Application Layer

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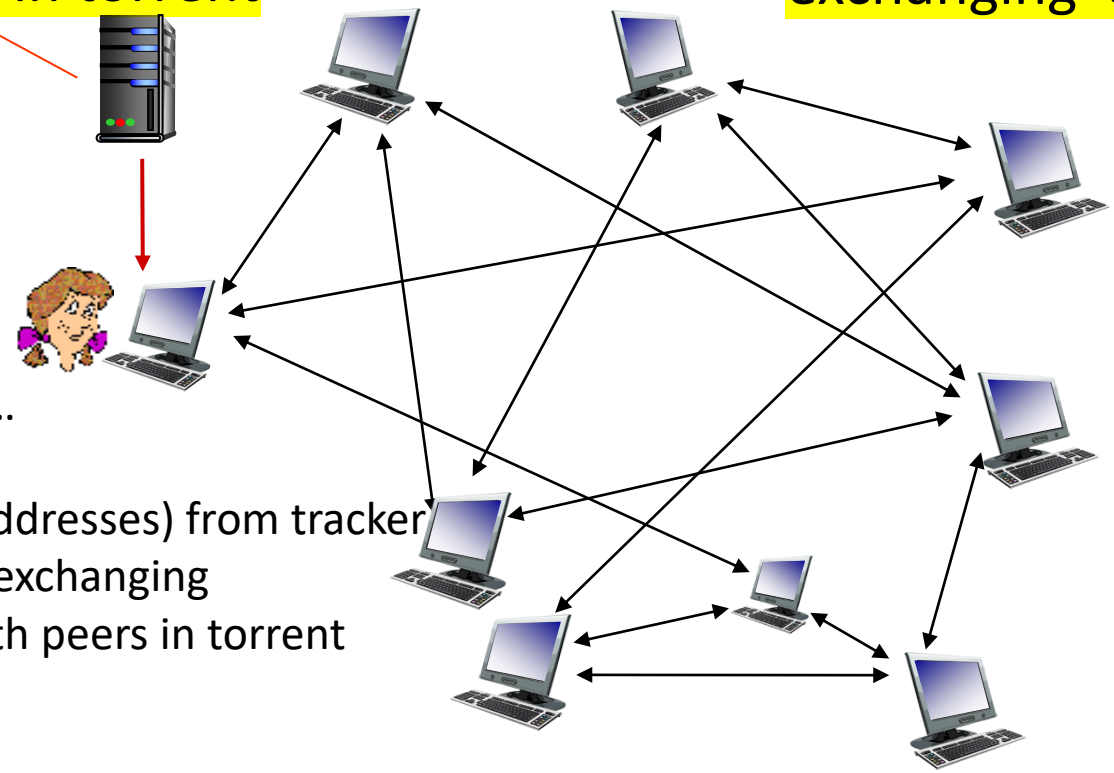
P2P file distribution: BitTorrent

- file divided into 256KBytes chunks
- peers in torrent send/receive file chunks

tracker: tracks peers participating in torrent

torrent: group of peers exchanging chunks of a file

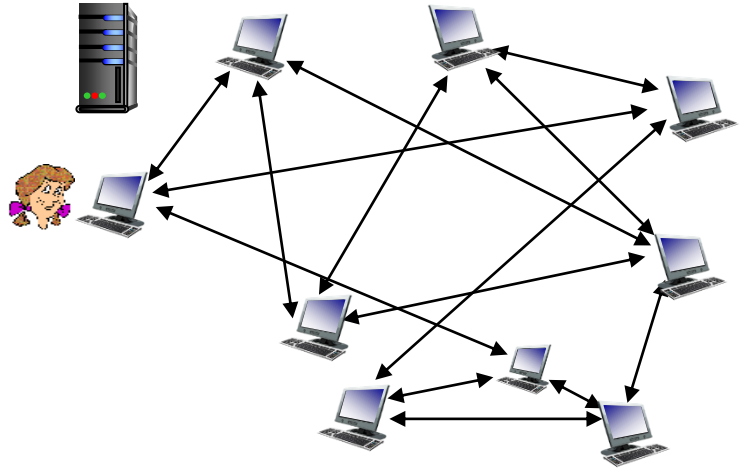


Alice arrives …
… obtains list
of peers (IP addresses) from tracker
… and begins exchanging
file chunks with peers in torrent

- Establish connections with neighbors and ask which chunks they have and request the chunk to these neighbors…
  Generally rarest chunks are collected first to increase the availability.

P2P file distribution: BitTorrent

- peer joining torrent:
  - has no chunks, but will accumulate them over time from other peers
  - registers with tracker to get list of peers, connects to subset of peers ("neighbors")



- while downloading, peer uploads chunks to other peers
- peer may change peers with whom it exchanges chunks
- *churn:* peers may come and go
- once peer has entire file, it may (selfishly) leave or (selflessly) remain in torrent

BitTorrent: requesting, sending file chunks

Requesting chunks:

- at any given time, different peers have different subsets of file chunks
- periodically, Alice asks each peer for list of chunks that they have
- Alice requests missing chunks from peers, rarest first

Sending chunks: tit-for-tat

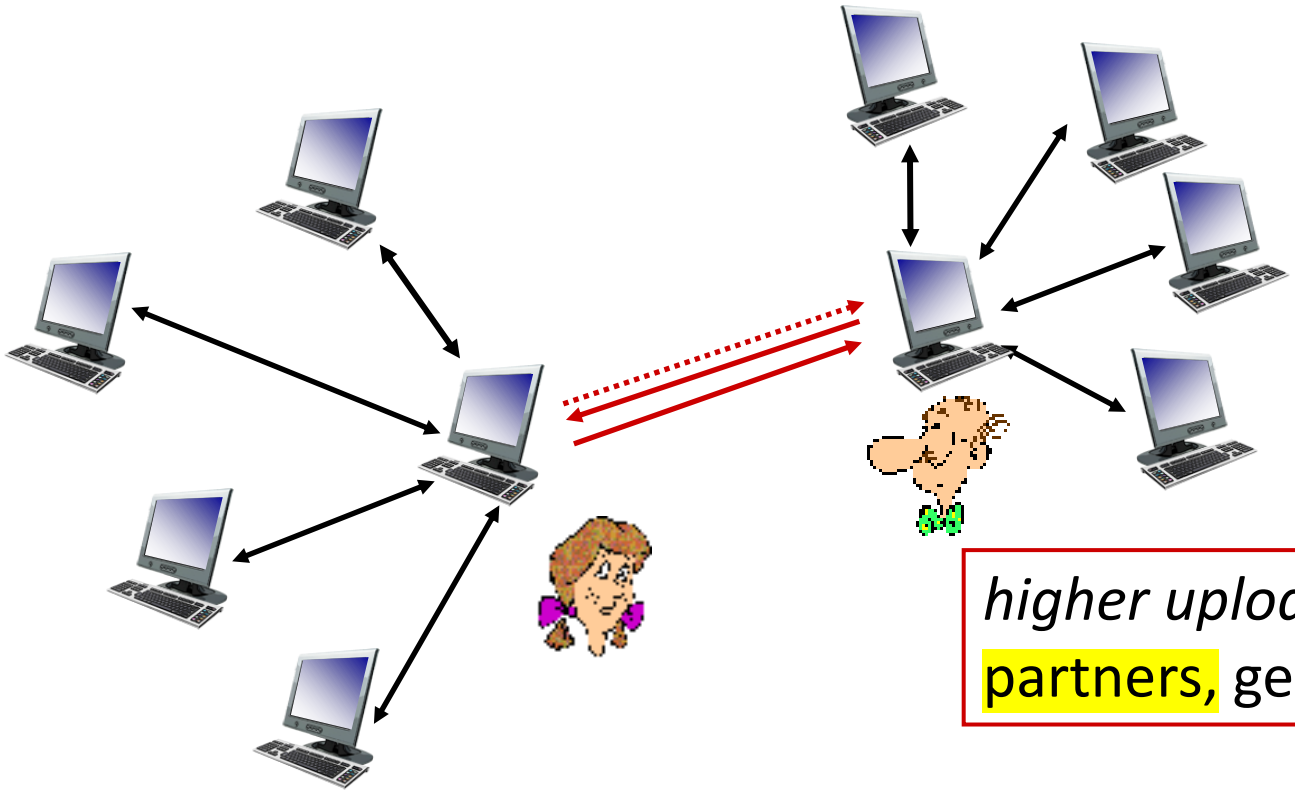
- Alice sends chunks to those four peers currently sending her chunks *at highest rate*
  - other peers are choked by Alice (do not receive chunks from her)
  - re-evaluate top 4 every10 secs
- every 30 secs: randomly select another peer, starts sending chunks
  - "optimistically unchoke" this peer
  - newly chosen peer may join top 4

BitTorrent: tit-for-tat

(1) Alice “optimistically unchokes” Bob

(2) Alice becomes one of Bob’s top-four providers; Bob reciprocates

(3) Bob becomes one of Alice’s top-four providers



higher upload rate: find better trading partners, get file faster !

Application layer: overview

- Principles of network applications
- Web and HTTP
- E-mail, SMTP, IMAP
- The Domain Name System DNS
- P2P applications
- **video streaming and content distribution networks**
- socket programming with UDP and TCP

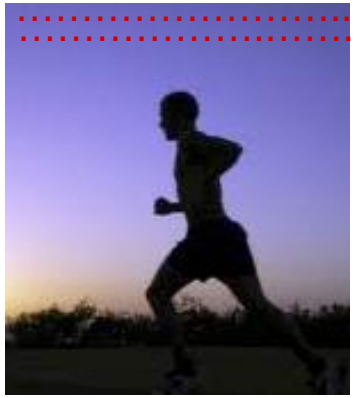
Video Streaming and CDNs: context

- stream video traffic: major consumer of Internet bandwidth
  - Netflix, YouTube, Amazon Prime: 80% of residential ISP traffic (2020)
- challenge: scale - how to reach ~1B users?
  - single mega-video server won't work (why?)
- challenge: heterogeneity
  - different users have different capabilities (e.g., wired versus mobile; bandwidth rich versus bandwidth poor)
- *solution: distributed, application-level*

Multimedia: video

- video: sequence of images displayed at constant rate
  - e.g., 24 images/sec
- digital image: array of pixels
  - each pixel represented by bits
- coding: use redundancy *within* and *between* images to decrease # bits used to encode image
  - spatial (within image)
  - temporal (from one image to next)

spatial coding example: instead of sending *N* values of same color (all purple), send only two values: color value (*purple*) *and number of repeated values (*N)



