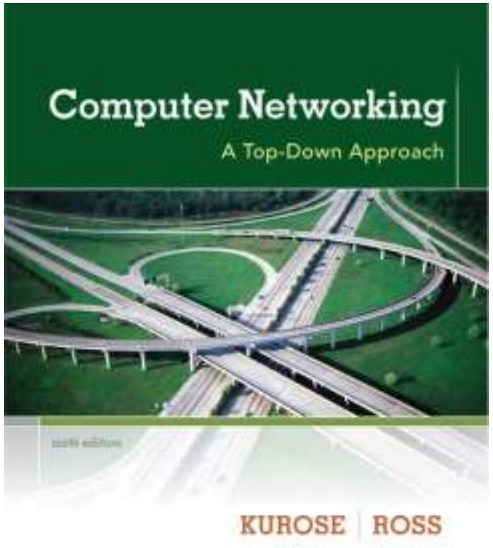
Chapter 2
Application Layer



Computer Networking: A Top Down Approach
6th edition
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Addison-Wesley
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App-layer protocol defines

- types of messages exchanged,
  - e.g., request, response
- message syntax:
  - what fields in messages & how fields are delineated
- message semantics
  - meaning of information in fields
- rules for when and how processes send & respond to messages

open protocols:

- defined in RFCs
- allows for interoperability
- e.g., HTTP, SMTP

proprietary protocols:

- e.g., Skype

What transport service does an app need?

data integrity

- some apps (e.g., file transfer, web transactions) require 100% reliable data transfer
- other apps (e.g., audio) can tolerate some loss

timing

- some apps (e.g., Internet telephony, interactive games) require low delay to be "effective"

throughput

- some apps (e.g., multimedia) require minimum amount of throughput to be "effective"
- other apps ("elastic apps") make use of whatever throughput they get

security

- encryption, data integrity, …

Internet transport protocols services

TCP service:

- *reliable transport* between sending and receiving process
- *flow control:* sender won't overwhelm receiver
- *congestion control:* throttle sender when network overloaded
- *does not provide:* timing, minimum throughput guarantee, security
- *connection-oriented:* setup required between client and server processes

UDP service:

- *unreliable data transfer* between sending and receiving process
- *does not provide:* reliability, flow control, congestion control, timing, throughput guarantee, security, orconnection setup,

Q: why bother? Why is there a UDP?

Chapter 2: outline

2.1 principles of network applications
  - app architectures
  - app requirements

2.2 Web and HTTP

2.3 FTP

2.4 electronic mail
  - SMTP, POP3, IMAP

2.5 DNS

2.6 P2P applications

2.7 socket programming with UDP and TCP

Web and HTTP

First, a review…

- *web page* consists of *objects*
- object can be HTML file, JPEG image, Java applet, audio file,…
- web page consists of *base HTML-file* which includes *several referenced objects*
- each object is 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's application layer protocol
- client/server model
  - *client:* browser that requests, receives, (using HTTP protocol) and "displays" Web objects
  - *server:* Web server sends (using HTTP protocol) objects in response to requests

HTTP overview (continued)

uses TCP:

- client initiates TCP connection (creates socket) to server, port 80
- server accepts TCP connection from client
- HTTP messages (application-layer protocol messages) exchanged between browser (HTTP client) and Web server (HTTP server)
- TCP connection closed

HTTP is "stateless"

- server maintains no information about past client requests

aside

protocols that maintain "state" are complex!

- past history (state) must be maintained
- if server/client crashes, their views of "state" may be inconsistent, must be reconciled

HTTP connections

non-persistent HTTP

- at most one object sent over TCP connection
  - connection then closed
- downloading multiple objects required multiple connections

persistent HTTP

- multiple objects can be sent over single TCP connection between client, server

Non-persistent HTTP

suppose user enters URL:
`www.someSchool.edu/someDepartment/home.index`

(contains 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 (cont.)

