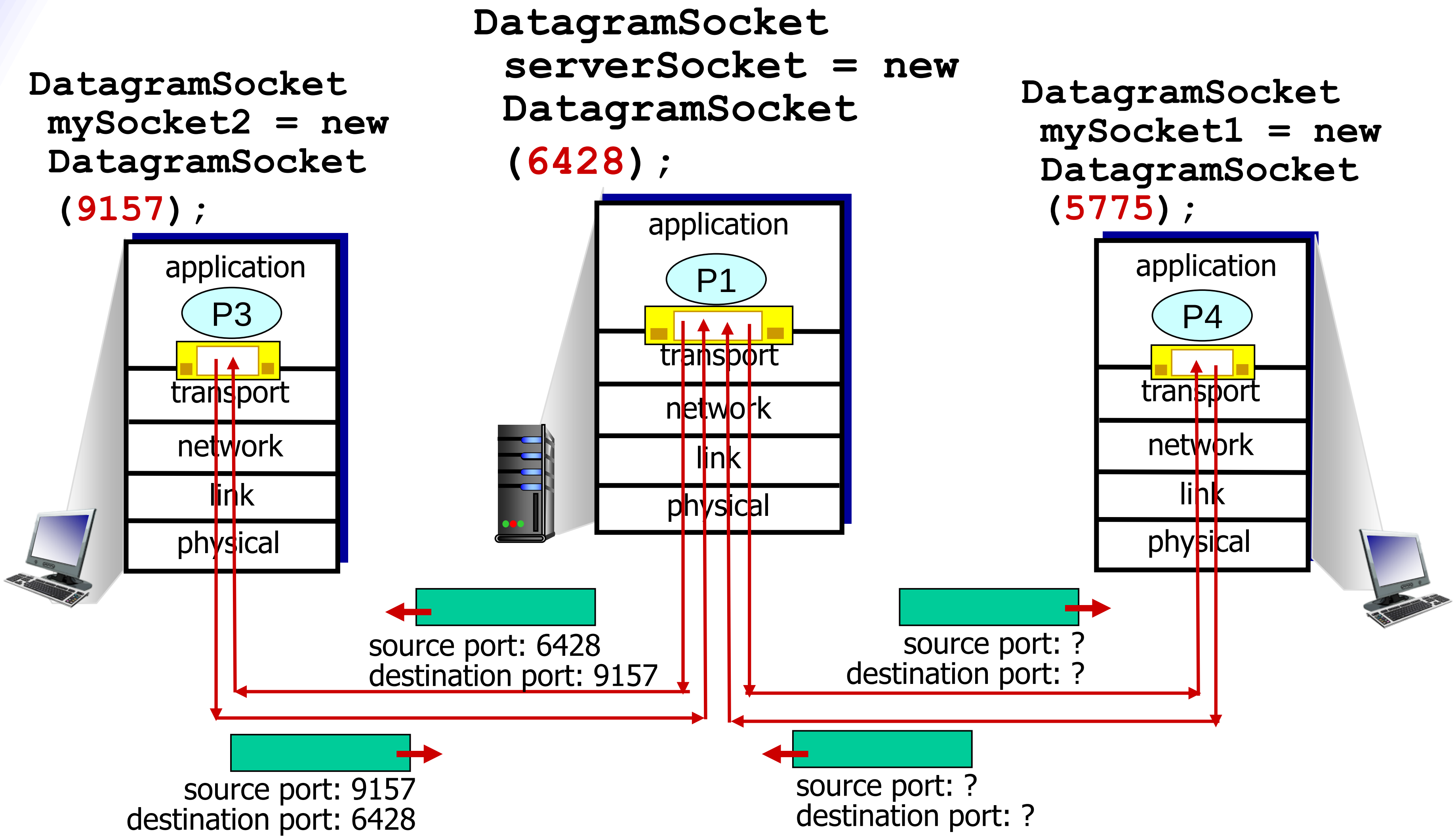
```
DatagramSocket mySocket1
= new DatagramSocket(12534);
```

- *note:* when creating datagram to send into UDP socket, must specify
  - destination IP address
  - destination port #

- when host receives UDP segment:
  - checks destination port # in segment
  - directs UDP segment to socket with that port #

→ IP datagrams with *same destination port #,* but different source IP addresses and/or source port numbers will be directed to *same socket* at destination

