COMP 6461

Computer Networks & Protocols

Winter 2023

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Lecture 3a

Application Layer (Part 2)

Application layer: overview

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

Web and HTTP

First, a quick review…

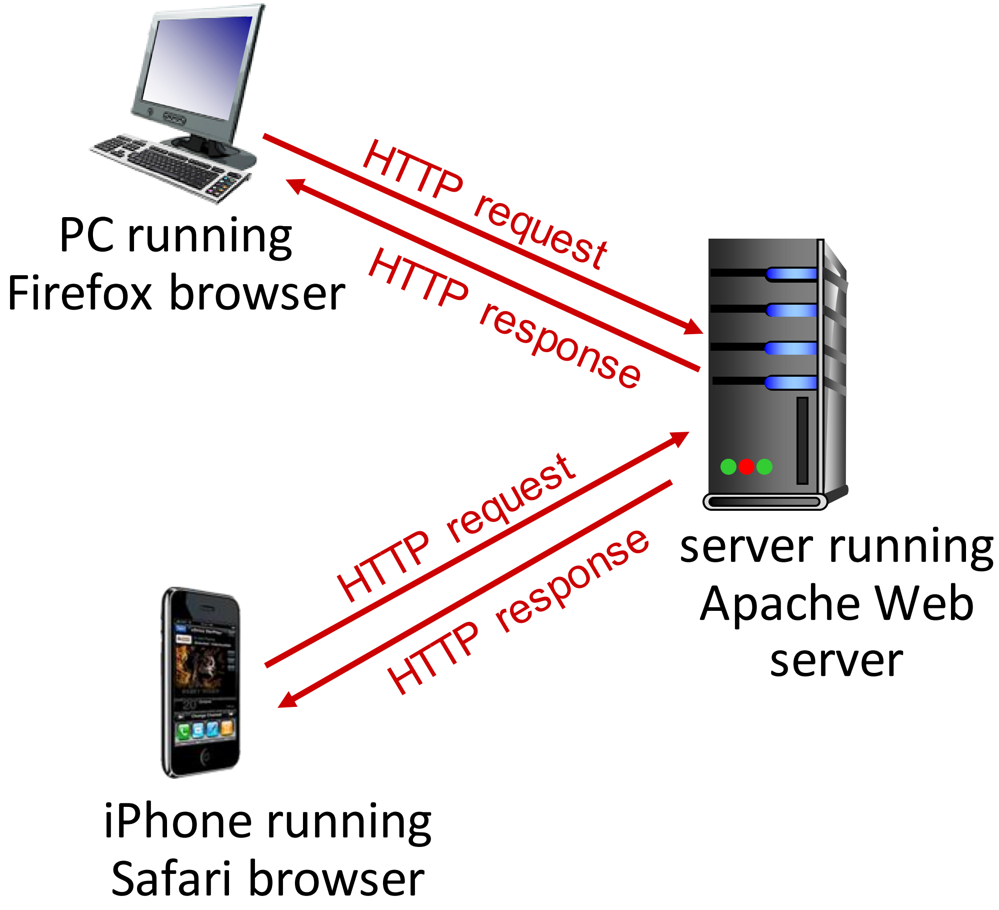
- web page consists of *objects,* each of which can be stored on different Web servers
- object can be HTML file, JPEG image, Java applet, audio file,…
- web page consists of *base HTML-file* which includes *several referenced objects, each* addressable by a *URL,* e.g.,

$$\underbrace{\texttt{www.someschool.edu}}_{\text{host name}}\underbrace{\texttt{/someDept/pic.gif}}_{\text{path name}}$$

HTTP overview

HTTP: HyperText Transfer Protocol

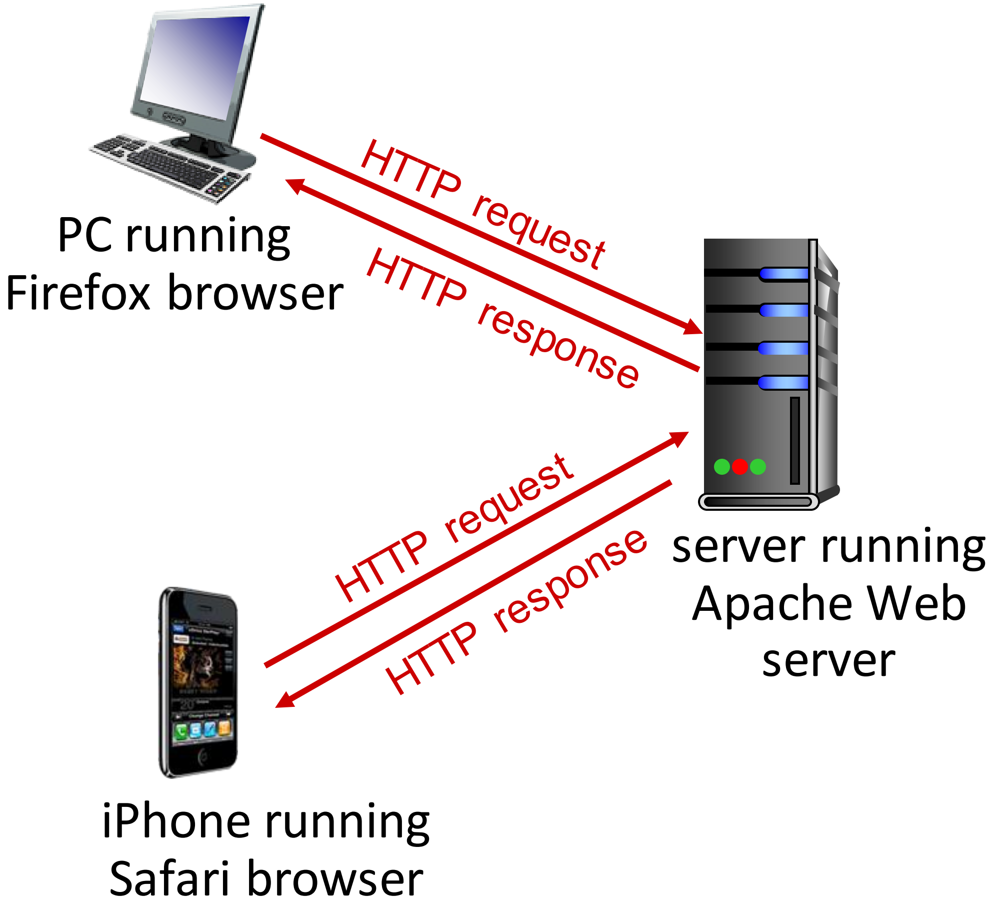
- Web application's layer protocol
- Client/Server model
- Client: browser that requests, receives (using HTTP protocol), and displays web objects.
- Server: web server that sends (using HTTP protocol) objects in response to requests.



HTTP overview (continued)

HTTP uses TCP (at transport layer)

- client initiates TCP connection (create socket) to server, port 80
- server accepts TCP connection from client
- HTTP messages (application layer protocol messages) exchanges between browser (HTTP client) and web server (HTTP server)
- Close TCP connection



HTTP is "stateless"

- server maintains *no* information about past client requests

HTTP connections: two types

Non-persistent HTTP

1. TCP connection opened
2. at most one object sent over TCP connection
3. TCP connection closed

downloading multiple objects required multiple connections

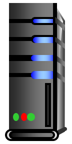
Persistent HTTP

- TCP connection opened to a server
- multiple objects can be sent over *single* TCP connection between client, and that server
- TCP connection closed

Non-persistent HTTP: example

User enters URL: **`www.someSchool.edu/someDepartment/home.index`**
(containing text, references to 10 jpeg images)

1a. HTTP client initiates TCP connection to HTTP server (process) at www.someSchool.edu on port 80



1b. HTTP server at host www.someSchool.edu waiting for TCP connection at port 80 "accepts" connection, notifying client

2. HTTP client sends HTTP *request message* (containing URL) into TCP connection socket. Message indicates that client wants object someDepartment/home.index

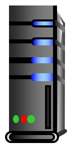
3. HTTP server receives request message, forms *response message* containing requested object, and sends message into its socket

time

Non-persistent HTTP: example (cont.)