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

time

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

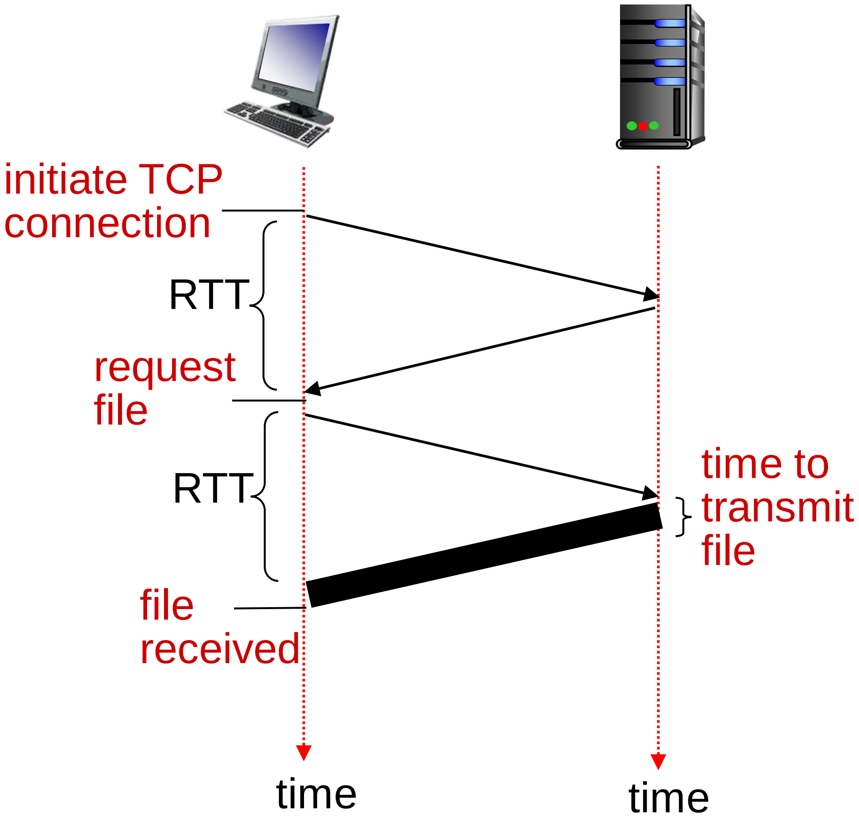
Non-persistent HTTP: response time

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

HTTP response time:

- one RTT to initiate TCP connection
- one RTT for HTTP request and first few bytes of HTTP response to return
- file transmission time
- non-persistent HTTP response time =

  2RTT+ file transmission time



Persistent HTTP

non-persistent HTTP issues:

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

persistent HTTP:

- 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

HTTP request message

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

carriage return character

line-feed character

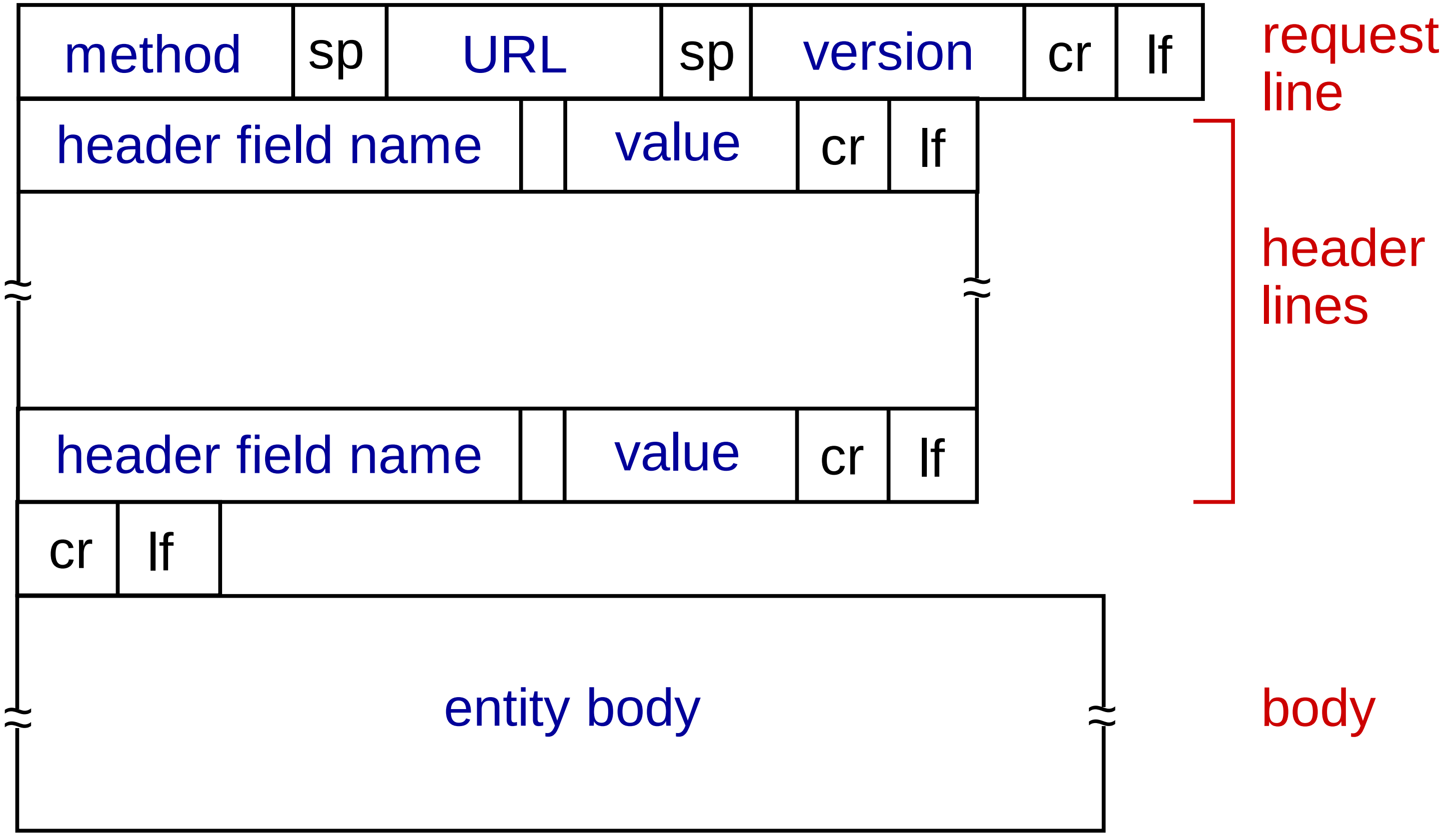
request line
(GET, POST,
HEAD commands)

```
GET /index.html HTTP/1.1\r\n
Host: www-net.cs.umass.edu\r\n
User-Agent: Firefox/3.6.10\r\n
Accept: text/html,application/xhtml+xml\r\n
Accept-Language: en-us,en;q=0.5\r\n
Accept-Encoding: gzip,deflate\r\n
Accept-Charset: ISO-8859-1,utf-8;q=0.7\r\n
Keep-Alive: 115\r\n
Connection: keep-alive\r\n
\r\n
```