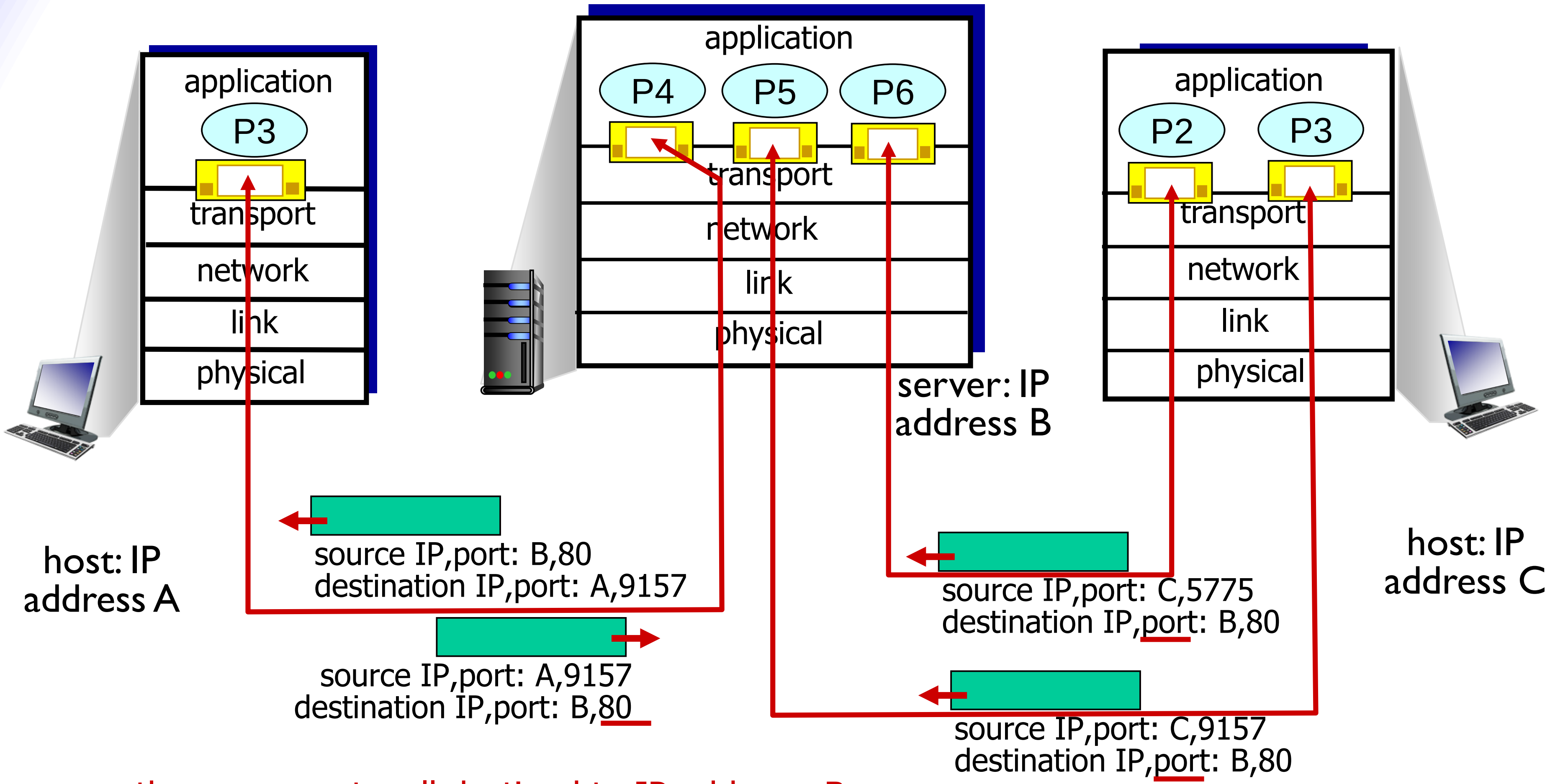
Example



To reverse the communication direction, just reverse the source and destination port numbers!