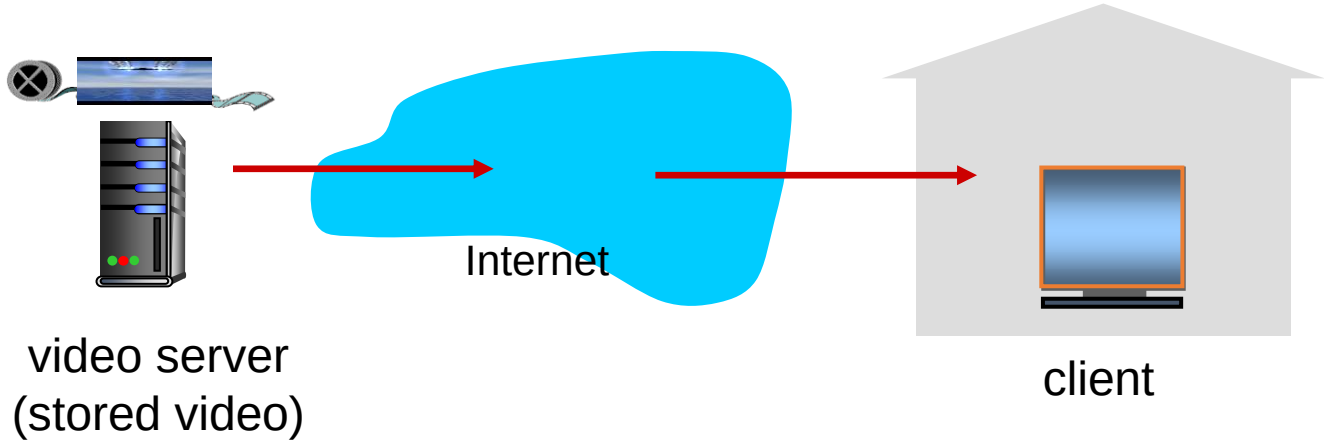
frame *i*

frame *i+1*

temporal coding example: instead of sending complete frame at i+1, send only differences from frame i

Streaming stored video

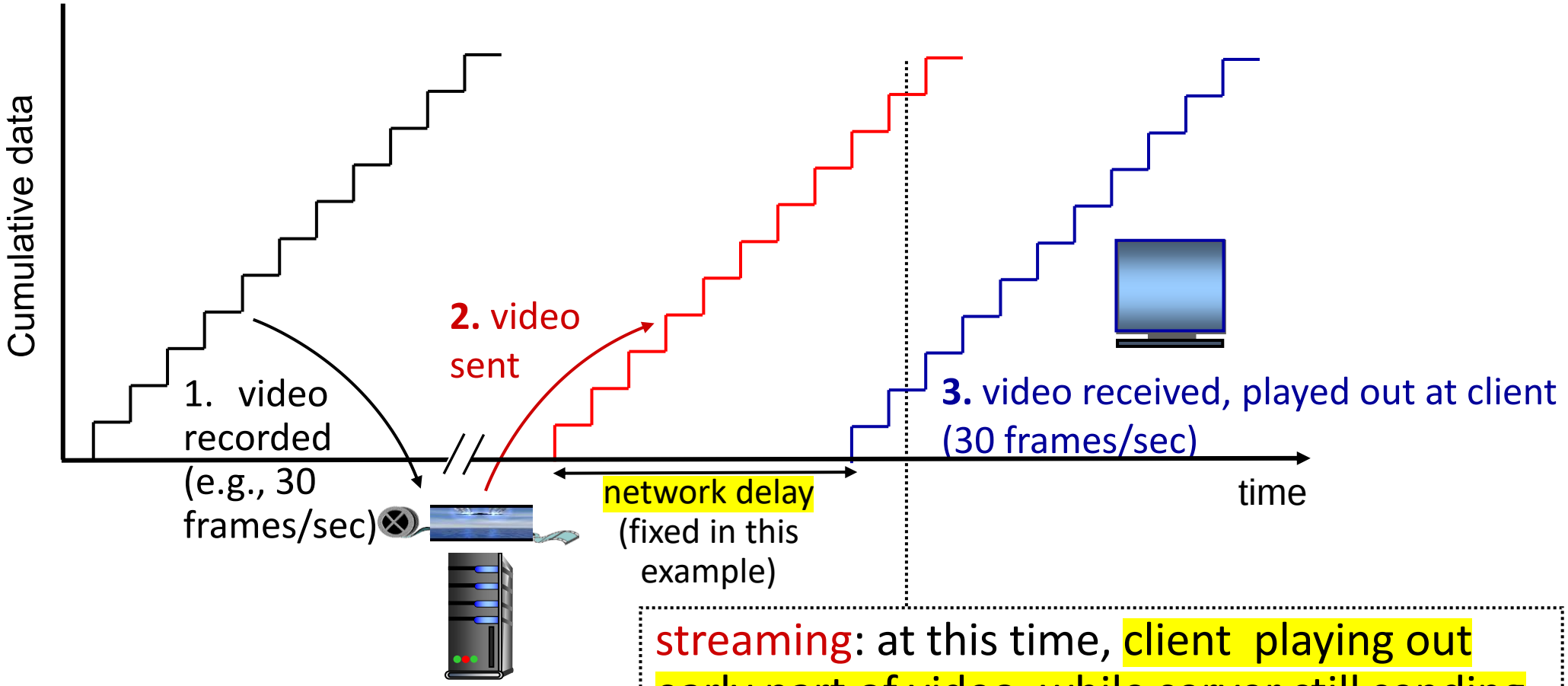
simple scenario:



Main challenges:

- server-to-client bandwidth will *vary* over time, with changing network congestion levels (in house, in access network, in network core, at video server)
- packet loss and delay due to congestion will delay playout, or result in poor video quality

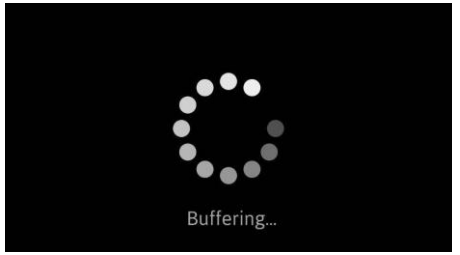
Streaming stored video



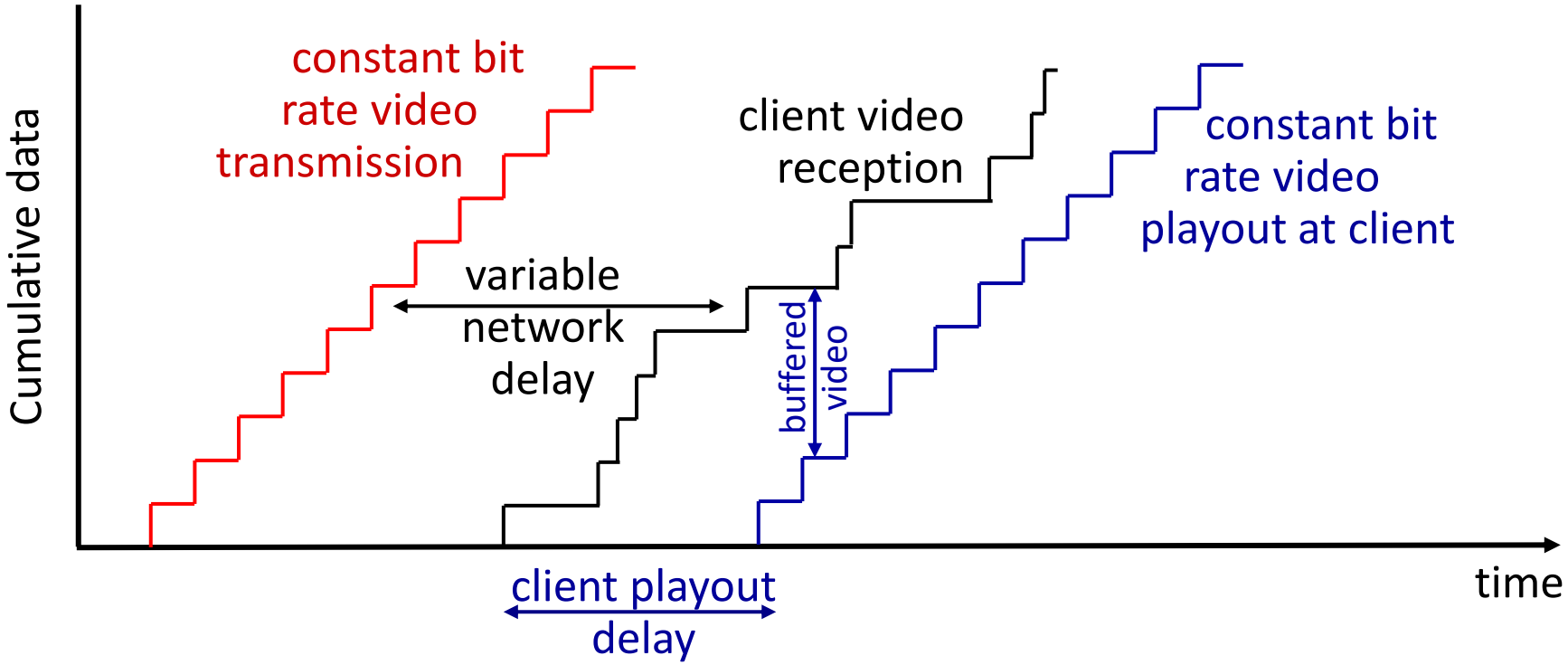
streaming: at this time, client playing out early part of video, while server still sending later part of video

Streaming stored video: challenges

- continuous playout constraint: once client playout begins, playback must match original timing
  - … but network delays are variable (jitter), so will need client-side buffer to match playout requirements
- other challenges:
  - client interactivity: pause, fast-forward, rewind, jump through video
  - video packets may be lost, retransmitted



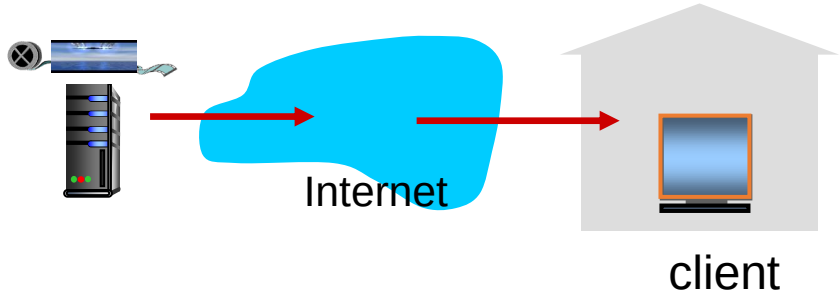
Streaming stored video: playout buffering



- *client-side buffering and playout delay:* compensate for network-added delay, delay jitter

Streaming multimedia: DASH

- *DASH: Dynamic, Adaptive Streaming over HTTP*
- *server:*
  - divides video file into multiple chunks
  - each chunk stored, encoded at different rates
  - *manifest file:* provides URLs for different chunks



- *client:*
  - periodically measures server-to-client bandwidth
  - consulting manifest, requests one chunk at a time
    - chooses maximum coding rate sustainable given current bandwidth
    - can choose different coding rates at different points in time (depending on available bandwidth at time)

Content distribution networks (CDNs)

- *challenge:* how to stream content (selected from millions of videos) to hundreds of thousands of *simultaneous* users?