header
lines

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

HTTP request message: general format



method sp URL sp version cr lf

header field name value cr lf

header field name value cr lf

cr lf

entity body

request line

header lines

body

Uploading form input

POST method:

- web page often includes form input
- input is uploaded to server in entity body

URL method:

- uses GET method
- input is uploaded in URL field of request line:

```
www.somesite.com/animalsearch?monkeys&banana
```

Method types

HTTP/1.0:

- GET
- POST
- HEAD
  - asks server to leave requested object out of response

HTTP/1.1:

- GET, POST, HEAD
- PUT
  - uploads file in entity body to path specified in URL field
- DELETE
  - deletes file specified in the URL field

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 ...
```

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 msg

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

  `400 Bad Request`
  - request msg not understood by server

  `404 Not Found`
  - requested document not found on this server

  `505 HTTP Version Not Supported`

Trying out HTTP (client side) for yourself

1. Telnet to your favorite Web server:

```
telnet cis.poly.edu 80
```

opens TCP connection to port 80 (default HTTP server port) at cis.poly.edu. anything typed in sent to port 80 at cis.poly.edu

2. type in a GET HTTP request:

```
GET /~ross/ HTTP/1.1
Host: cis.poly.edu
```

by typing this in (hit carriage return twice), you send this minimal (but complete) GET request to HTTP server

3. look at response message sent by HTTP server!

(or use Wireshark to look at captured HTTP request/response)

User-server state: cookies

many Web sites use cookies

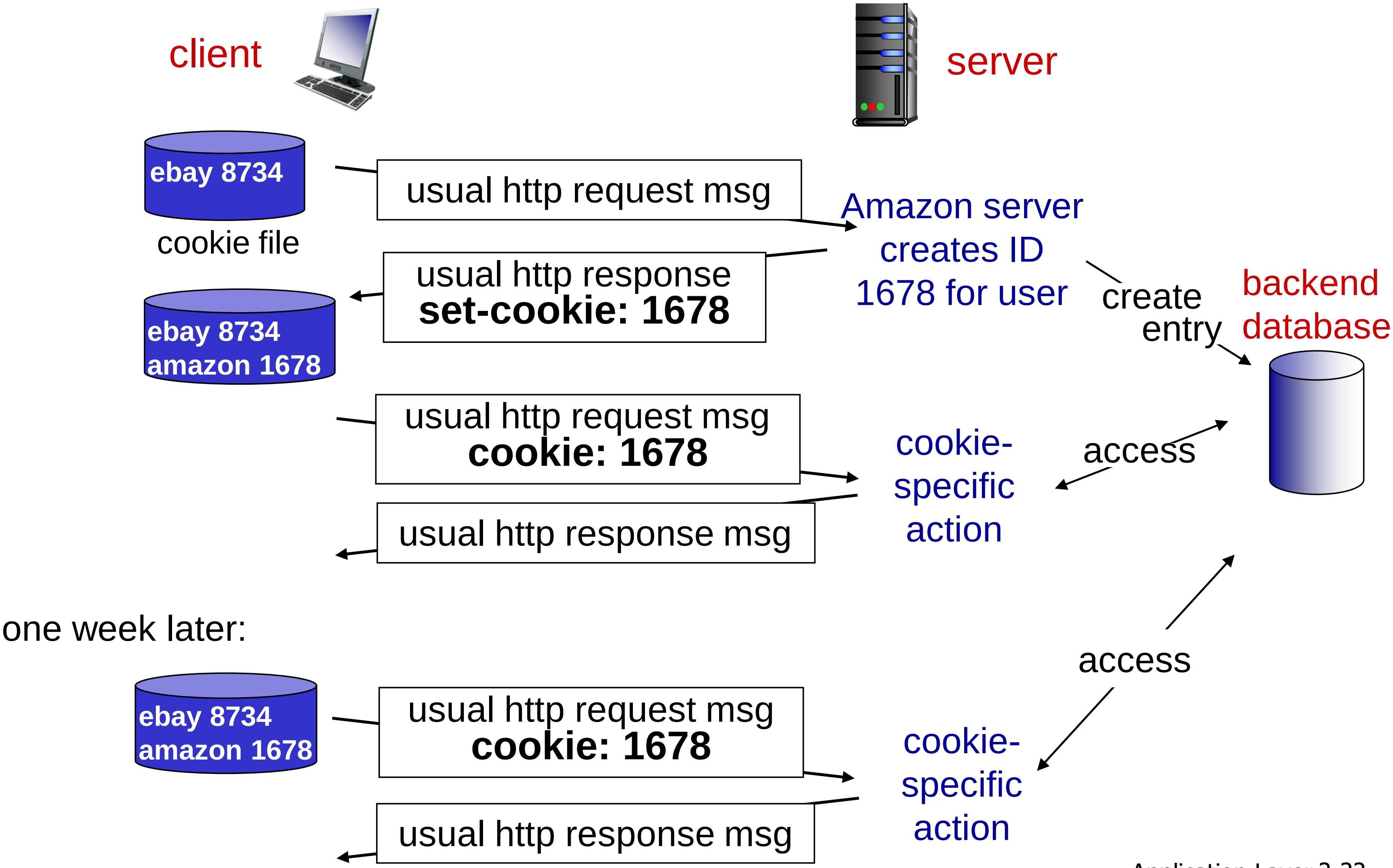
four components:

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 always access Internet from PC
- visits specific e-commerce site for first time
- when initial HTTP requests arrives at site, site creates:
  - unique ID
  - entry in backend database for ID

Cookies: keeping "state" (cont.)



client

server

ebay 8734

cookie file

usual http request msg

Amazon server
creates ID
1678 for user

usual http response
set-cookie: 1678

create
entry

backend
database

ebay 8734
amazon 1678

usual http request msg
cookie: 1678

cookie-