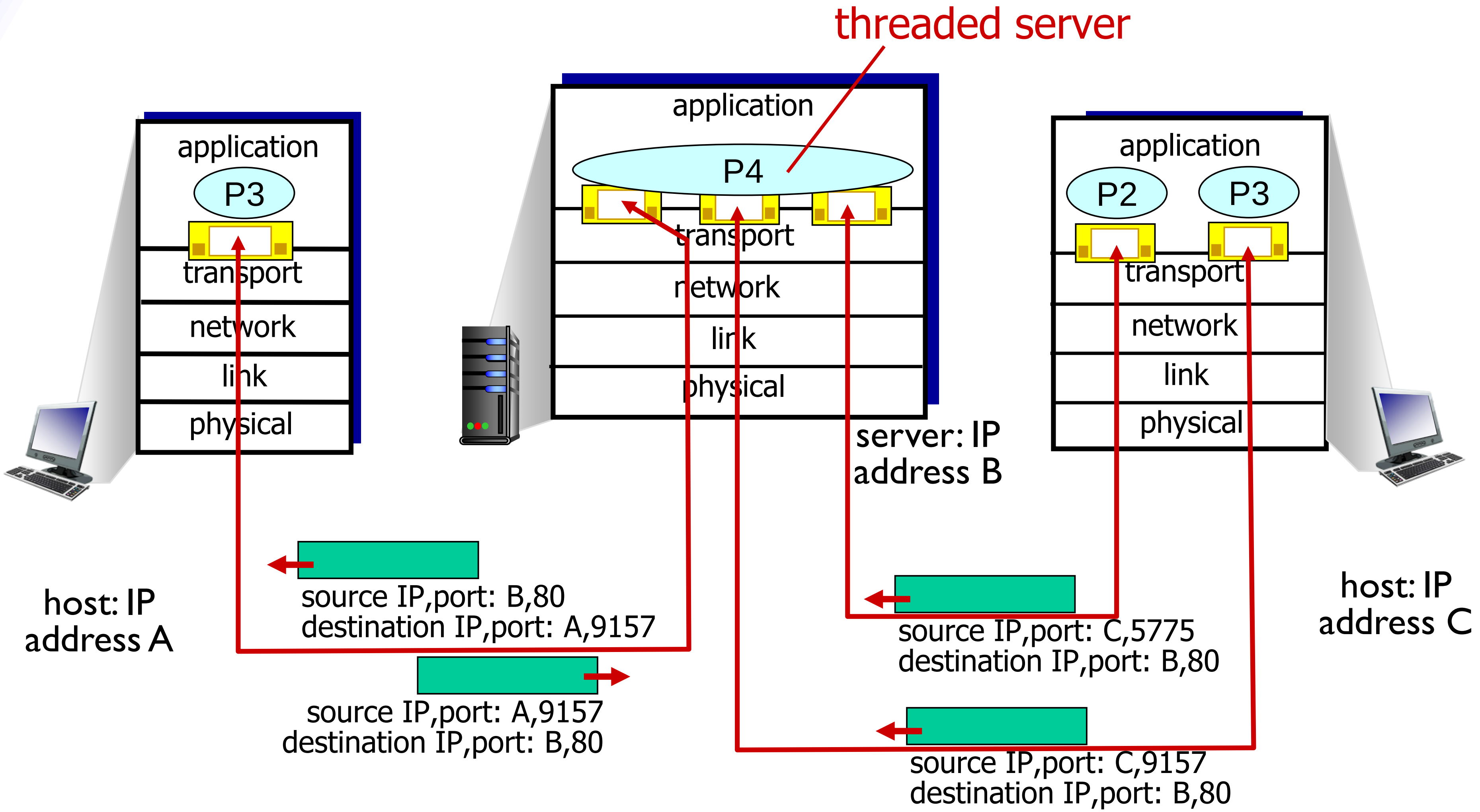
- TCP socket identified by 4-tuple:
  - source IP address
  - source port number
  - destination IP address
  - destination port number
- demultiplexing: receiver uses all four values to direct segment to appropriate socket
- server host may support many simultaneous TCP sockets:
  - each socket identified by its own 4-tuple
- web servers have different sockets for each connecting client
  - non-persistent HTTP will have different socket for each request

Example



three segments, all destined to IP address: B,
destination port: 80 are demultiplexed to *different* sockets

Example



Only 1 process. A new thread (sub-process) is created with a new socket for each new client connection.