- option 1: single, large "mega-server"
  - single point of failure
  - point of network congestion
  - long path to distant clients
  - multiple copies of video sent over outgoing link

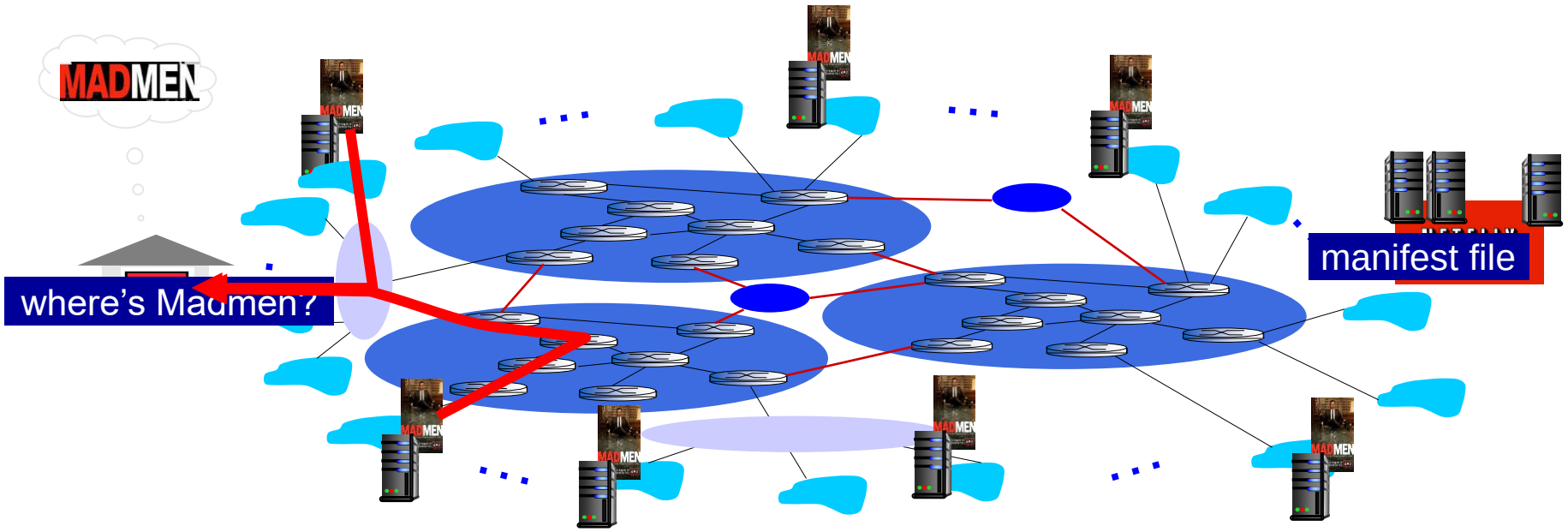
….quite simply: this solution *doesn't scale*

Content distribution networks (CDNs)

- *challenge:* how to stream content (selected from millions of videos) to hundreds of thousands of *simultaneous* users?
- option 2: store/serve multiple copies of videos at multiple geographically distributed sites *(CDN)*
  - *enter deep:* push CDN servers deep into many access networks
    - close to users
    - Akamai: 240,000 servers deployed in more than 120 countries (2015)

Content distribution networks (CDNs)

- CDN: stores copies of content at CDN nodes
  - e.g. Netflix stores copies of MadMen
- subscriber requests content from CDN
  - directed to nearby copy, retrieves content
  - may choose different copy if network path congested



Content distribution networks (CDNs)

Internet host-host communication as a service

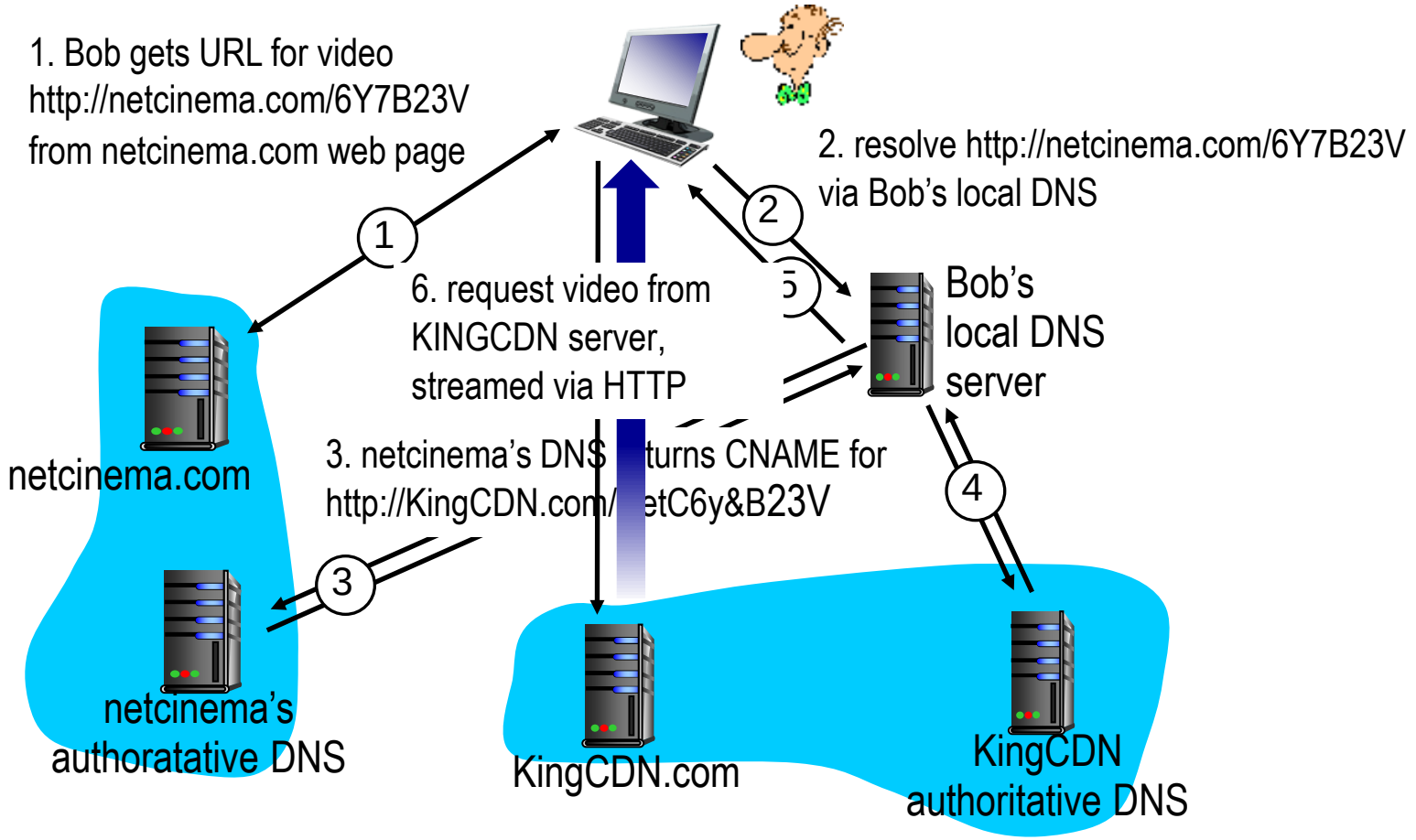
OTT challenges: coping with a congested Internet

- from which CDN node to retrieve content?
- viewer behavior in presence of congestion?
- what content to place in which CDN node?

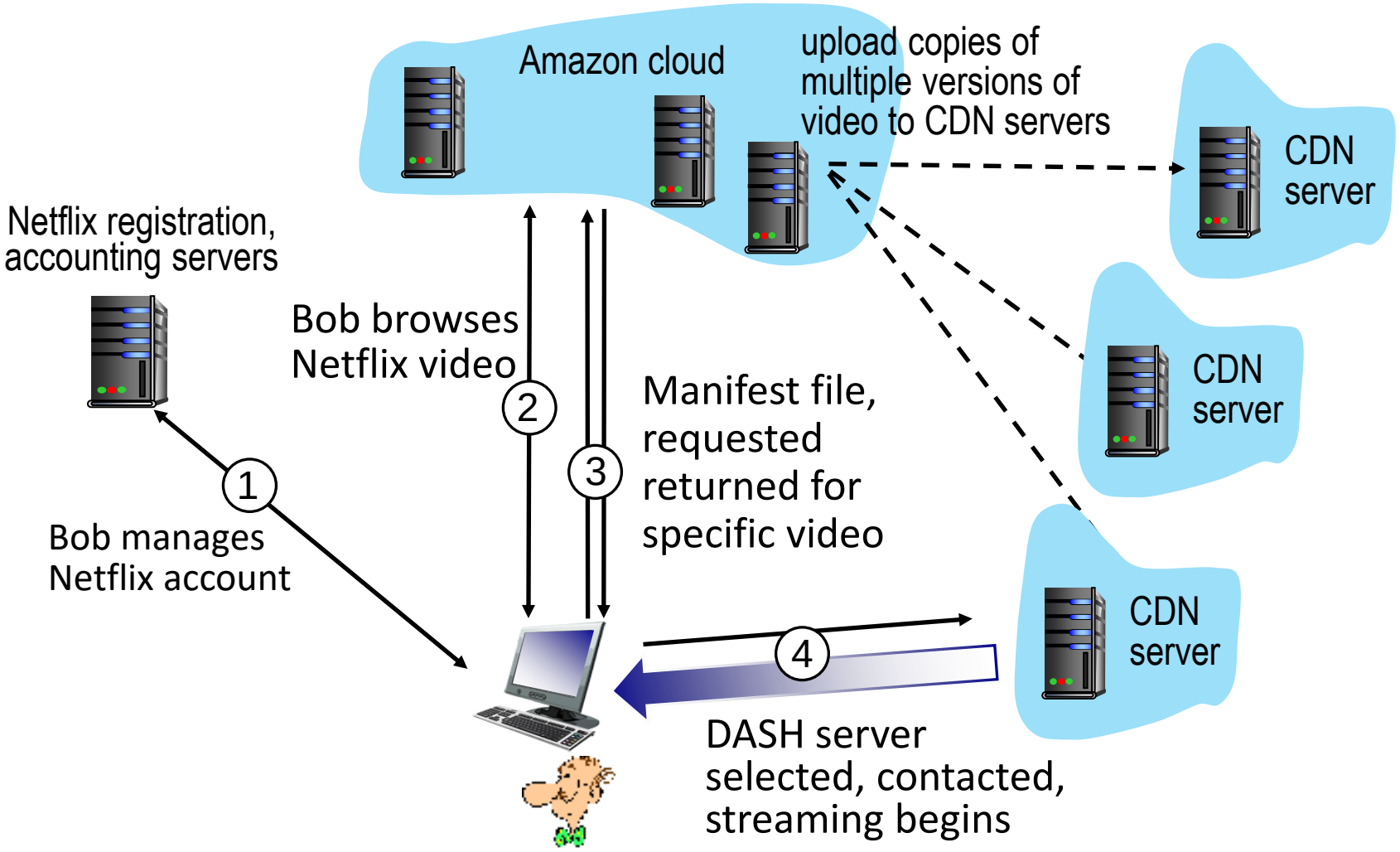
CDN content access: a closer look

Bob (client) requests video http://netcinema.com/6Y7B23V

- video stored in CDN at http://KingCDN.com/NetC6y&B23V



Case study: Netflix



Chapter 2: Summary

our study of network application layer is now complete!