specific
action

access

usual http response msg

one week later:

access

ebay 8734
amazon 1678

usual http request msg
cookie: 1678

cookie-
specific
action

usual http response msg

Cookies (continued)

what cookies can be used for:

- authorization
- shopping carts
- recommendations
- user session state (Web e-mail)

aside

cookies and privacy:

- cookies permit sites to learn a lot about you
- you may supply name and e-mail to sites

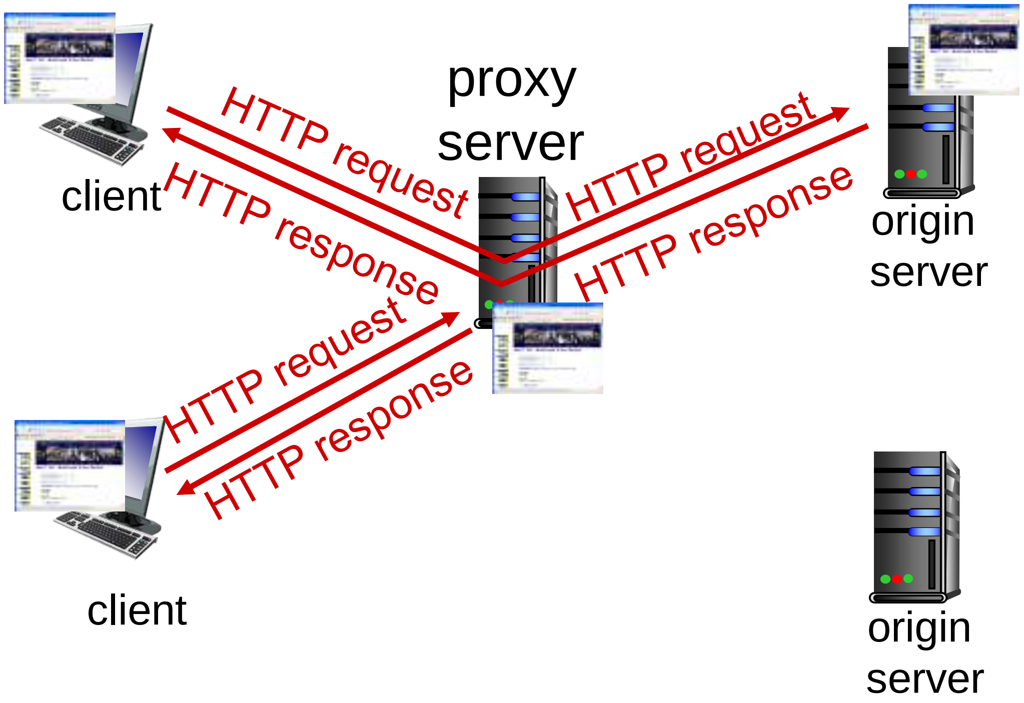
how to keep "state":

- protocol endpoints: maintain state at sender/receiver over multiple transactions
- cookies: http messages carry state

Web caches (proxy server)

goal: satisfy client request without involving origin server

- user sets browser: Web accesses via cache
- browser sends all HTTP requests to cache
  - object in cache: cache returns object
  - else cache requests object from origin server, then returns object to client



More about Web caching

- cache acts as both client and server
  - server for original requesting client
  - client to origin server
- typically cache is installed by ISP (university, company, residential ISP)

why Web caching?