User enters URL: **`www.someSchool.edu/someDepartment/home.index`**

(containing text, references to 10 jpeg images)



4. HTTP server closes TCP connection.

5. HTTP client receives response message containing html file, displays html. Parsing html file, finds 10 referenced jpeg objects

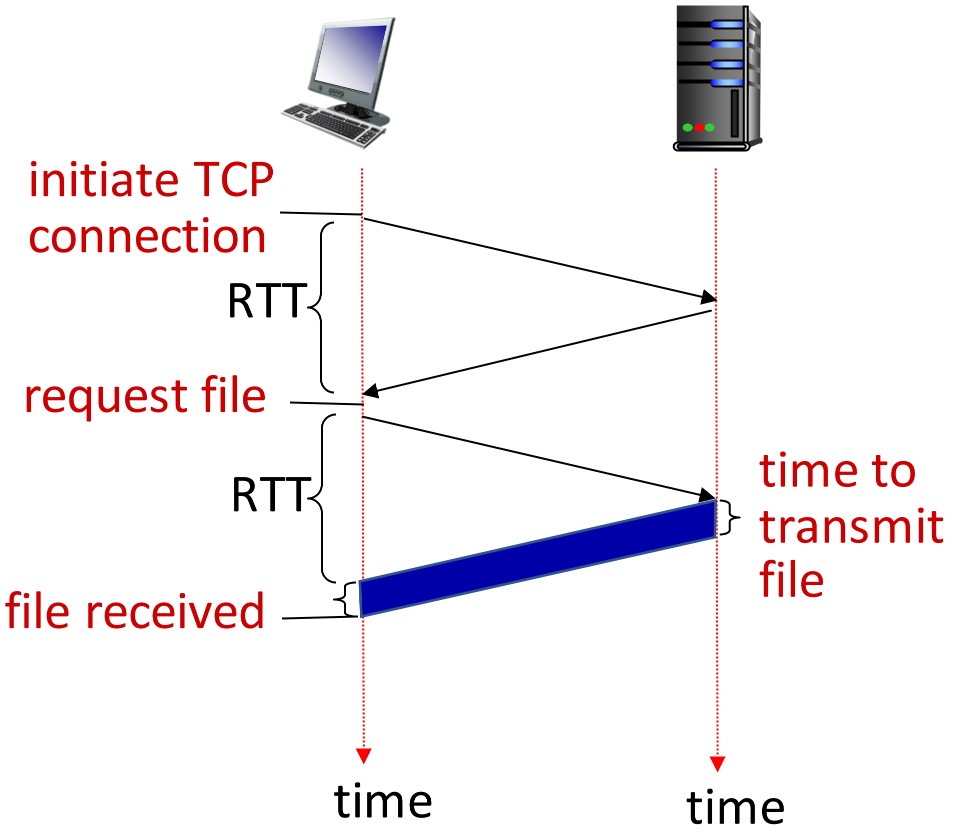
6. Steps 1-5 repeated for each of 10 jpeg objects

time

Non-persistent HTTP: response time

RTT (definition): time for a small packet to travel from client to server and back

HTTP response time (per object):
- one RTT to initiate TCP connection
- one RTT for HTTP request and first few bytes of HTTP response to return
- obect/file transmission time



Non-persistent HTTP response time = 2RTT+ file transmission time

Persistent HTTP (HTTP 1.1)

Non-persistent HTTP issues:

- requires 2 RTTs per object
- OS overhead for *each* TCP connection
- browsers often open multiple parallel TCP connections to fetch referenced objects in parallel

***Persistent HTTP** (HTTP1.1):*

- server leaves connection open after sending response
- subsequent HTTP messages between same client/server sent over open connection
- client sends requests as soon as it encounters a referenced object
- as little as one RTT for all the referenced objects (cutting response time in half)

HTTP request message

- two types of HTTP messages: *request, response*
- HTTP request message:
  - ASCII (human-readable format)

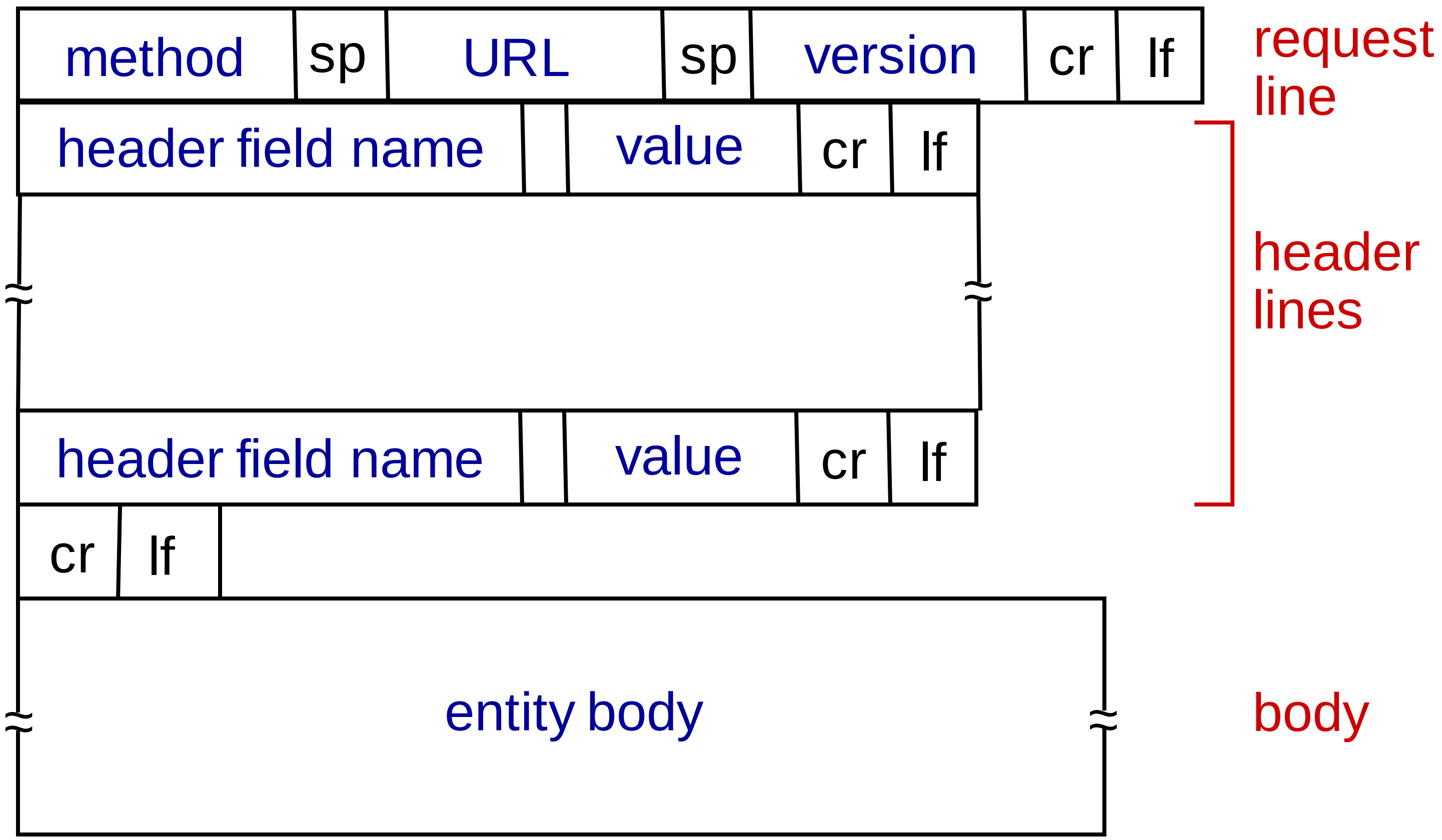
carriage return character

line-feed character

request line (GET, POST, HEAD commands)

carriage return, line feed at start of line indicates end of header lines

HTTP request message: general format



Other HTTP request messages

POST method:

- web page often includes form input
- user input sent from client to server in entity body of HTTP POST request message

GET method (for sending data to server):

- include user data in URL field of HTTP GET request message (following a '?'):

www.somesite.com/animalsearch?monkeys&banana

HEAD method:

- requests headers (only) that would be returned *if* specified URL were requested with an HTTP GET method.