- application architectures
  - client-server
  - P2P
- application service requirements:
  - reliability, bandwidth, delay
- Internet transport service model
  - connection-oriented, reliable: TCP
  - unreliable, datagrams: UDP

- specific protocols:
  - HTTP
  - SMTP, IMAP
  - DNS
  - P2P: BitTorrent
- video streaming, CDNs

Chapter 2: Summary

Most importantly: learned about *protocols*!

- typical request/reply message exchange:
  - client requests info or service
  - server responds with data, status code
- message formats:
  - *headers*: fields giving info about data
  - *data:* info(payload) being communicated

important themes:

- centralized vs. decentralized
- stateless vs. stateful
- scalability
- reliable vs. unreliable message transfer
- "complexity at network edge"

Transport Layer

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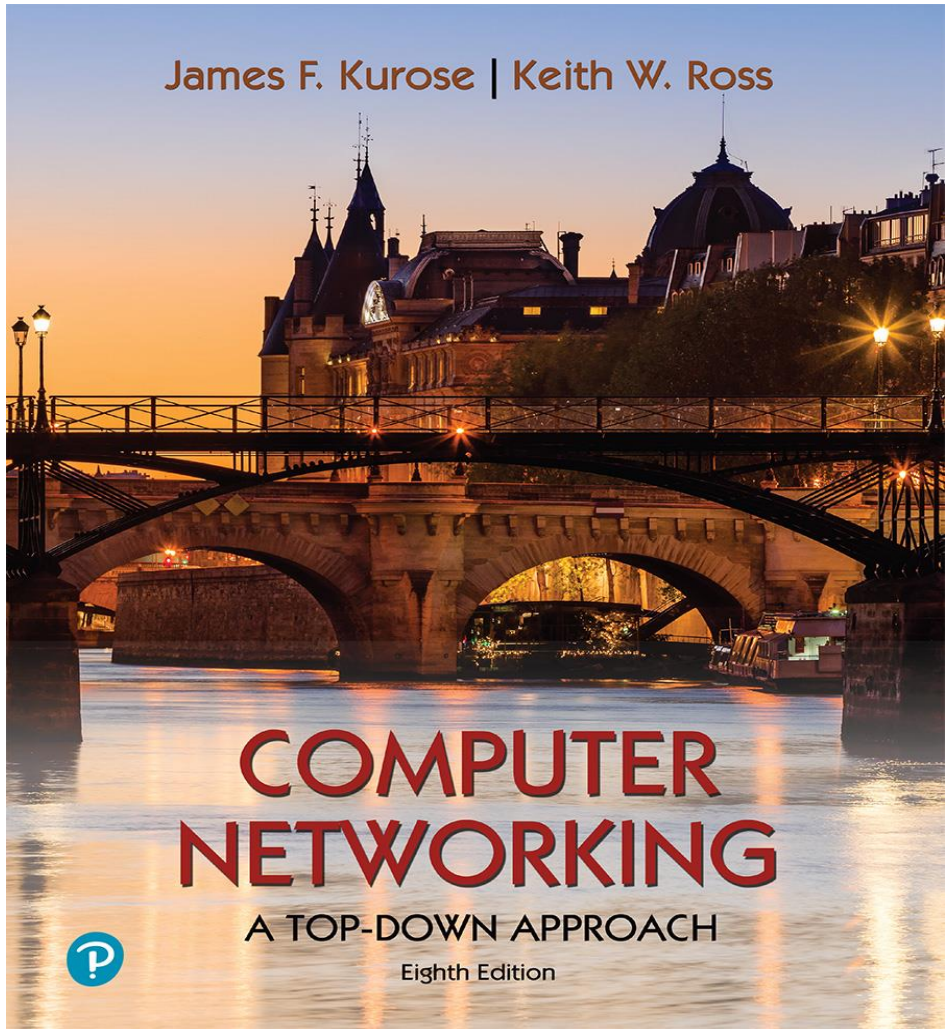
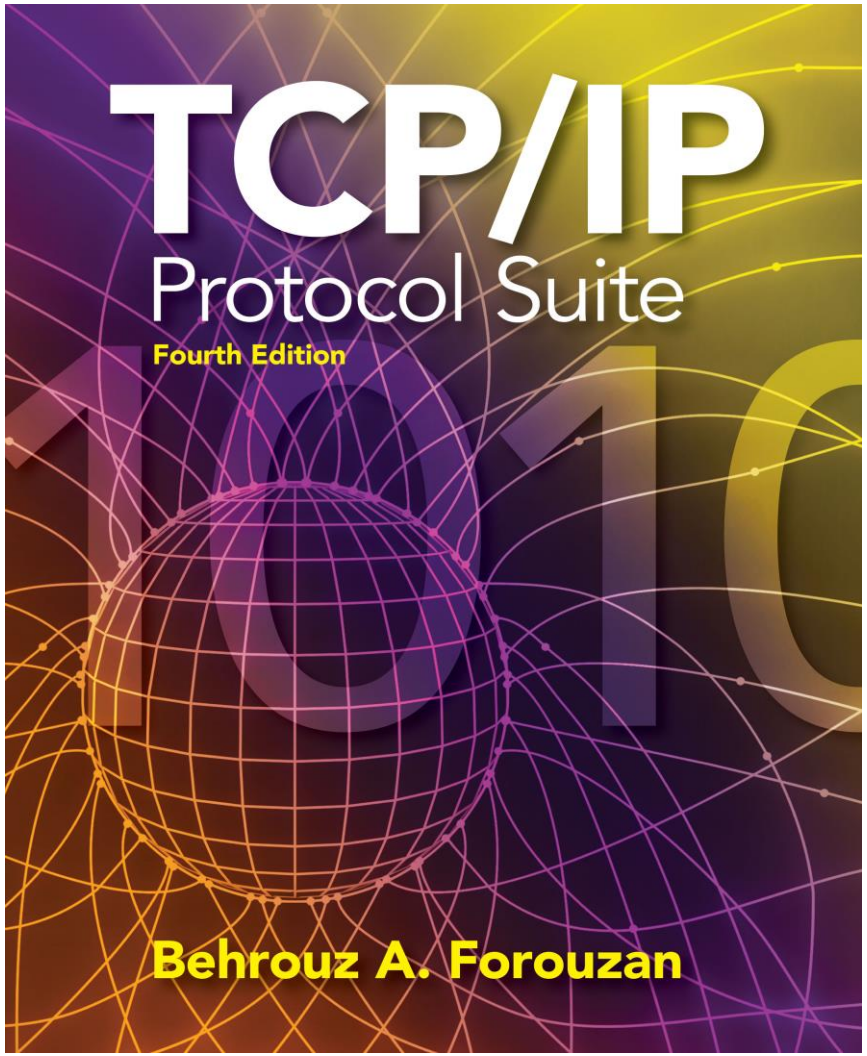
Sources