- reduce response time for client request
- reduce traffic on an institution's access link
- Internet dense with caches: enables "poor" content providers to effectively deliver content (so too does P2P file sharing)

Caching example:

assumptions:

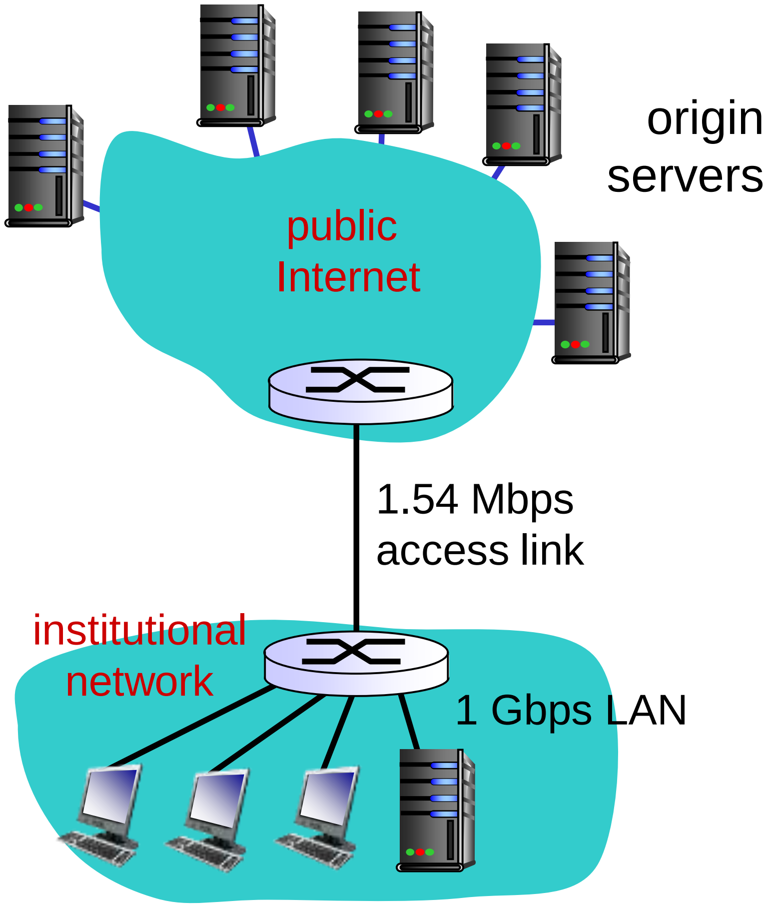
- avg object size: 100K bits
- avg request rate from browsers to origin servers:15/sec
- avg data rate to browsers: 1.50 Mbps
- RTT from institutional router to any origin server: 2 sec
- access link rate: 1.54 Mbps

consequences:

problem!

- access link utilization = 99%
- total delay = Internet delay + access delay + LAN delay

  = 2 sec + minutes + usecs



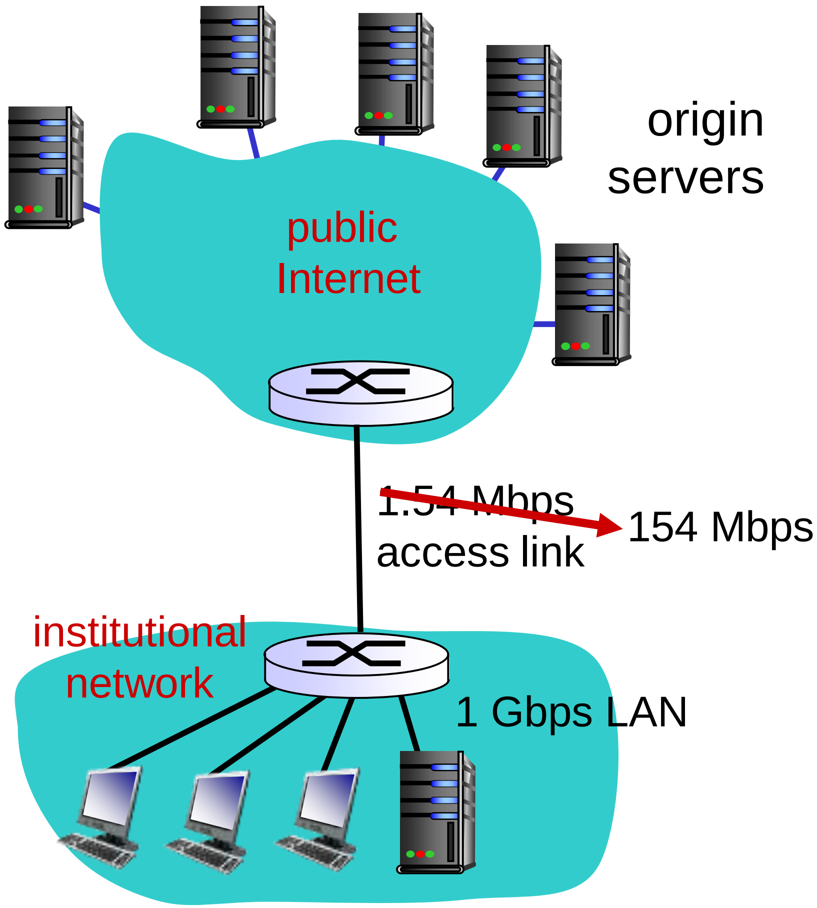
Caching example: fatter access link

assumptions:

- avg object size: 100K bits
- avg request rate from browsers to origin servers: 15/sec
- avg data rate to browsers: 1.50 Mbps
- RTT from institutional router to any origin server: 2 sec
- access link rate: ~~1.54 Mbps~~ → 154 Mbps

consequences:

- access link utilization = ~~99%~~ → 9.9%
- total delay = Internet delay + access delay + LAN delay
  = 2 sec + ~~minutes~~ → msecs + usecs