PUT method:

- uploads new file (object) to server
- completely replaces file that exists at specified URL with content in entity body of POST HTTP request message

HTTP response message

status line (protocol status code status phrase)

header lines

data, e.g., requested HTML file

```
HTTP/1.1 200 OK\r\n
Date: Sun, 26 Sep 2010 20:09:20 GMT\r\n
Server: Apache/2.0.52 (CentOS)\r\n
Last-Modified: Tue, 30 Oct 2007 17:00:02
GMT\r\n
ETag: "17dc6-a5c-bf716880"\r\n
Accept-Ranges: bytes\r\n
Content-Length: 2652\r\n
Keep-Alive: timeout=10, max=100\r\n
Connection: Keep-Alive\r\n
Content-Type: text/html; charset=ISO-8859-
1\r\n
\r\n
data data data data data ...
```

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

HTTP response status codes

- status code appears in 1st line in server-to-client response message.
- some sample codes:

  200 OK
  - request succeeded, requested object later in this message

  301 Moved Permanently
  - requested object moved, new location specified later in this message (in Location: field)

  400 Bad Request
  - request msg not understood by server

  404 Not Found
  - requested document not found on this server

  505 HTTP Version Not Supported

Maintaining user/server state: cookies

Recall: HTTP GET/response interaction is *stateless*

Web sites and client browser use *cookies* to maintain some state between transactions

four components:

1) cookie header line of HTTP *response* message

2) cookie header line in next HTTP *request* message

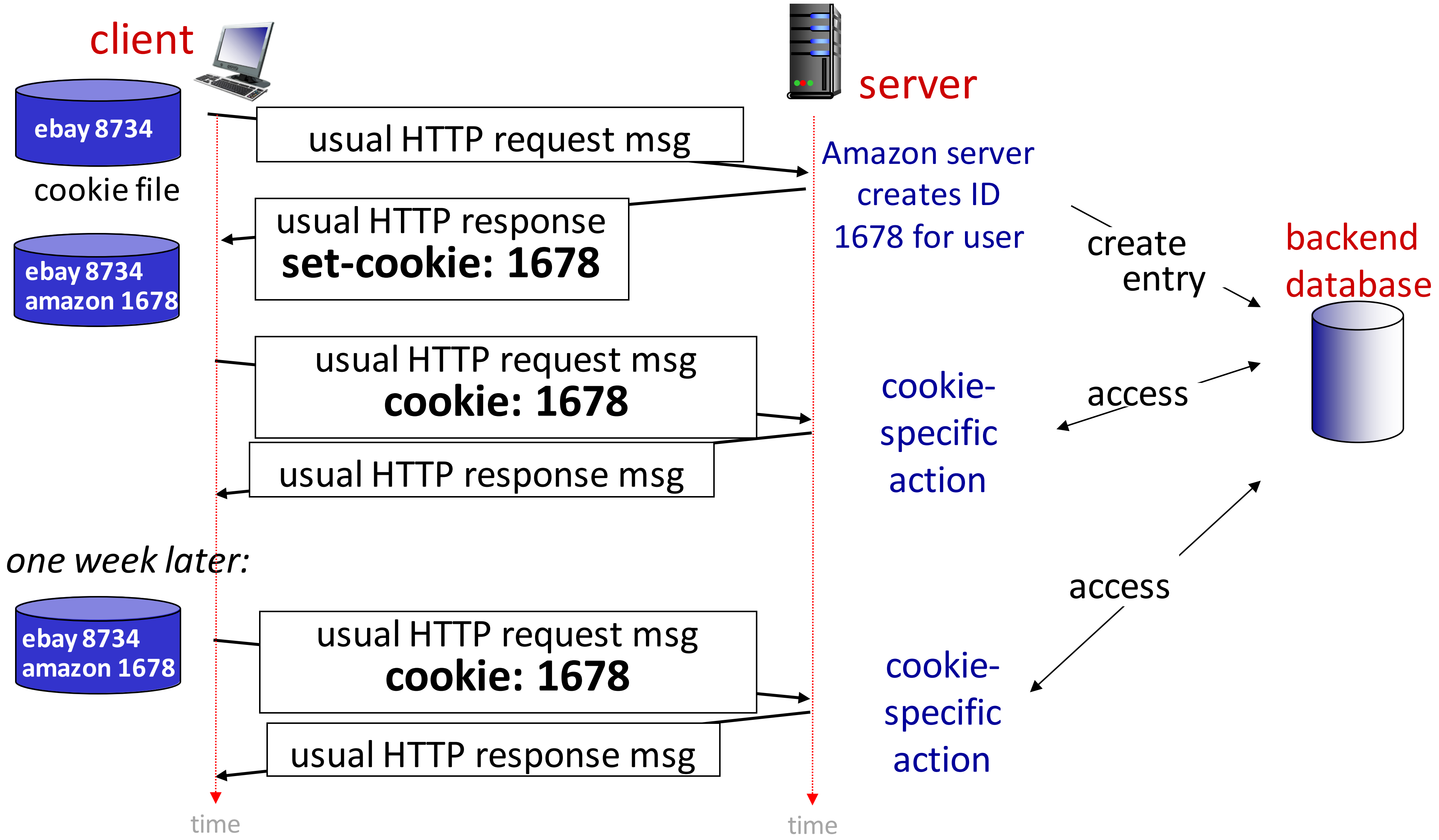
3) cookie file kept on user's host, managed by user's browser

4) back-end database at Web site

Example:

- Susan uses browser on laptop, visits specific e-commerce site for first time
- when initial HTTP requests arrives at site, site creates:
  - unique ID (aka "cookie")
  - entry in backend database for ID
- subsequent HTTP requests from Susan to this site will contain cookie ID value, allowing site to "identify" Susan