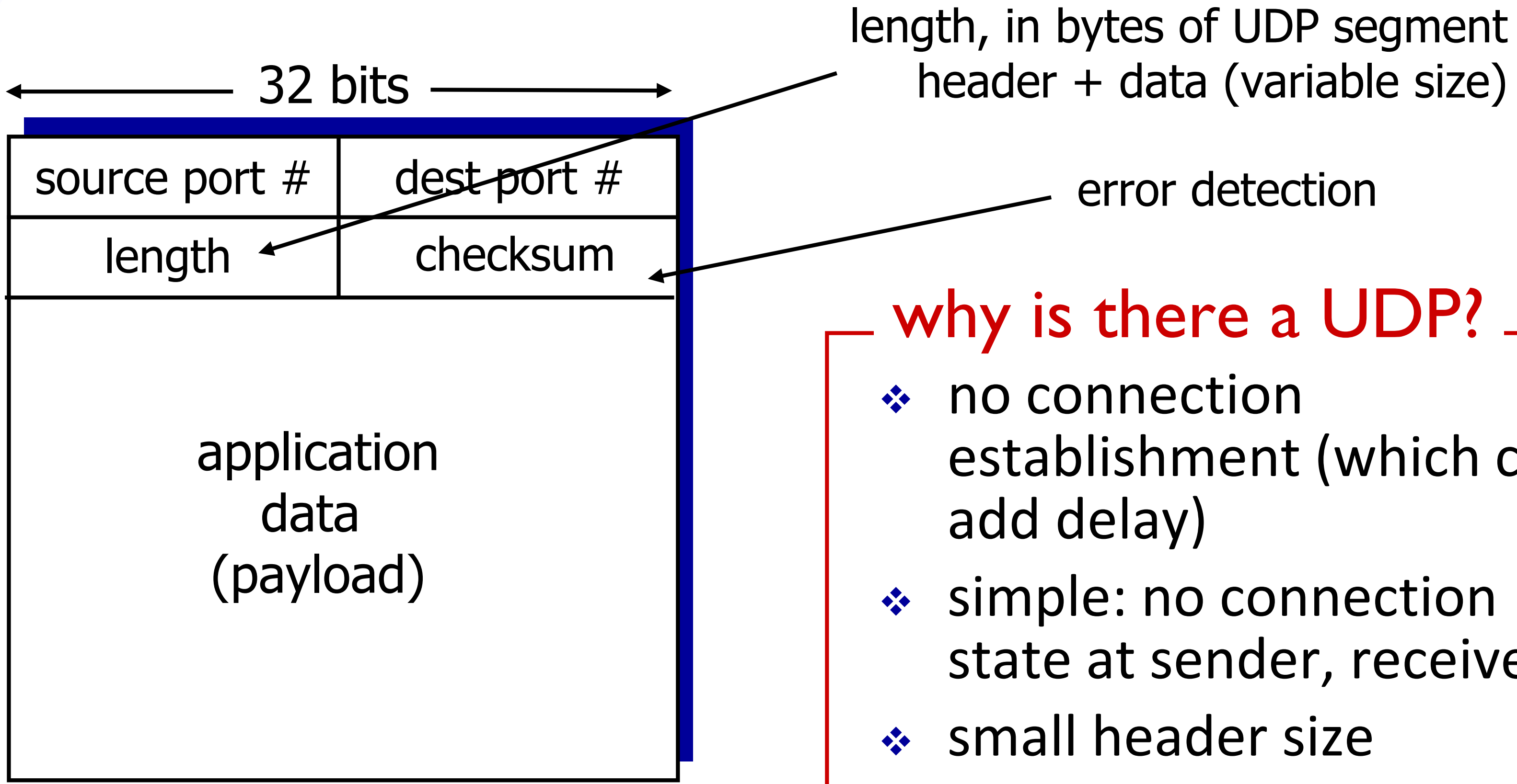
6.3 Connectionless transport: UDP

- "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 use:
  - streaming multimedia apps (loss tolerant, rate sensitive)
  - Domain Name System (DNS)
  - Simple Network Management Protocol (SNMP)
- reliable transfer over UDP:
  - add reliability at application layer
  - application-specific error recovery!

Why build an application over UDP rather than over TCP?

- Real-time applications require minimum delay, can tolerate some data loss
- Can support more active clients
- Small packet header overhead – TCP (20 bytes), UDP (8 bytes)



UDP segment format

why is there a UDP?

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

Goal: detect "errors" (e.g., flipped bits) in transmitted segment

sender:

- treat segment contents, including header fields, as sequence of 16-bit integers
- checksum: addition (one's complement sum) of segment contents
- sender puts checksum value into UDP checksum field

receiver:

- compute checksum of received segment
- check if computed checksum equals checksum field value:
  - NO - error detected
  - YES - no error detected.

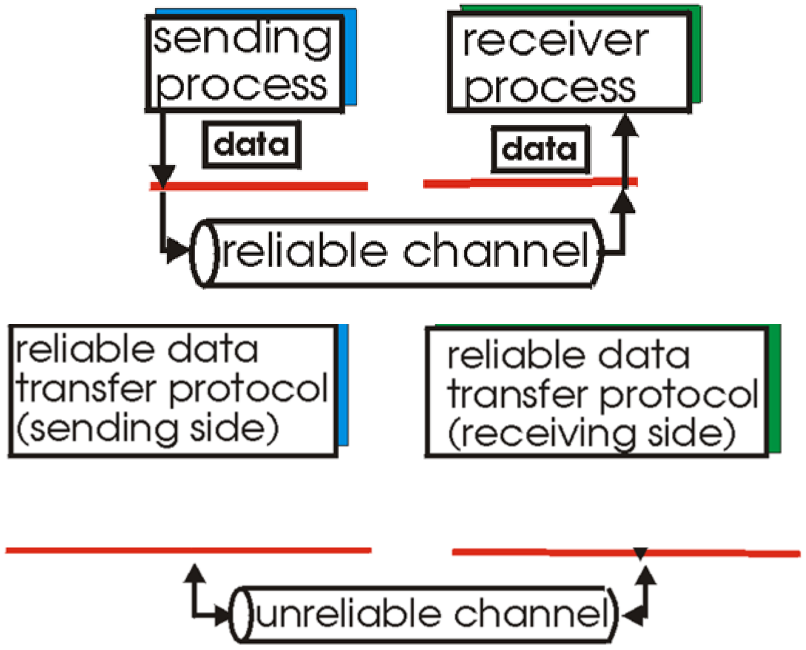
Note: detail of checksum is discussed in link layer

- the problem of implementing reliable data transfer occurs not only at the transport layer
- it is also a fundamentally important problem at the application layer, and link layer as well
- we may have a reliable data transfer protocol at the transport layer
- but the lower network layer is not reliable!