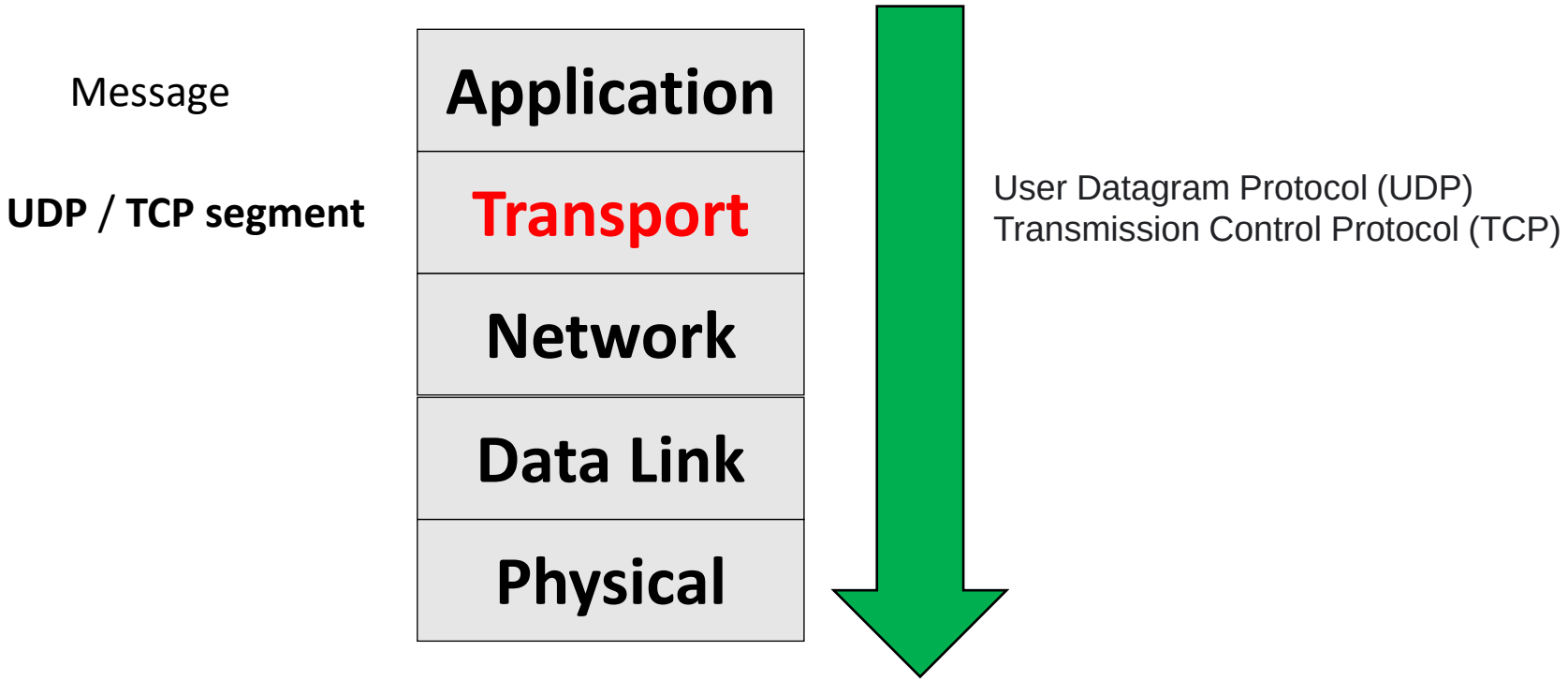


Computer Networking: A Top-Down Approach

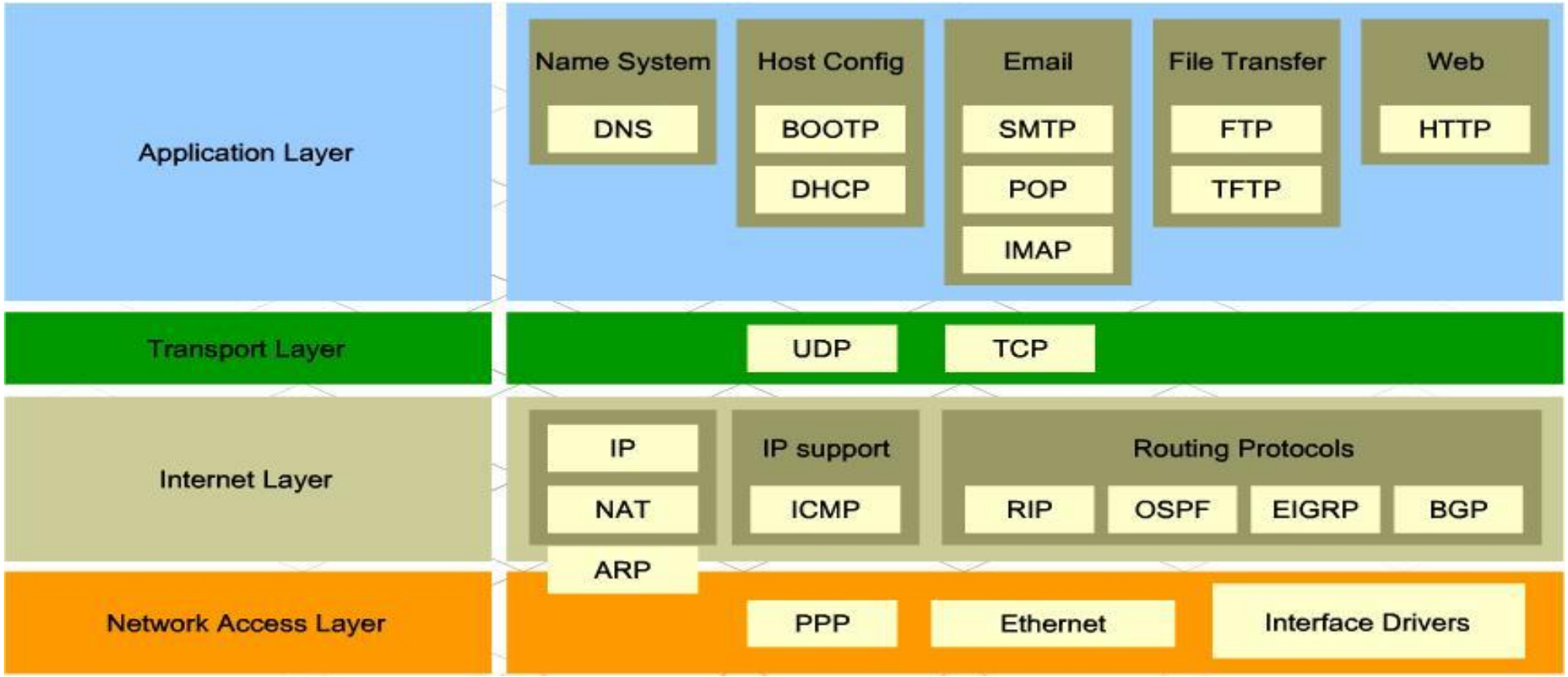


TCP/IP Protocol Suite

Top Down Approach

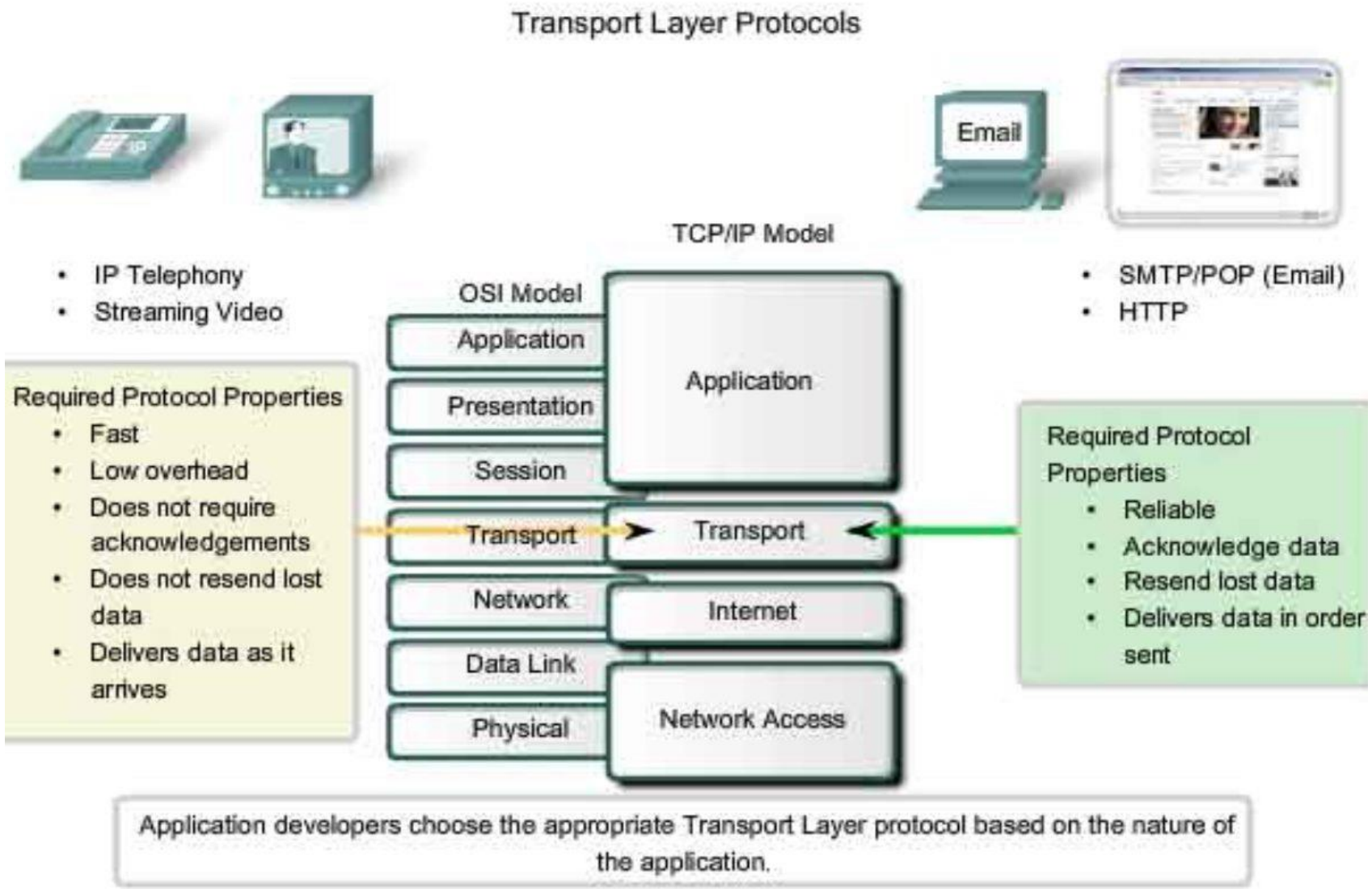


Protocols @ Different layers

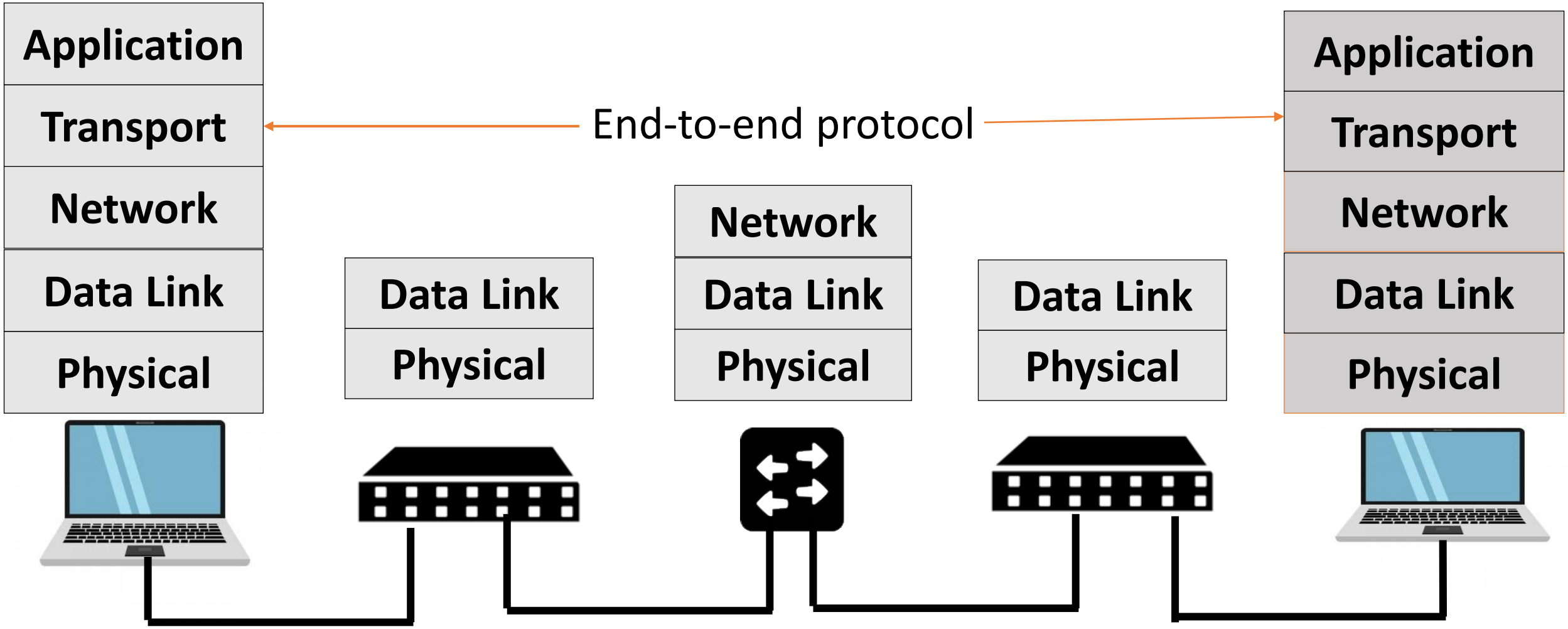


Source: http://walkwidnetwork.blogspot.com/2013/04/application-layer-internet-protocol.html