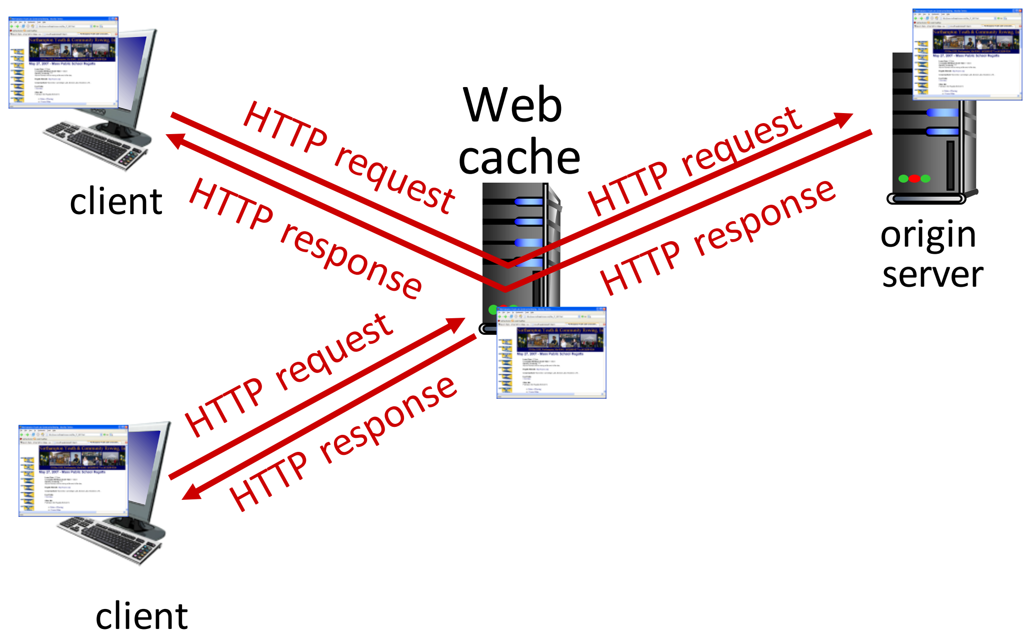
Maintaining user/server state: cookies



Web caches

Goal: satisfy client requests without involving origin server

- user configures browser to point to a (local) *Web cache*
- browser sends all HTTP requests to cache
  - *if* object in cache: cache returns object to client
  - *else* cache requests object from origin server, caches received object, then returns object to client



Web caches (aka proxy servers)

- Web cache acts as both client and server
  - server for original requesting client
  - client to origin server
- server tells cache about object's allowable caching in response header:

```
Cache-Control: max-age=<seconds>
```

```
Cache-Control: no-cache
```

Why Web caching?

- reduce response time for client request
  - cache is closer to client
- reduce traffic on an institution's access link

Caching example

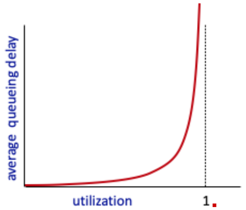
Scenario:

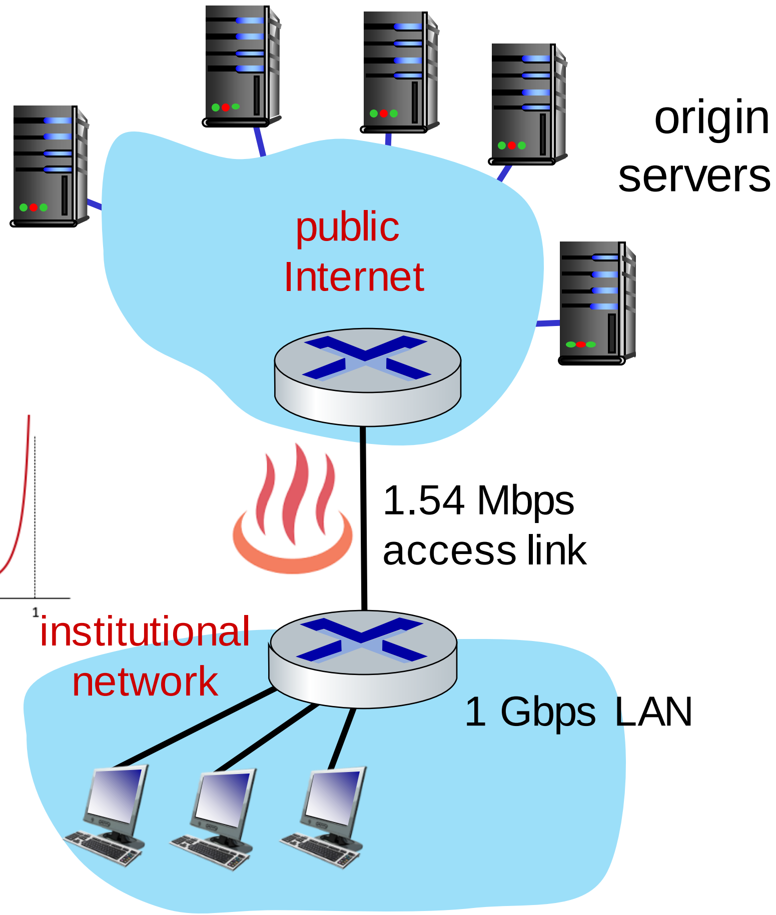
- access link rate: 1.54 Mbps
- RTT from institutional router to server: 2 sec
- web object size: 100K bits (0.1 Mbits)
- average request rate from browsers to origin servers: 15 req/sec
  - avg data rate to browsers: 1.50 Mbps (15 x 0.1)

Performance:

- access link utilization = .97
- LAN utilization: .0015 (15/10000)
- end-end delay = Internet delay + access link delay + LAN delay
  = 2 sec + minutes + usecs

problem: large queueing delays at high utilization!





Option 1: buy a faster access link

Scenario: 154 Mbps

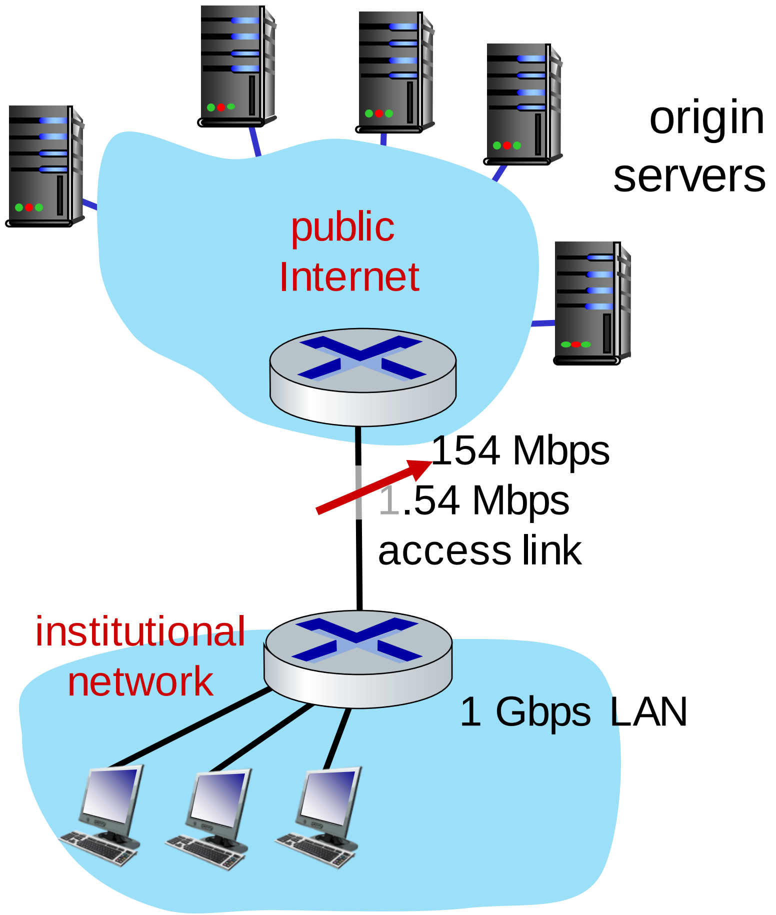
- access link rate: ~~1.54~~ Mbps
- RTT from institutional router to server: 2 sec
- web object size: 100K bits
- average request rate from browsers to origin servers: 15/sec
  - avg data rate to browsers: 1.50 Mbps

Performance:

- access link utilization = ~~.97~~ → .0097
- LAN utilization: .0015
- end-end delay = Internet delay + access link delay + LAN delay

  = 2 sec + ~~minutes~~ + usecs → msecs

Cost: faster access link (expensive!)