Application layer

Transport layer

Network layer



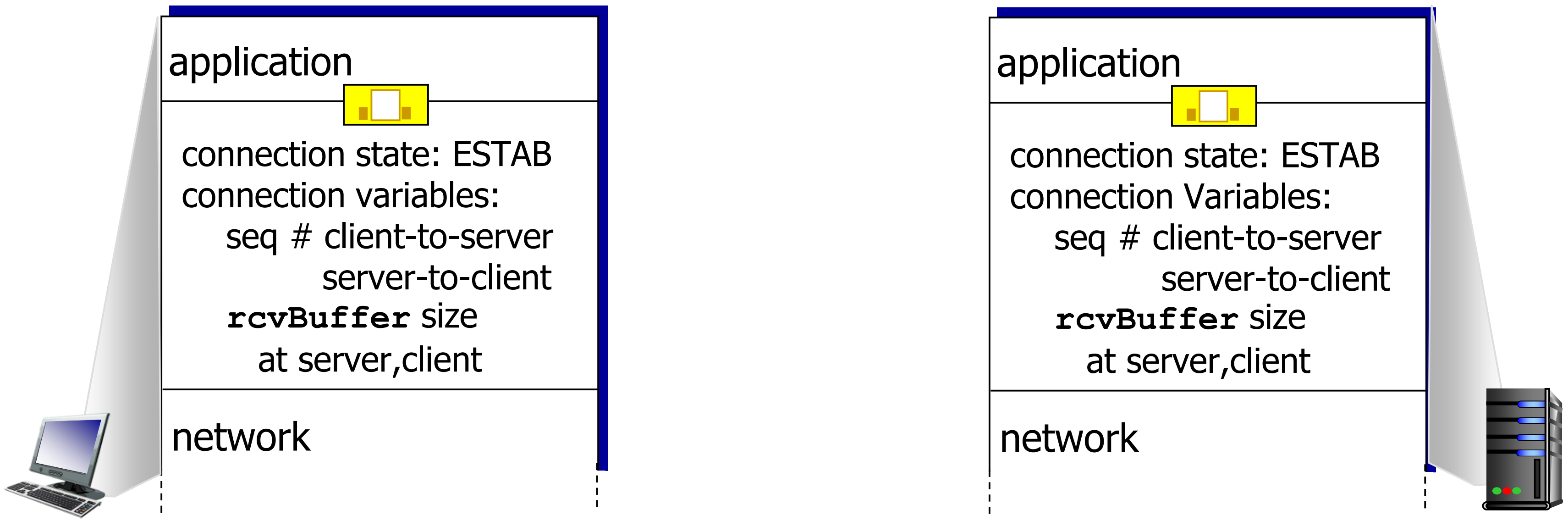
- to provide reliable data transfer, TCP relies on:

  error detection
  re-transmissions
  cumulative acknowledgments
  timers
  header fields for sequence and acknowledgment numbers

6.4 Connection-oriented transport: TCP

before exchanging data, sender/receiver "handshake":