Cost: increased access link speed (not cheap!)

Caching example: install local cache

assumptions:

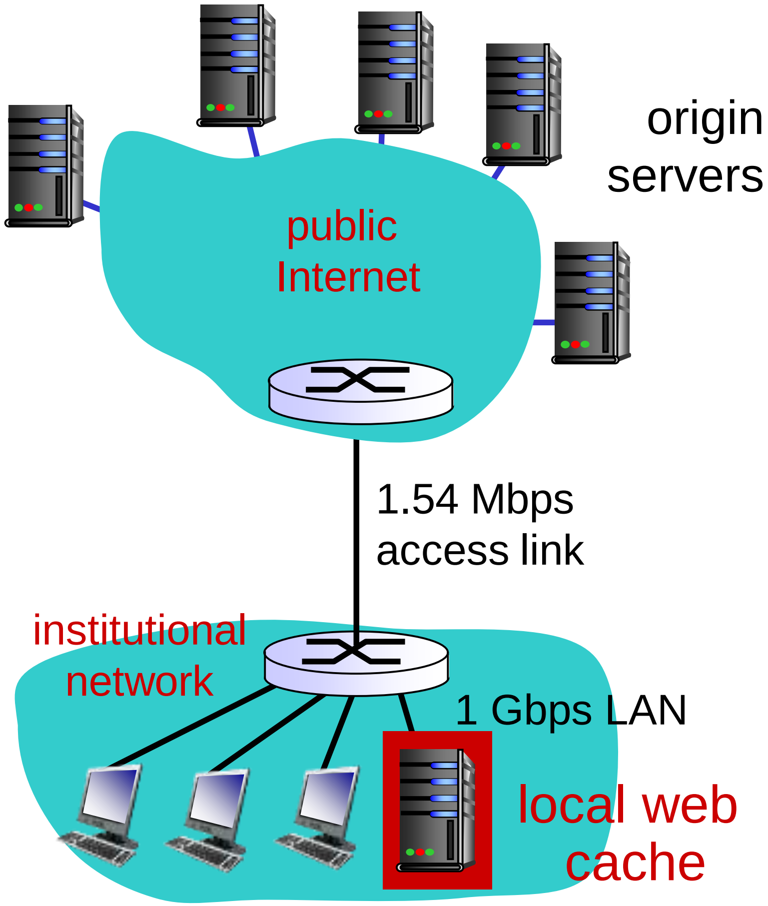
- avg object size: 100K bits
- avg request rate from browsers to origin servers:15/sec
- avg data rate to browsers: 1.50 Mbps
- RTT from institutional router to any origin server: 2 sec
- access link rate: 1.54 Mbps

consequences:

- access link utilization = ?
- total delay = ?

How to compute link utilization, delay?

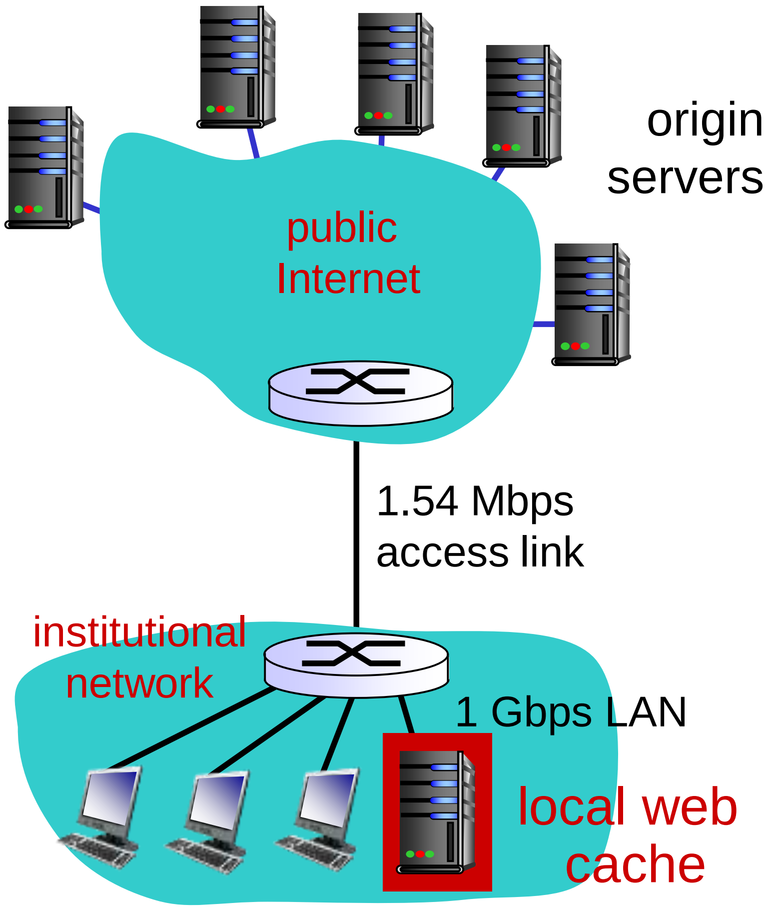
Cost: web cache (cheap!)



Caching example: install local cache

Calculating access link utilization, delay with cache:

- suppose cache hit rate is 0.4
  - 40% requests satisfied at cache, 60% requests satisfied at origin
- access link utilization:
  - 60% of requests use access link
- data rate to browsers over access link = 0.6*1.50 Mbps = .9 Mbps
  - utilization = 0.9/1.54 = .58
- total delay
  - = 0.6 * (delay from origin servers) +0.4 * (delay when satisfied at cache)
  - = 0.6 (2.01) + 0.4 (~msecs)
  - = ~ 1.2 secs
  - less than with 154 Mbps link (and cheaper too!)

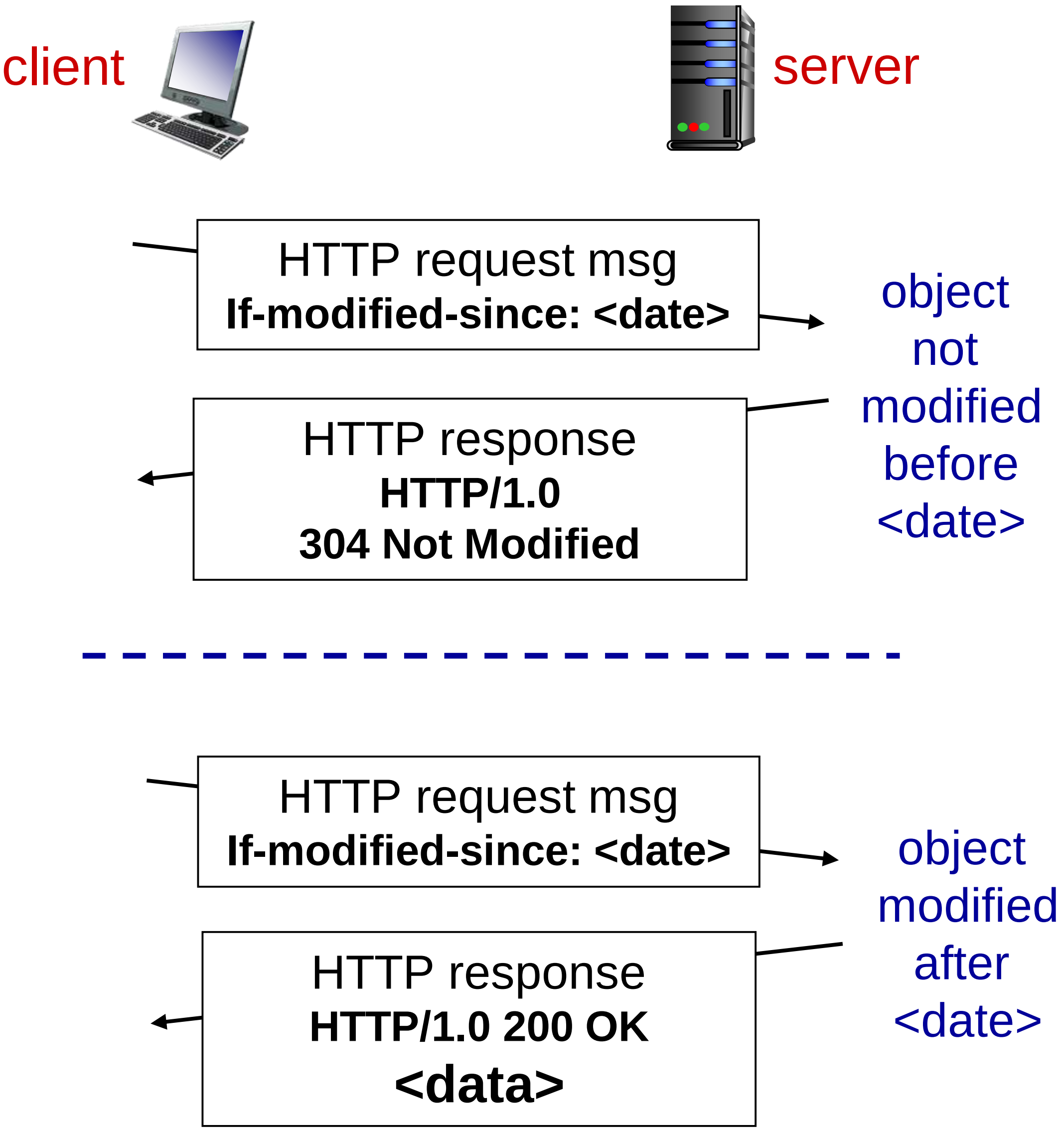


Conditional GET