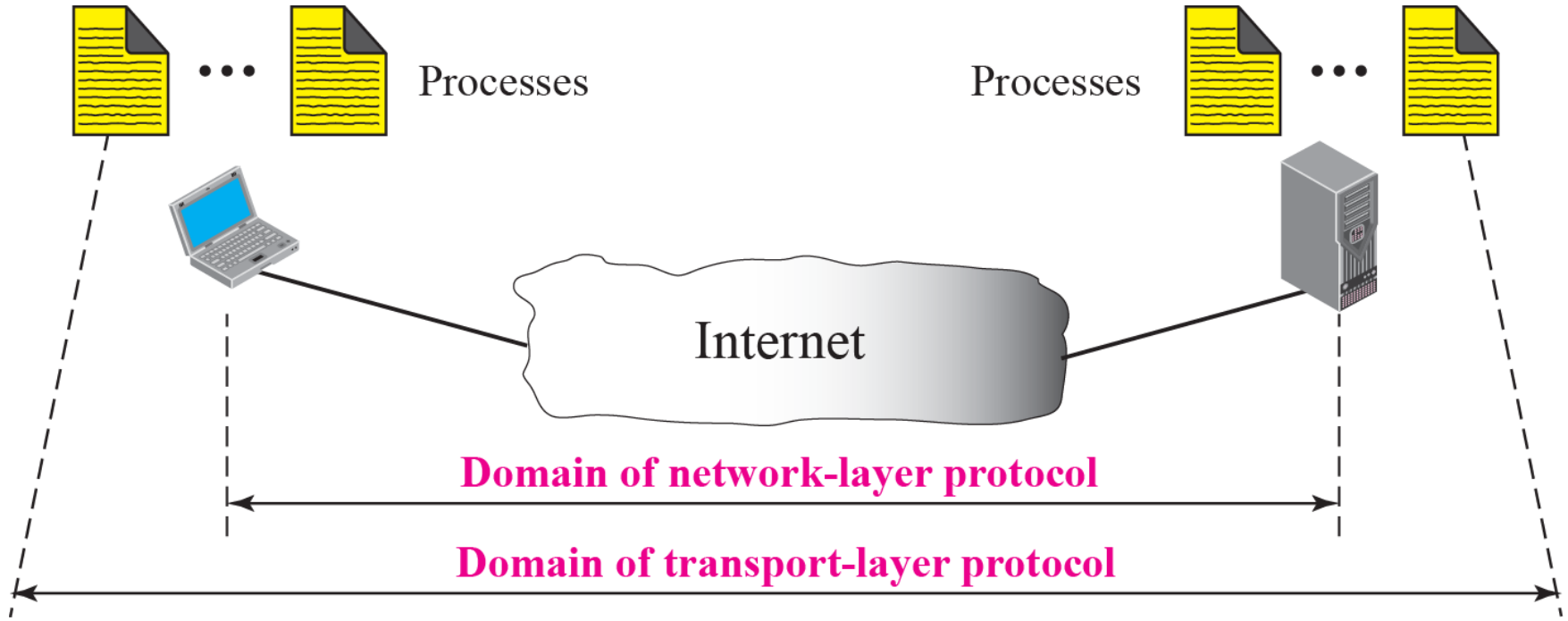
Transport Layer Protocols



Communication between two remote Machine

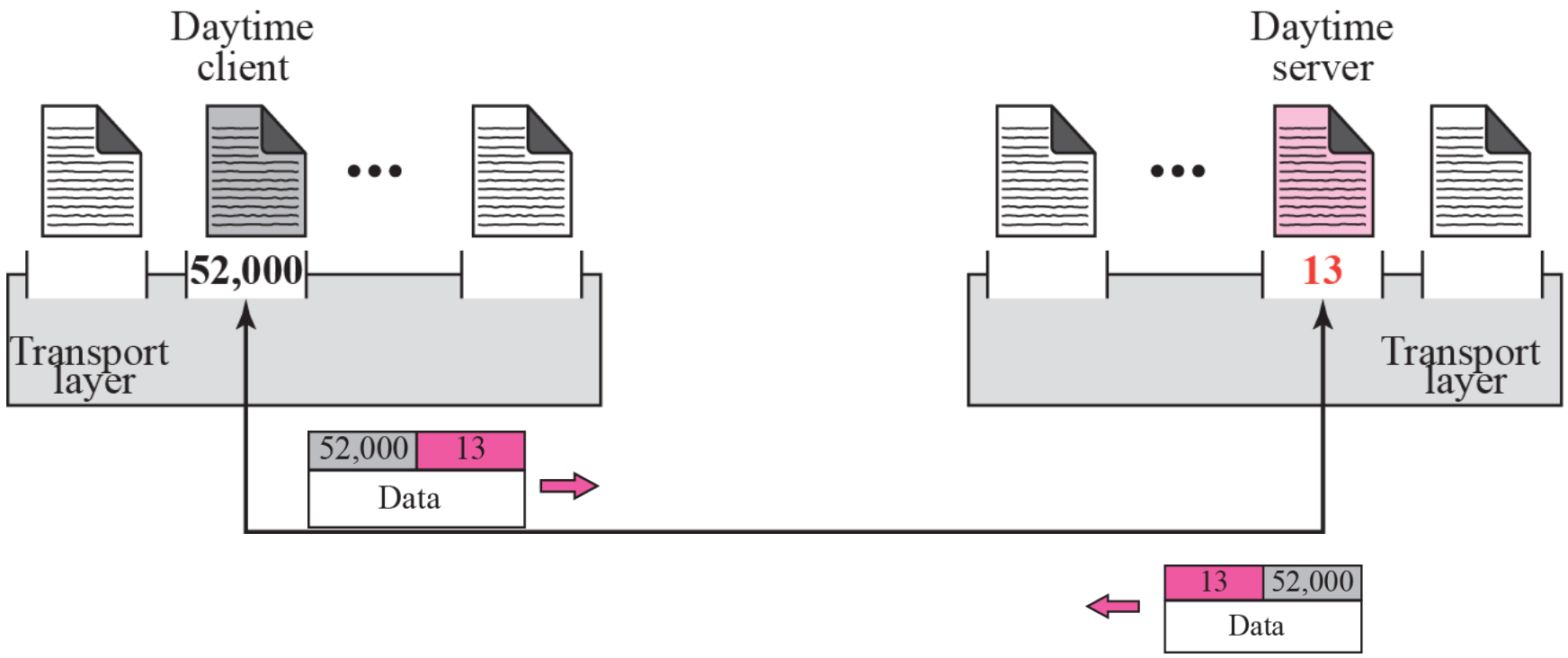


Network layer versus transport layer



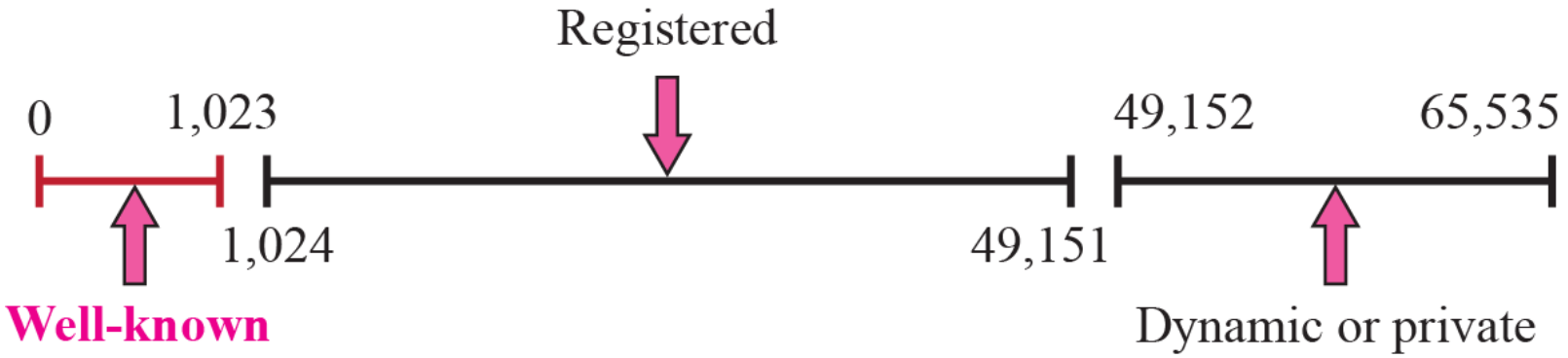
TCP/IP Protocol Suite

Port numbers



TCP/IP Protocol Suite

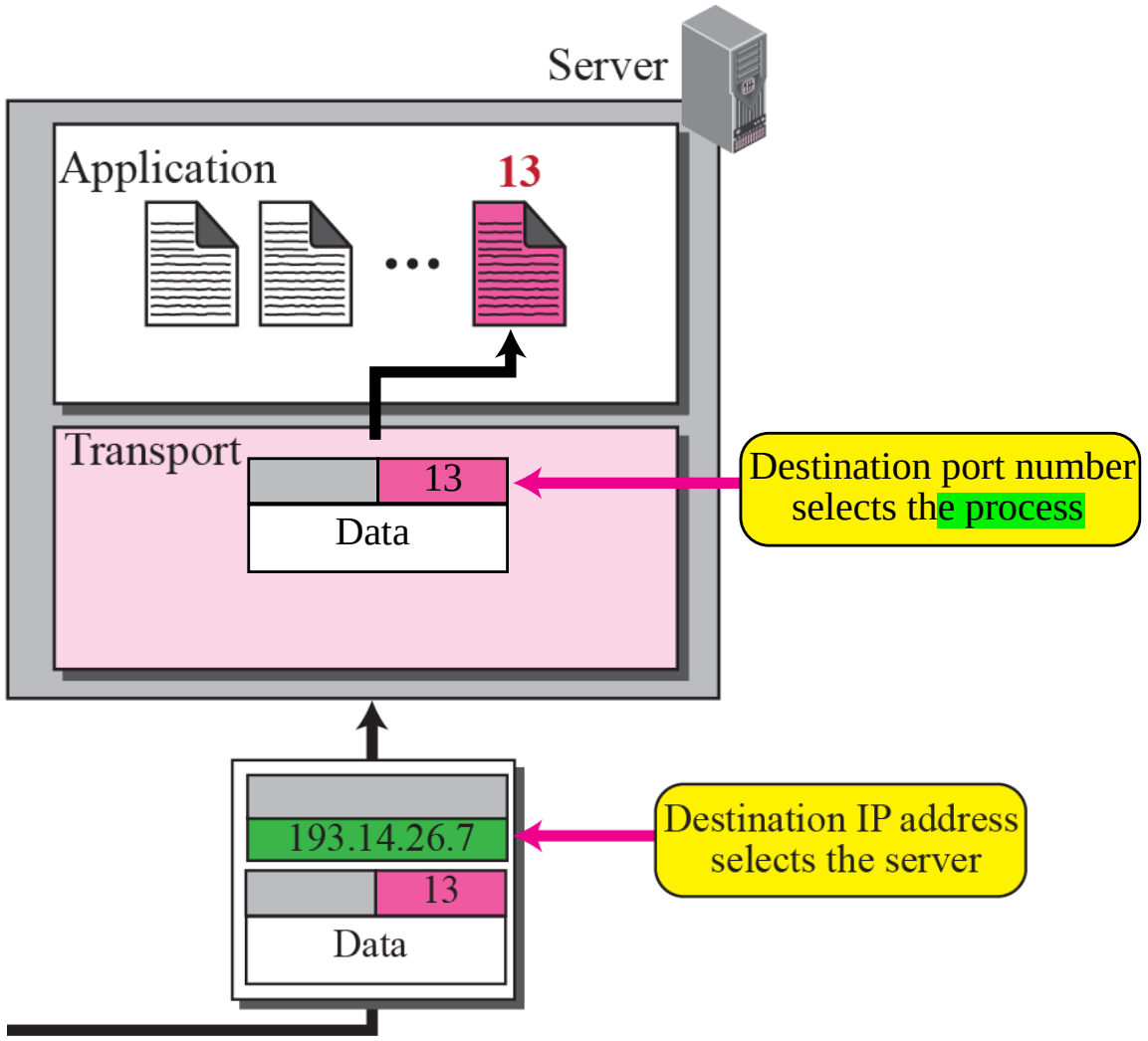
ICANN (Internet Corporation for Assigned Names and Numbers) Ranges



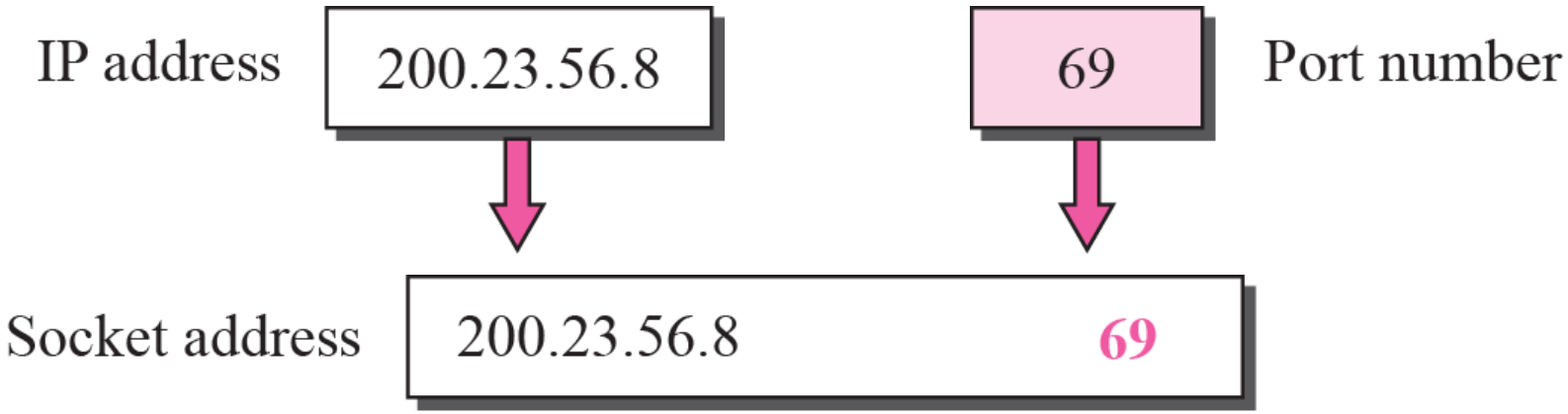
- *The well-known port numbers are less than 1,024. These are used by processes that provide widely used types of network services.*