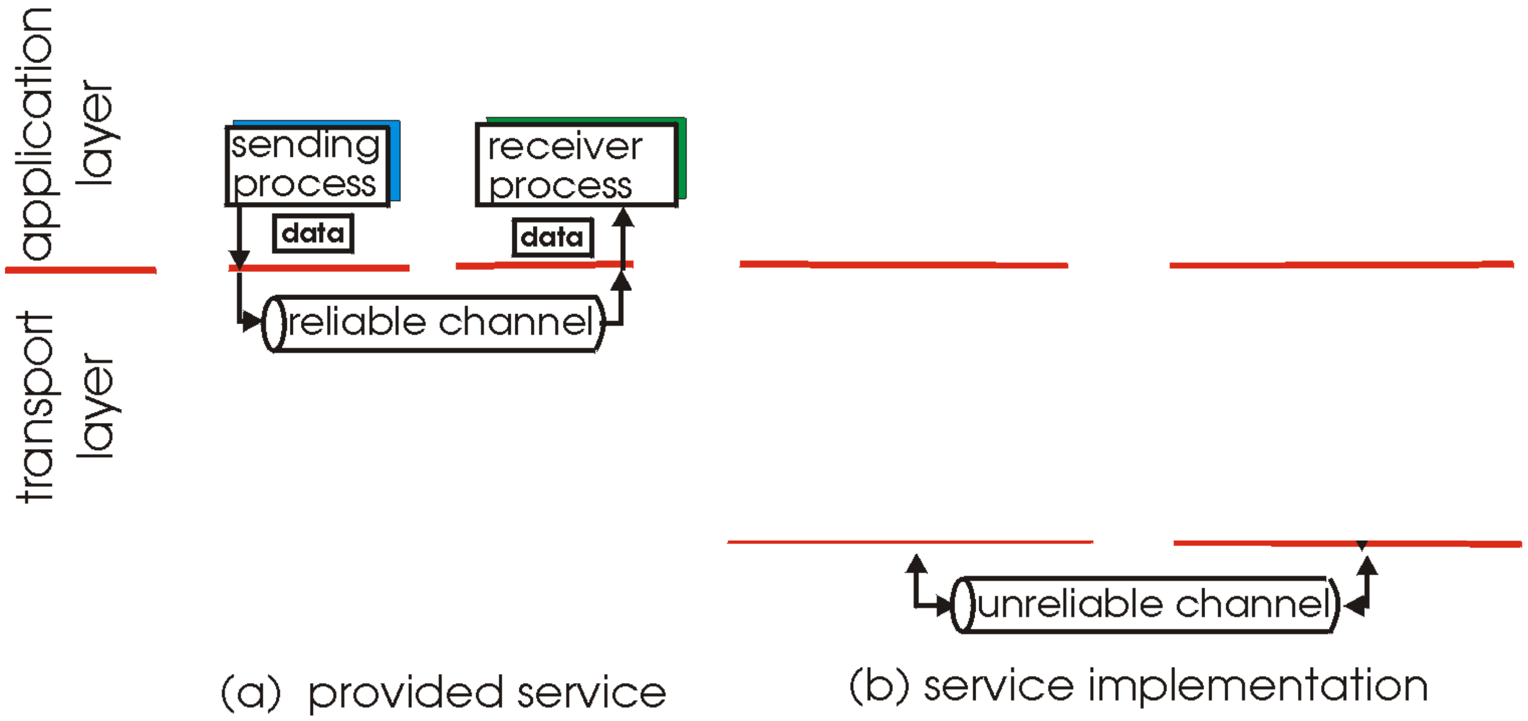
- agree to establish connection (each knowing the other willing to establish connection)
- agree on connection parameters




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

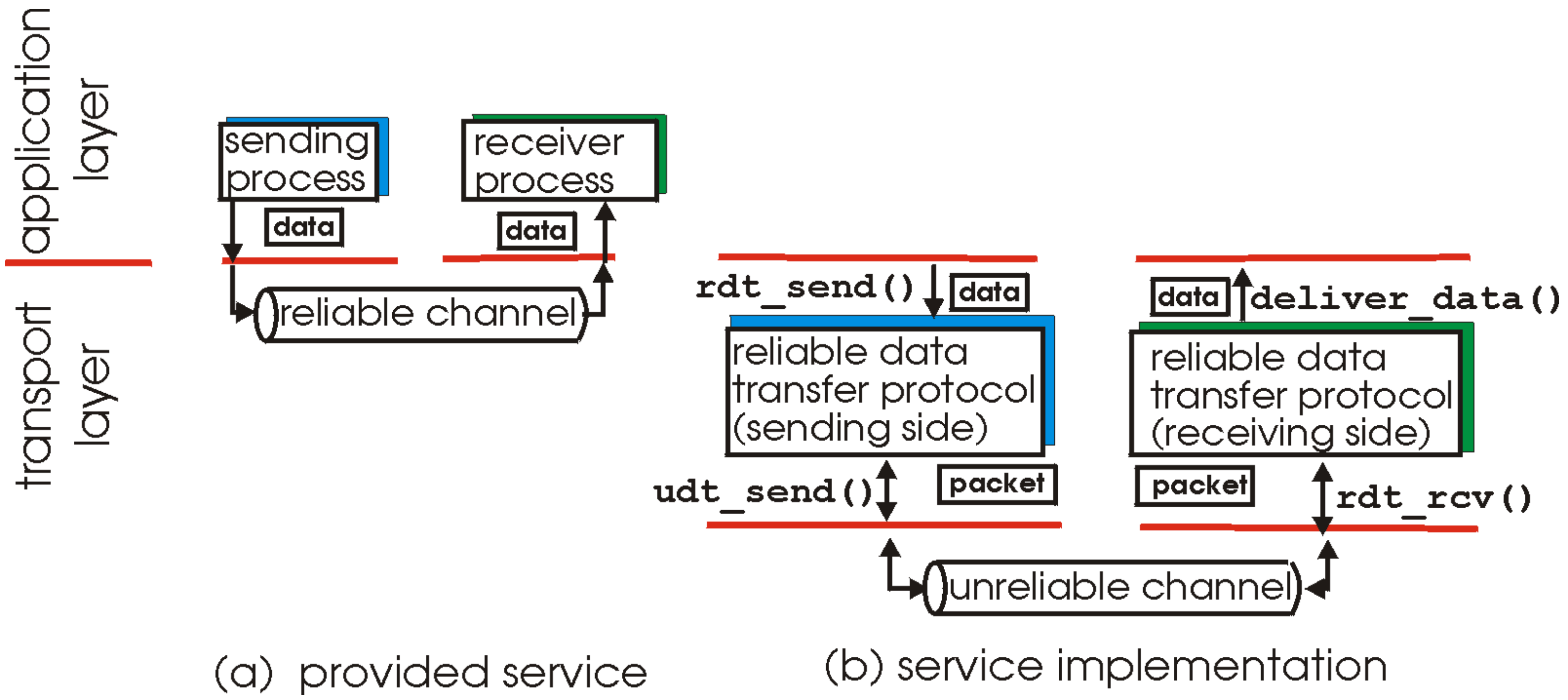
```
Socket connectionSocket =
   welcomeSocket.accept();
```