Option 2: install a web cache

Scenario:

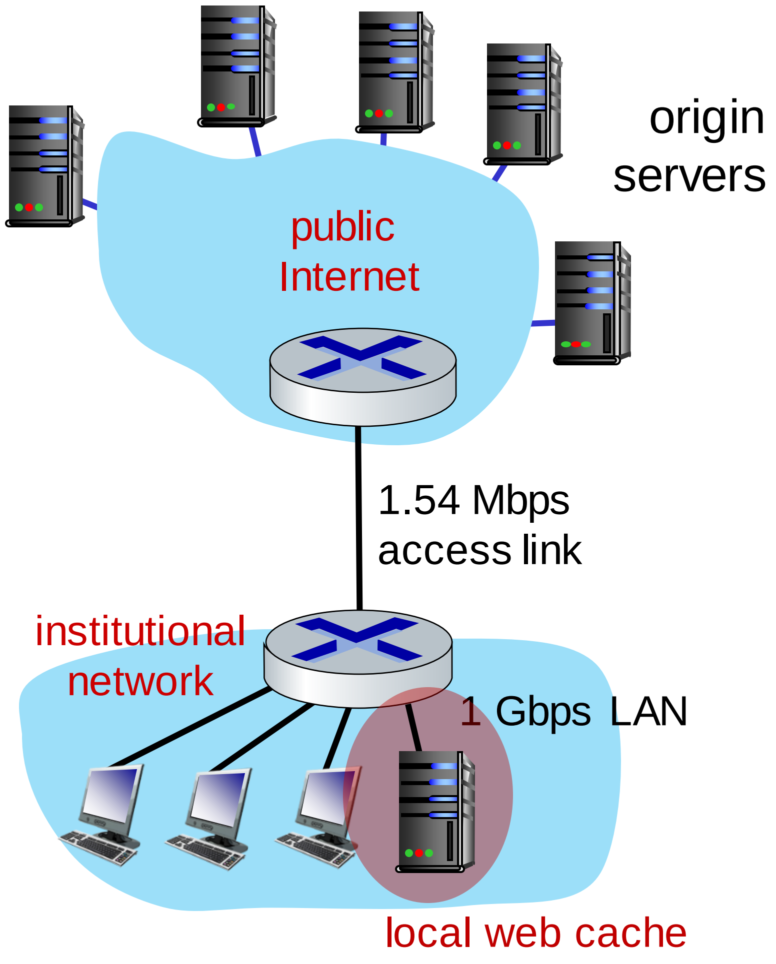
- access link rate: 1.54 Mbps
- RTT from institutional router to server: 2 sec
- web object size: 100K bits
- average request rate from browsers to origin servers: 15/sec
  - avg data rate to browsers: 1.50 Mbps

Cost: web cache (cheap!)

Performance:

- LAN utilization: .?
- access link utilization = ?
- average end-end delay = ?

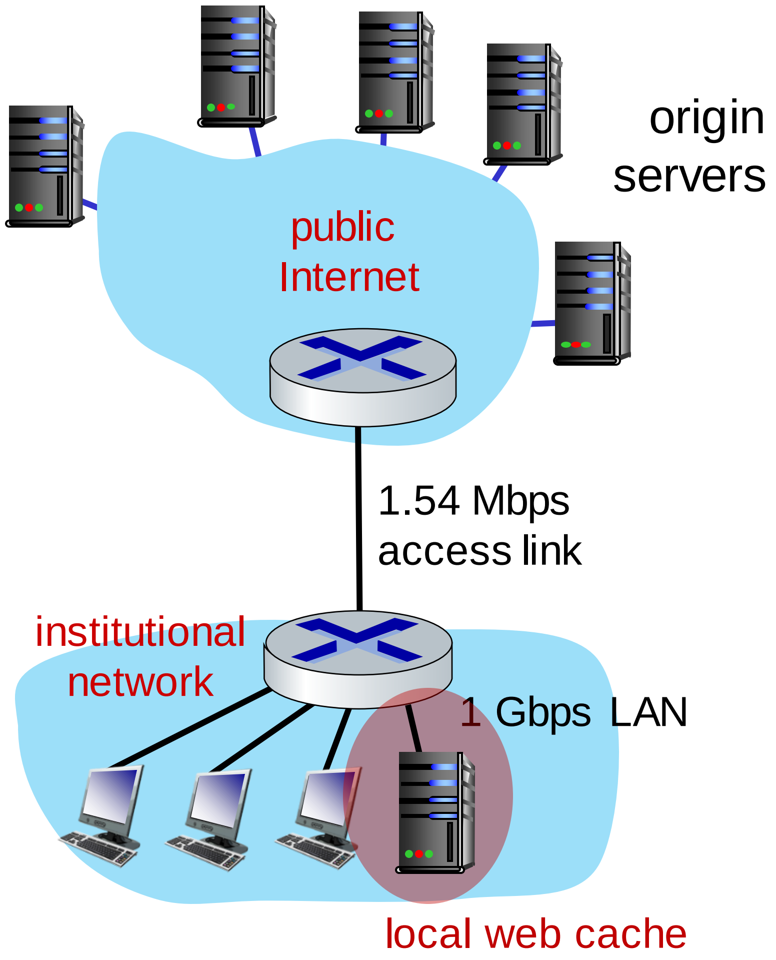
How to compute link utilization, delay?



Calculating access link utilization, end-end delay with cache:

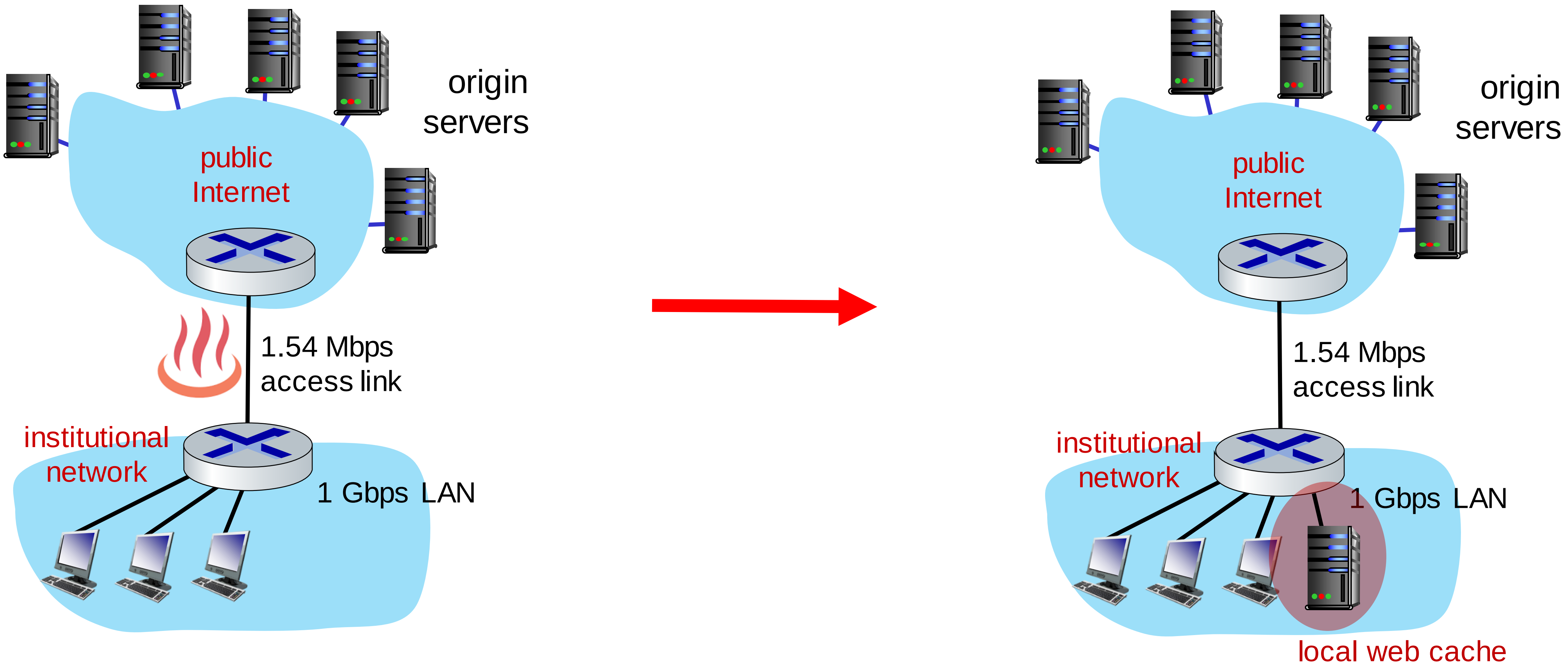
suppose cache hit rate is 0.4:

- 40% requests served by cache, with low (msec) delay (same access network)
- 60% requests satisfied at origin
  - rate to browsers over access link
    = 0.6 * 1.50 Mbps = .9 Mbps
  - access link utilization = 0.9/1.54 = .58 means low (msec) queueing delay at access link



lower average end-end delay than with 154 Mbps link (and cheaper too!)

Web caches (cont.)



Conditional GET

Goal: don't send object if *client* has up-to-date cached version

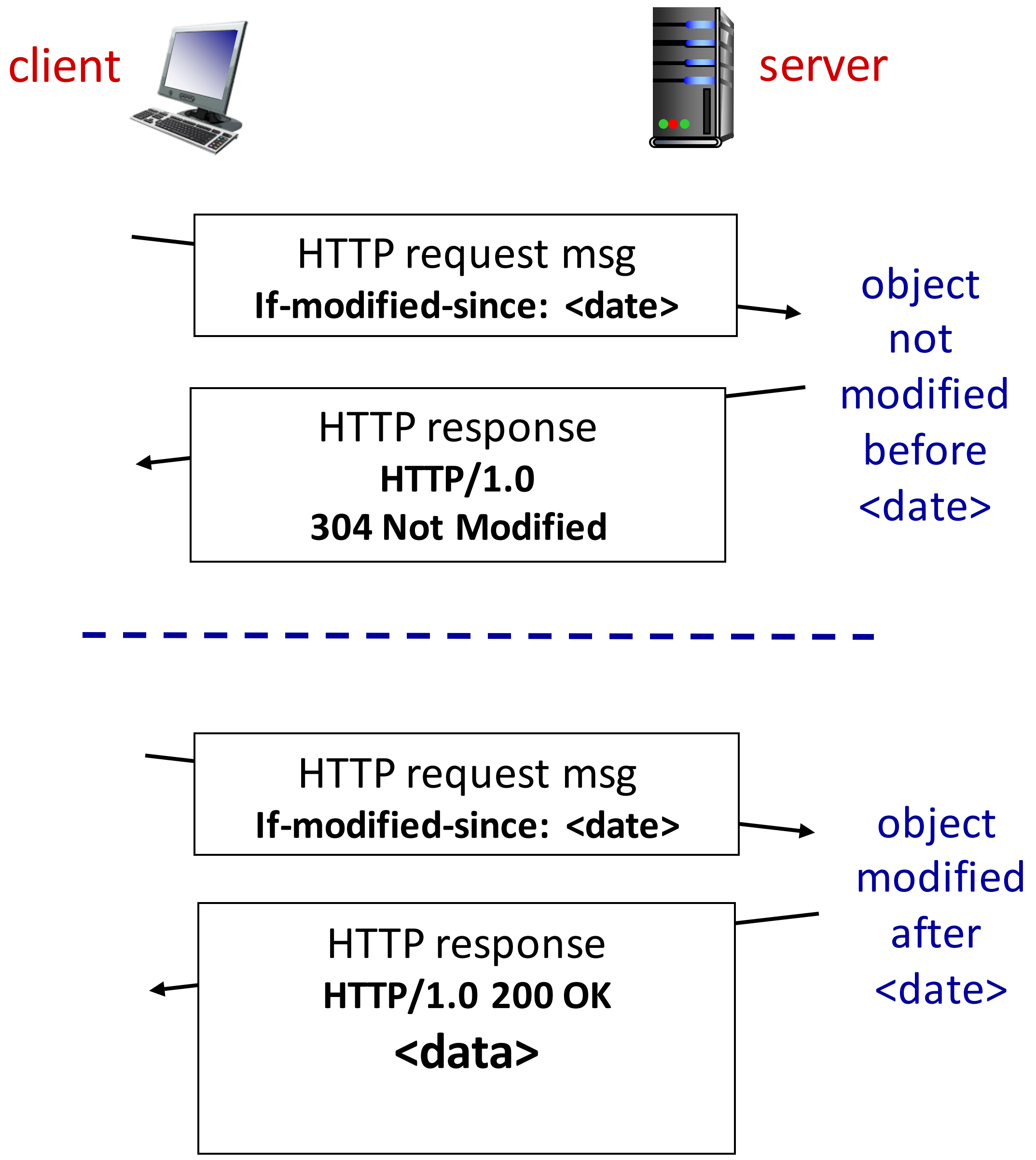
- no object transmission delay (or use of network resources)

- *client:* specify date of cached copy in HTTP request

  If-modified-since: <date>

- *server:* response contains no object if cached copy is up-to-date:

  HTTP/1.0 304 Not Modified



HTTP/2

Key goal: decreased delay in multi-object HTTP requests

HTTP1.1: introduced multiple, pipelined GETs over single TCP connection

- server responds *in-order* (FCFS: first-come-first-served scheduling) to GET requests
- with FCFS, small object may have to wait for transmission (head-of-line (HOL) blocking) behind large object(s)
- loss recovery (retransmitting lost TCP segments) stalls object transmission

HTTP/2

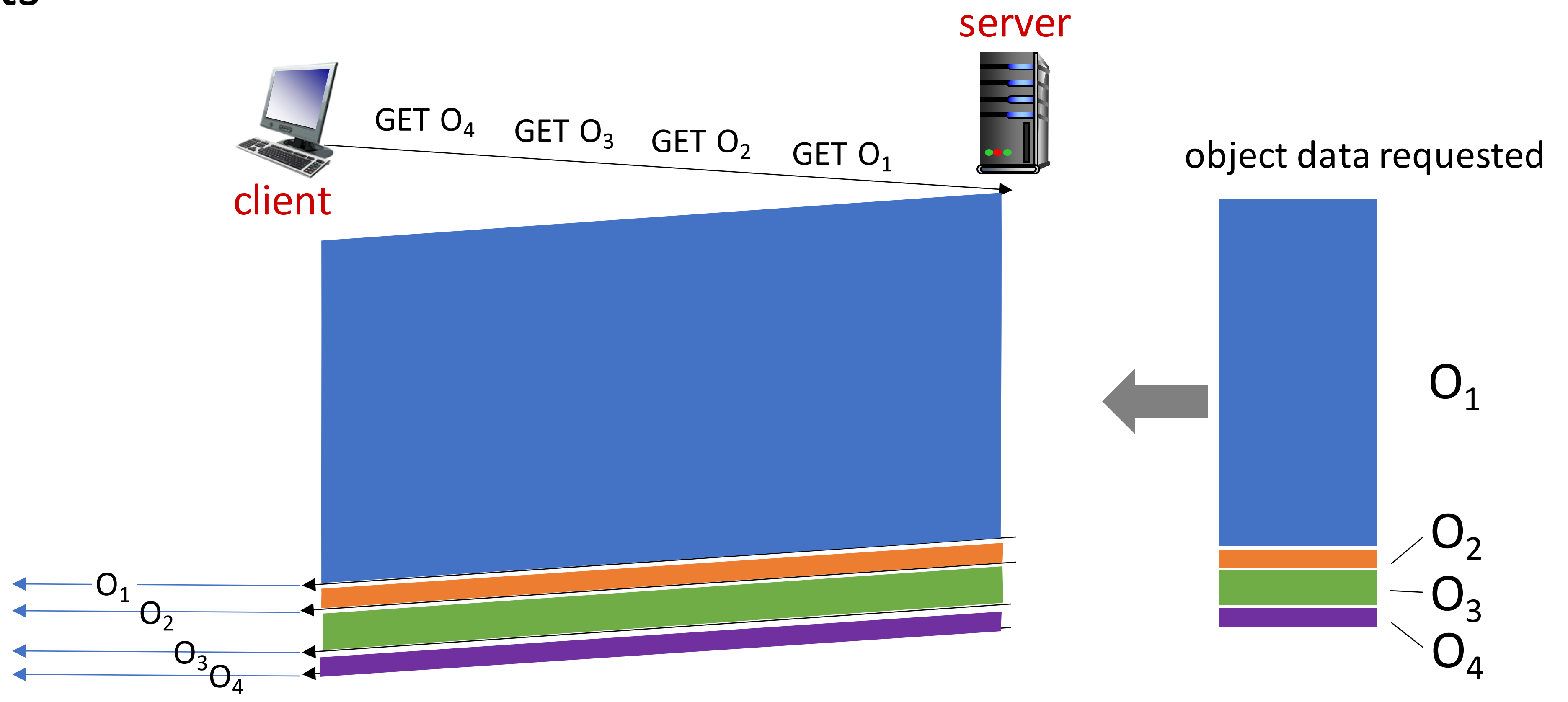
Key goal: decreased delay in multi-object HTTP requests