- **Registered Port Numbers:** They are assigned by IANA (**Internet Assigned Numbers Authority, Owner ICANN**) for specific service upon application by a requesting entity.
- **Dynamic Port Numbers:** This range is used for private or customized services, for temporary purposes, and for automatic allocation

https://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers#Well-known_ports

IP addresses versus port numbers

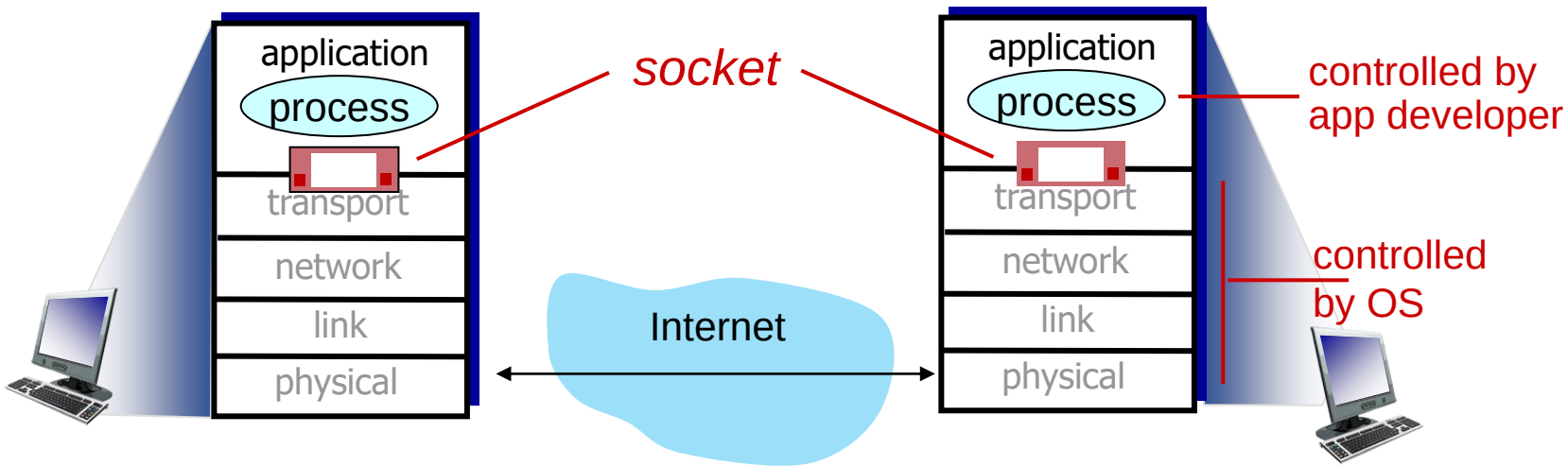


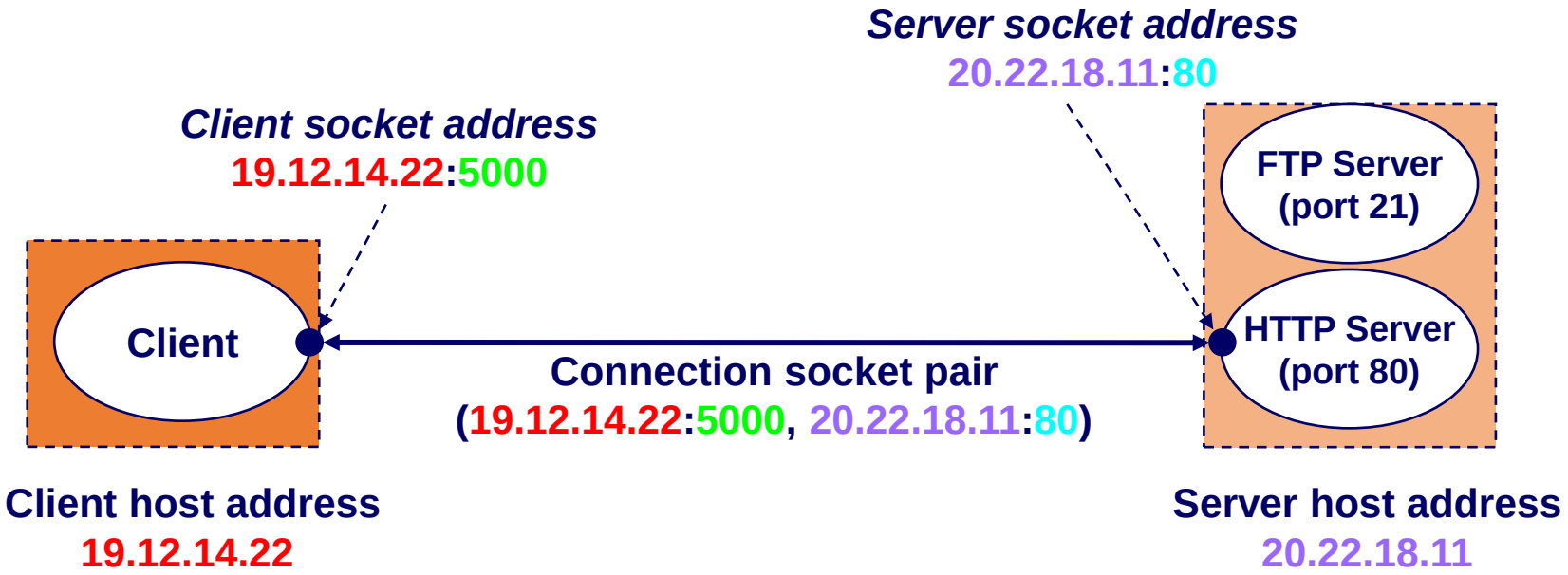
Socket address



TCP/IP Protocol Suite

Socket Pair


application
process
transport
network
link
physical
socket
Internet
application
process
transport
network
link
physical
controlled by
app developer
controlled
by OS