- important in application, transport, link layers
  - top-10 list of important networking topics!



- characteristics of unreliable channel will determine complexity of reliable data transfer protocol (rdt)

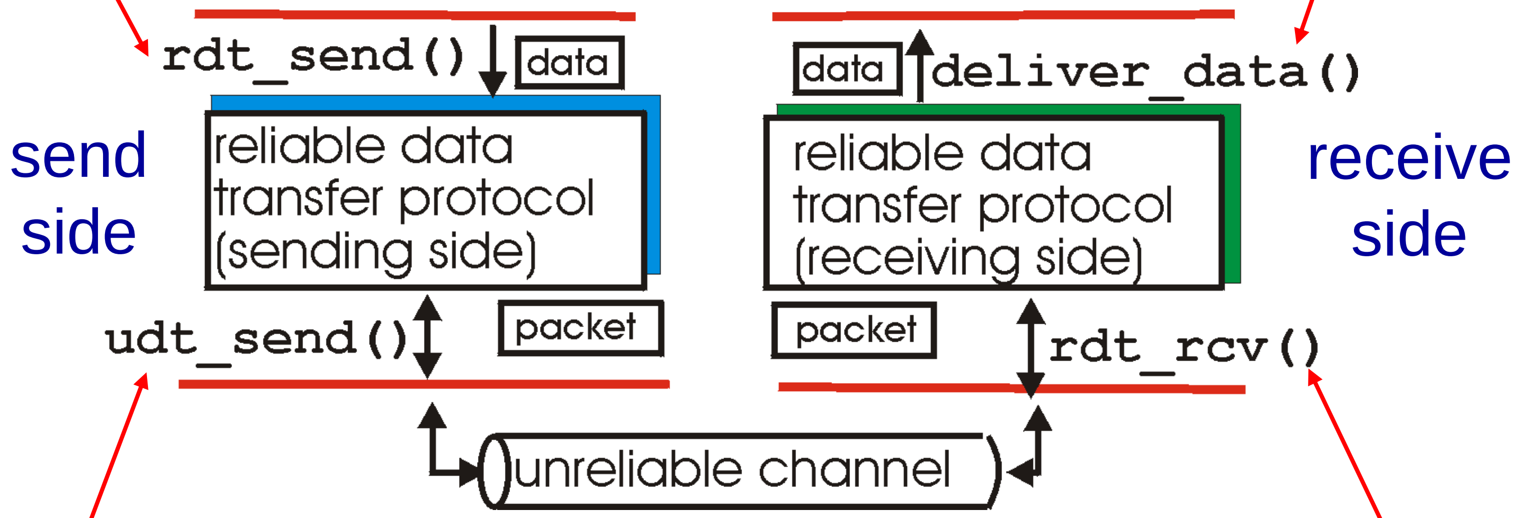
- important in application, transport, link layers
  - top-10 list of important networking topics!



- characteristics of unreliable channel will determine complexity of reliable data transfer protocol

rdt_send(): called from above, (e.g., by app.). Passed data to deliver to receiver upper layer