HTTP/2: [RFC 7540, 2015] increased flexibility at *server* in sending objects to client:

- methods, status codes, most header fields unchanged from HTTP 1.1
- transmission order of requested objects based on client-specified object priority (not necessarily FCFS)
- *push* unrequested objects to client
- divide objects into frames, schedule frames to mitigate HOL blocking

HTTP/2: mitigating HOL blocking

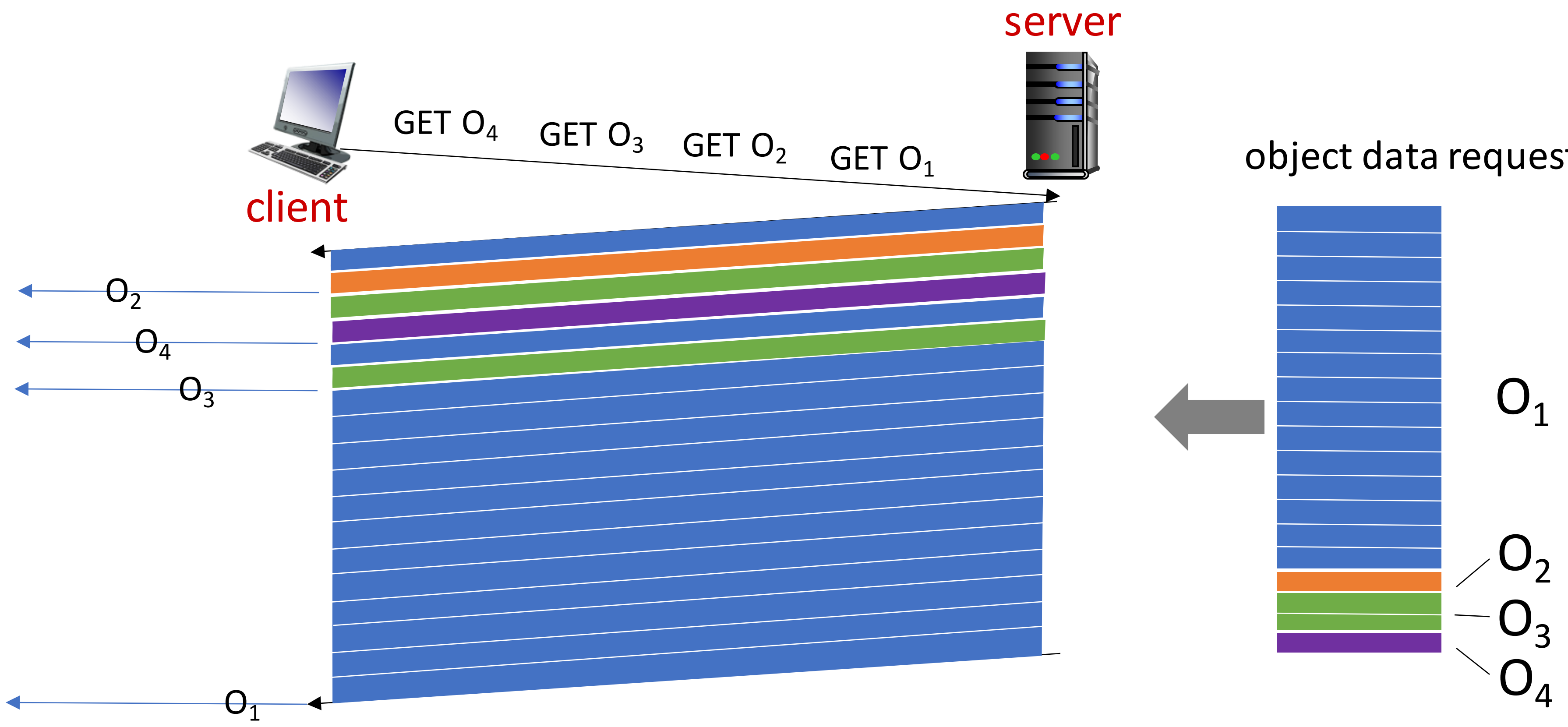
HTTP 1.1: client requests 1 large object (e.g., video file) and 3 smaller objects



objects delivered in order requested: O_2, O_3, O_4 wait behind O_1

HTTP/2: mitigating HOL blocking

HTTP/2: objects divided into frames, frame transmission interleaved



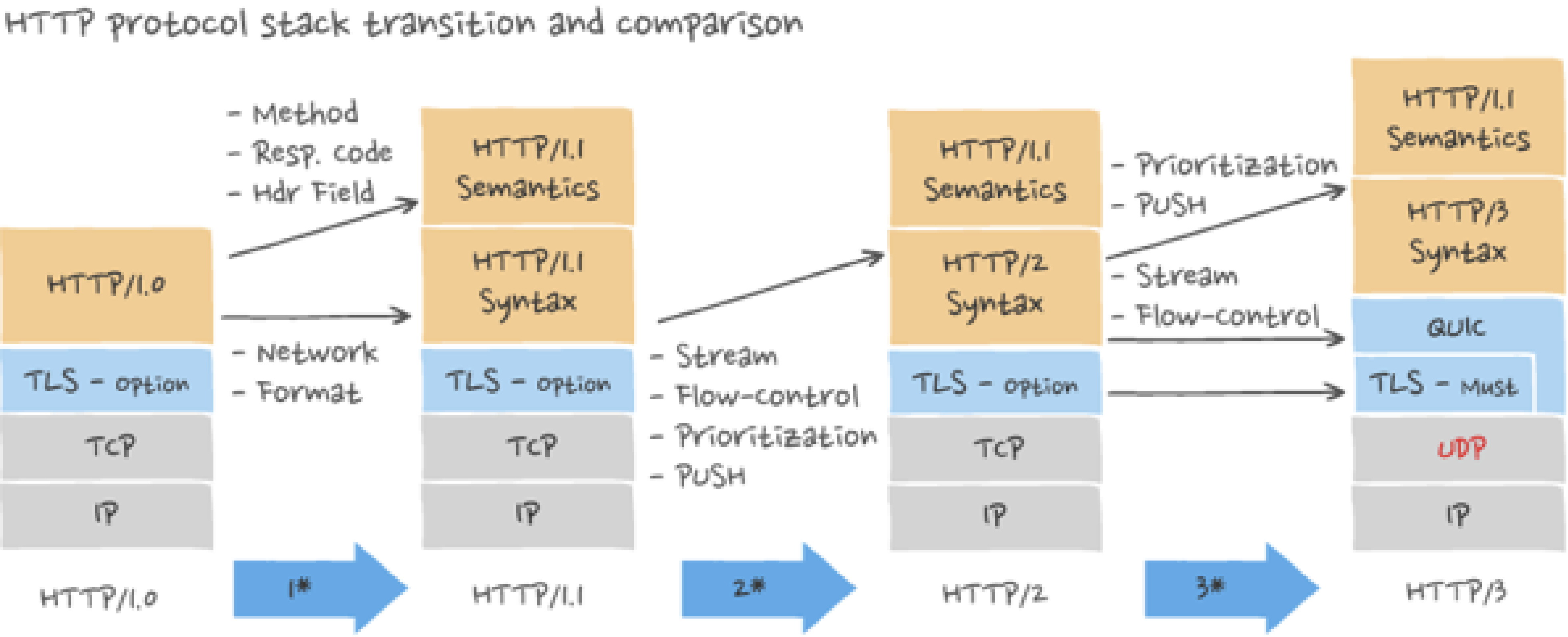
O_2, O_3, O_4 delivered quickly, O_1 slightly delayed