Server socket address
20.22.18.11:80
Client socket address
19.12.14.22:5000
FTP Server
(port 21)
HTTP Server
(port 80)
Client
Connection socket pair
(19.12.14.22:5000, 20.22.18.11:80)
Client host address
19.12.14.22
Server host address
20.22.18.11

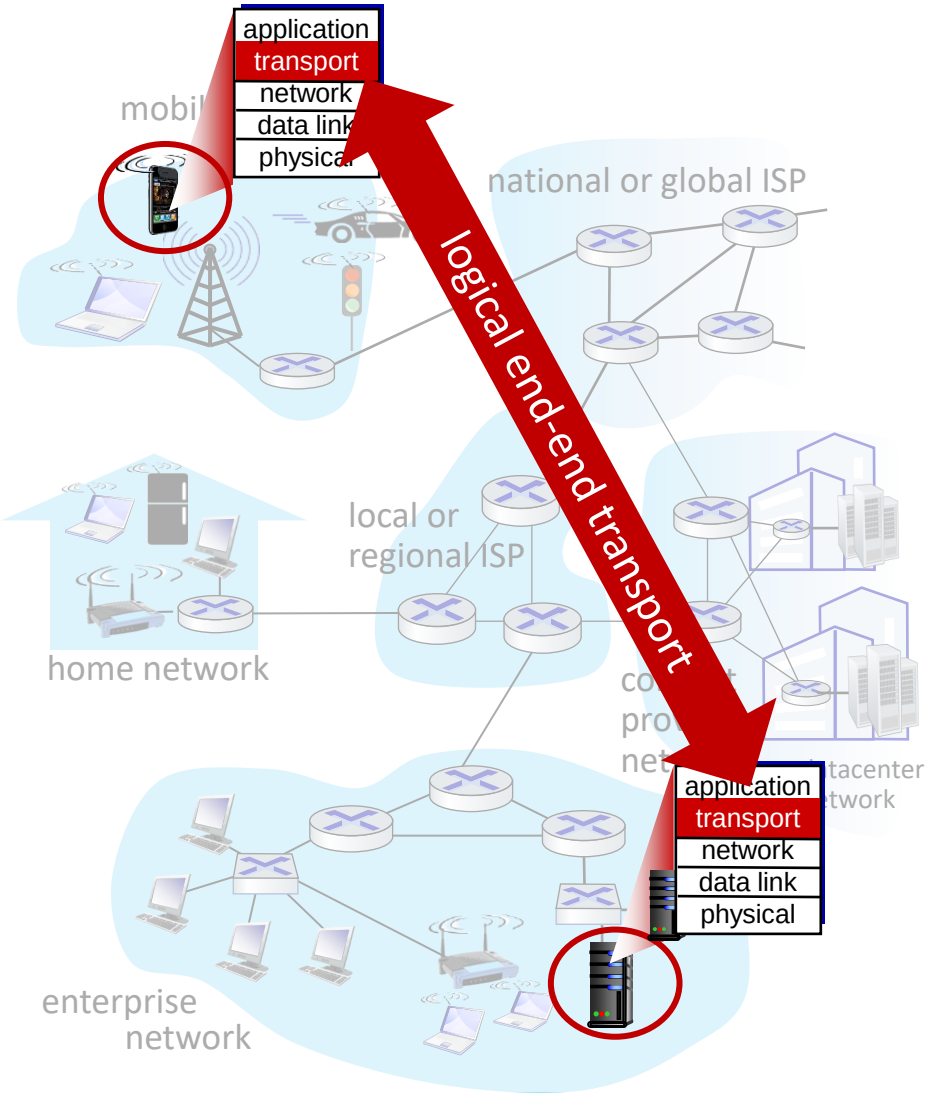
Transport layer: overview

Our goal:

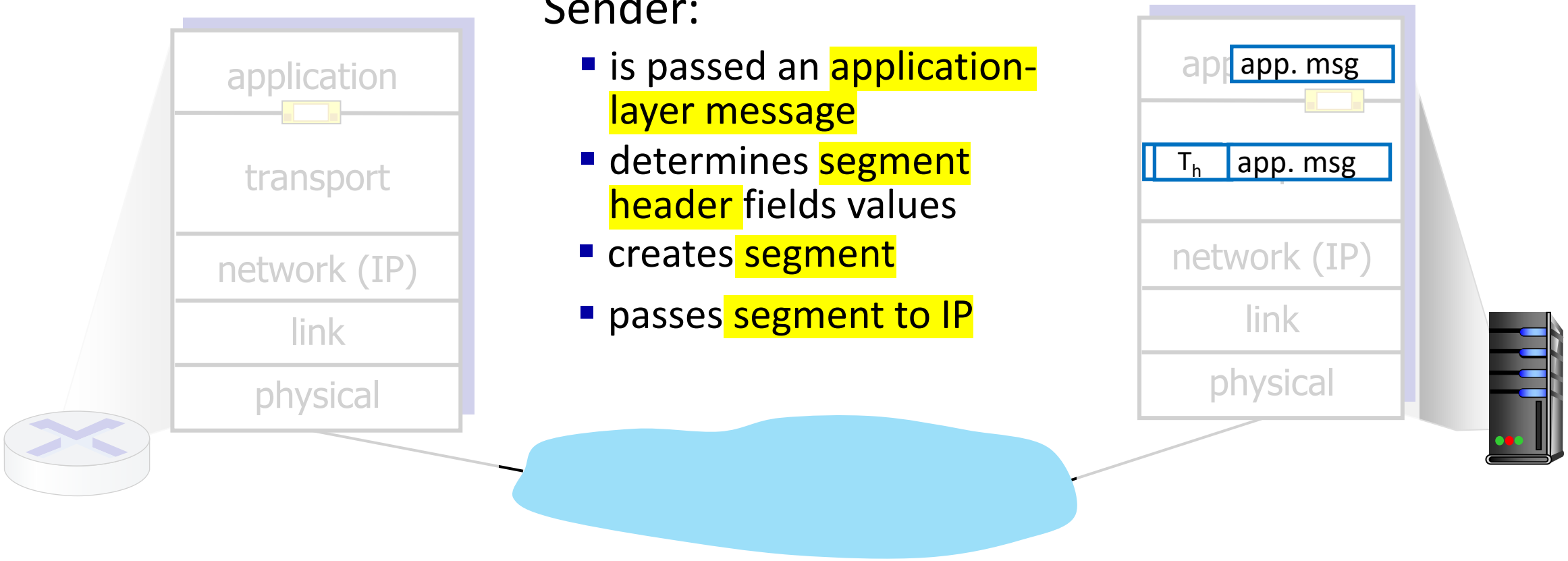
- understand principles behind transport layer services:
  - multiplexing, demultiplexing
  - reliable data transfer
  - flow control
  - congestion control
- learn about Internet transport layer protocols:
  - UDP: connectionless transport
  - TCP: connection-oriented reliable transport
  - TCP congestion control

Transport services and protocols

- provide *logical communication* between application processes running on different hosts
- transport protocols actions in end systems:
  - sender: breaks application messages into *segments*, passes to network layer
  - receiver: reassembles segments into messages, passes to application layer
- two transport protocols available to Internet applications
  - TCP, UDP



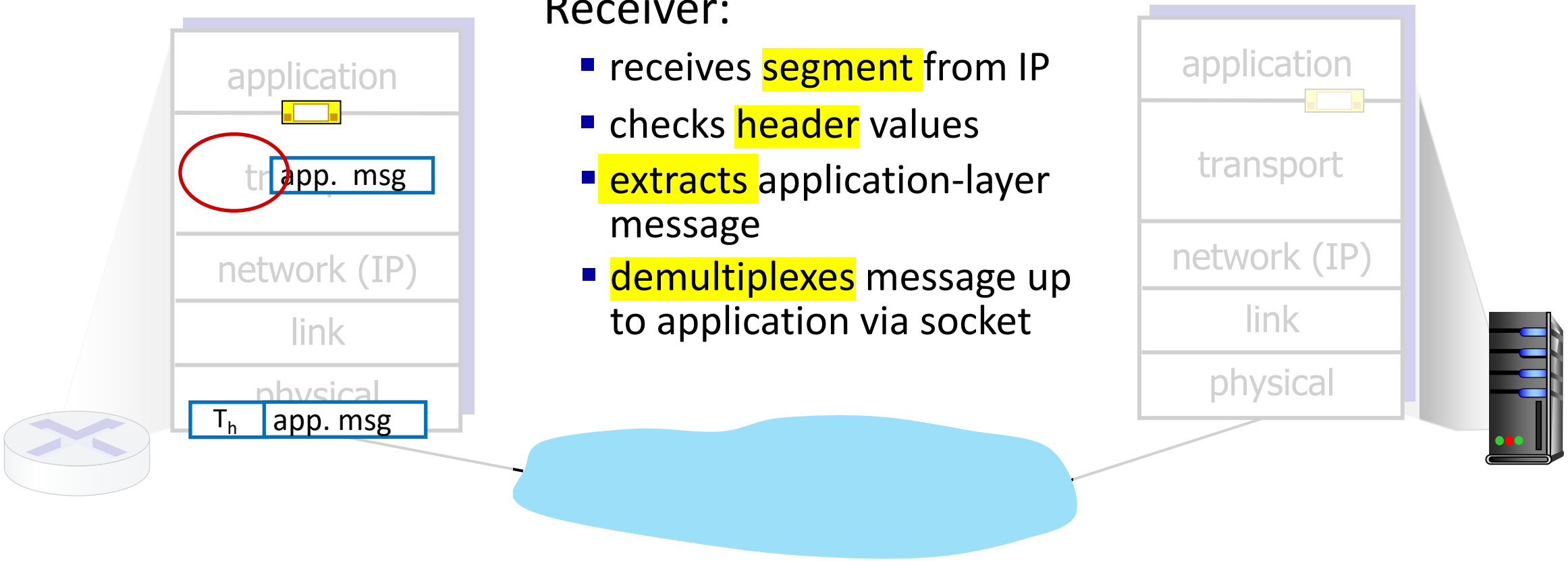
Transport Layer Actions



Sender:

- is passed an application-layer message
- determines segment header fields values
- creates segment
- passes segment to IP

Transport Layer Actions



Receiver:

- receives segment from IP
- checks header values
- extracts application-layer message
- demultiplexes message up to application via socket

Two principal Internet transport protocols

- **TCP:** Transmission Control Protocol
  - reliable, in-order delivery
  - congestion control
  - flow control
  - connection setup
- **UDP:** User Datagram Protocol
  - unreliable, unordered delivery
  - no-frills extension of “best-effort” IP
- services not available:
  - delay guarantees
  - bandwidth guarantees