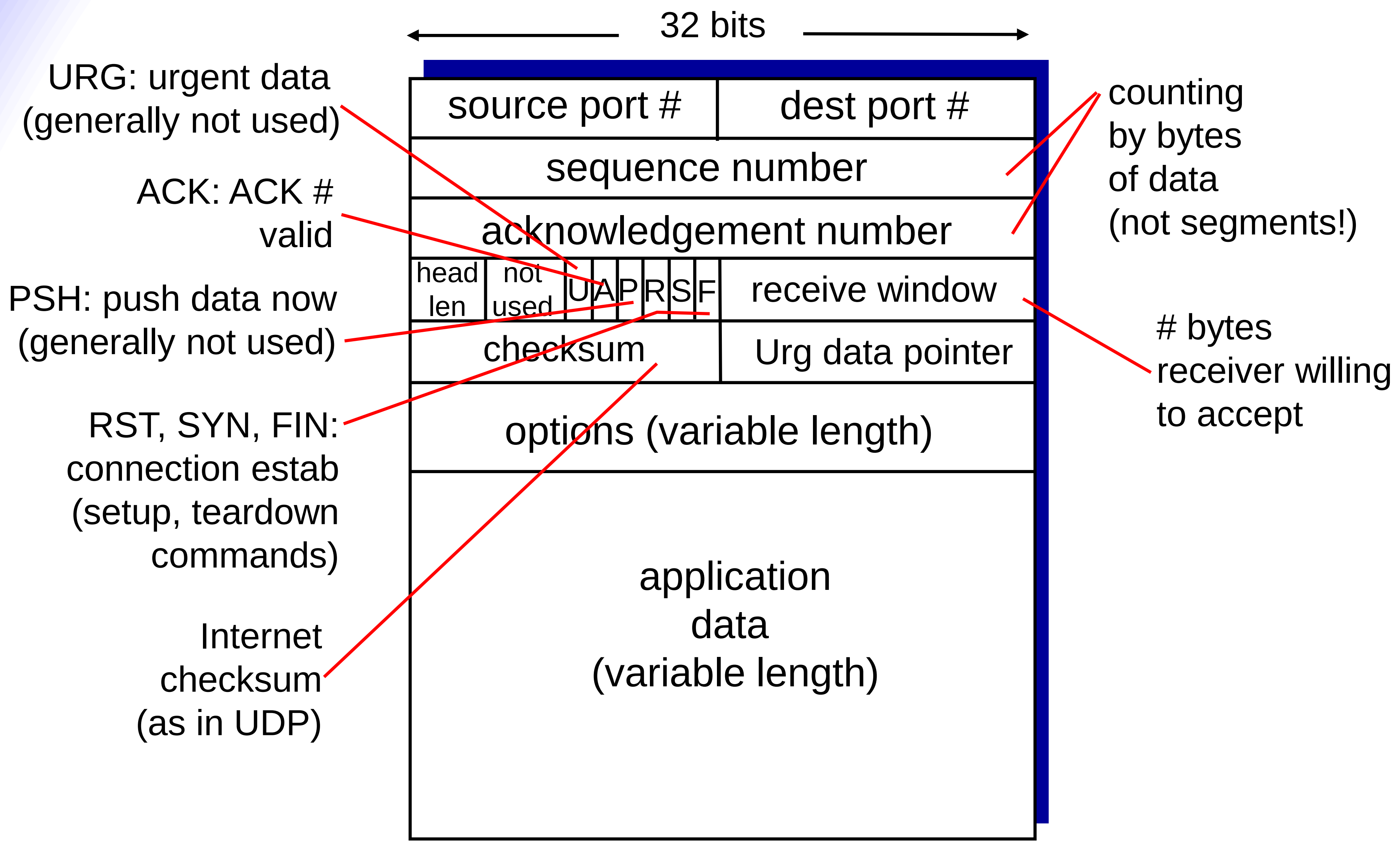
deliver_data(): called by **rdt** to deliver data to upper



udt_send(): called by rdt, to transfer packet over unreliable channel to receiver

rdt_rcv(): called when packet arrives on rcv-side of channel

Note: detail of reliable data transfer is discussed in link layer


32 bits
source port #
dest port #
sequence number
acknowledgement number
head len
not used
U
A
P
R
S
F
receive window
checksum
Urg data pointer
options (variable length)
application data (variable length)
URG: urgent data (generally not used)
ACK: ACK # valid
PSH: push data now (generally not used)
RST, SYN, FIN: connection estab (setup, teardown commands)
Internet checksum (as in UDP)
counting by bytes of data (not segments!)
bytes receiver willing to accept

- TCP views data as an unstructured, but ordered, stream of bytes
- sequence number is the byte-stream number of the first byte in the segment
- if host A sends 500,000 bytes to host B, maximum segment size is 1,000 bytes
- sequence number of the first segment is 0
- sequence number of the second segment is 1,000, and so on

- TCP connection provides full-duplex service
- host A receives data from host B, while it sends data to host B
- segment from host B has a sequence number
- the acknowledgment number that host A puts in its segment is the sequence number of the next byte host A is expecting from host B
- TCP connection is also always point-to-point (*multicasting is not possible*)

Summary

- transport-layer protocol – provides services to network applications
- simple service – multiplexing and demultiplexing
- UDP
- reliable data transfer - TCP

Reference

Chapter 3, Computer Networking:
A Top-Down Approach