HTTP/2 to HTTP/3

HTTP/2 over single TCP connection means:

- recovery from packet loss still stalls all object transmissions
  - as in HTTP 1.1, browsers have incentive to open multiple parallel TCP connections to reduce stalling, increase overall throughput
- no security over vanilla TCP connection
- HTTP/3: adds security, per object error- and congestion-control (more pipelining) over UDP
  - more on HTTP/3 in transport layer

HTTP/1 vs HTTP/2 vs. HTTP/3



A H3/QUIC History

Launched by Google in 2012, support in Chrome in 2013:

- Google reported improvements in application performance
  - Reduction in YouTube video rebuffering and Google search latency
- >35% of Google's egress traffic (~7% of the internet) in 2017
- >75% of FB's traffic in 2020
- Check here for the latest figures

Facebook is bringing QUIC to billions

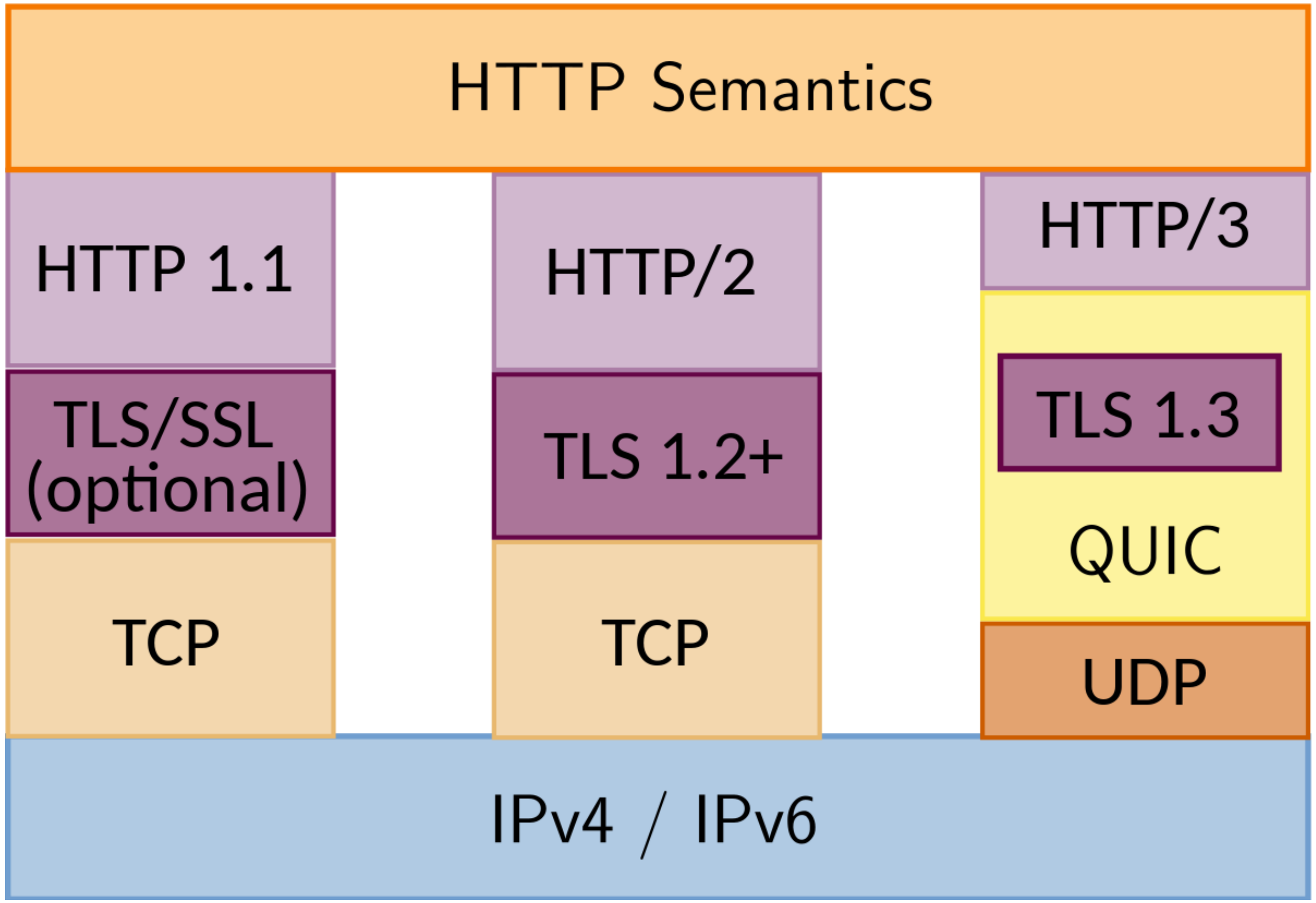
- QUIC for all content in the Facebook products
- QUIC had a transformative effect on video metrics in the Facebook app (e.g., stall rate was reduced by 20%)

QUIC Standardization: Six core documents are now with RFC editor

H3 (and QUIC) Support as of Today

Edge *	Firefox	Chrome	Safari	Opera	Safari on iOS *	Opera Mini *	Android Browser *	Opera Mobile *	Chrome for Android
12-18		4-78							
[2] 79-84	2-71	[2] 79-84		10-72					
[3] 85-86	[1] 72-87	[3] 85-86	3.1-13.1	[3] 73	3.2-13.7				
87-91	88-90	87-91	[4] 14	74-77	14.4		2.1-4.4.4	12-12.1	
92	91	92	[4] 14.1	78	14.7	all	92	64	92
	92-93	93-95	[4] 15-TP						

TCP/IP Protocol Stack (Until L3)



H3/QUIC Features

Main new features over TCP+TLS+H2:

- Connection establishment latency: 0-RTT (or 1-RTT)
- Customizable congestion control, improved retransmission machinery, forward error correction (FEC)
- Multiplexing w/o HoL blocking
- Connection migration: Moving between network interfaces without renegotiating the session

Reliable and prioritized delivery

- Decoupled retransmissions, congestion control and flow control
- Stream prioritization is managed by the sender

Encrypted delivery

- The network cannot identify the streams, so multiple connections are needed for QoS