- *Goal:* don't send object if cache has up-to-date cached version
  - no object transmission delay
  - lower link utilization
- *cache:* 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`



client

server

HTTP request msg
If-modified-since: <date>

object not modified before <date>

HTTP response
HTTP/1.0
304 Not Modified

HTTP request msg
If-modified-since: <date>

object modified after <date>

HTTP response
HTTP/1.0 200 OK
<data>

Chapter 2: outline

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Web Caching and HTTPS

- Caching as a technique to reduce user (perceived) response time

- *Who caches?*
  - Origin server (database – memory)
  - Gateway – reverse proxy (shared cache)
  - Proxy (e.g., ISP – share cache)
  - Browser (local to user)

- *The S stands to TLS, successor of SSL*
  - HTTP over TLS / HTTP over SSL
  - Application security layer guaranteeing privacy, integrity of communication between entities involved in communication
  - Application data are encrypted, middle-boxes can check who is involved in communication but cannot read the data

Potential Impact of HTTPS

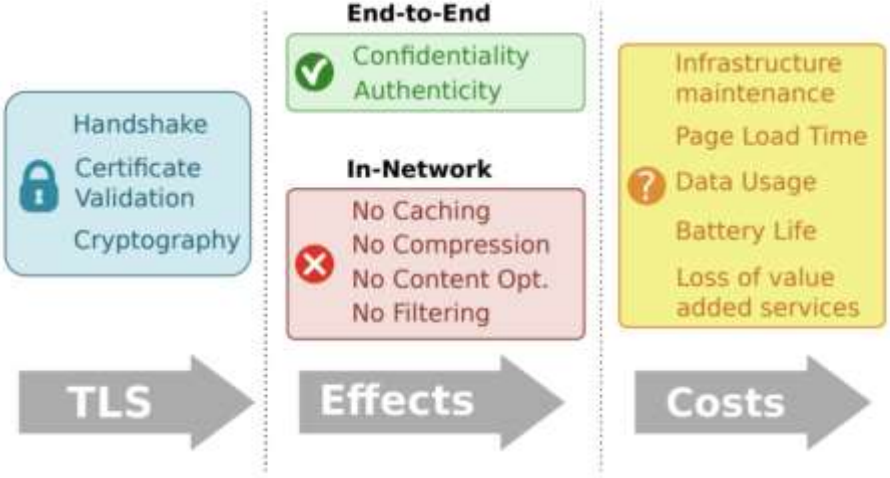
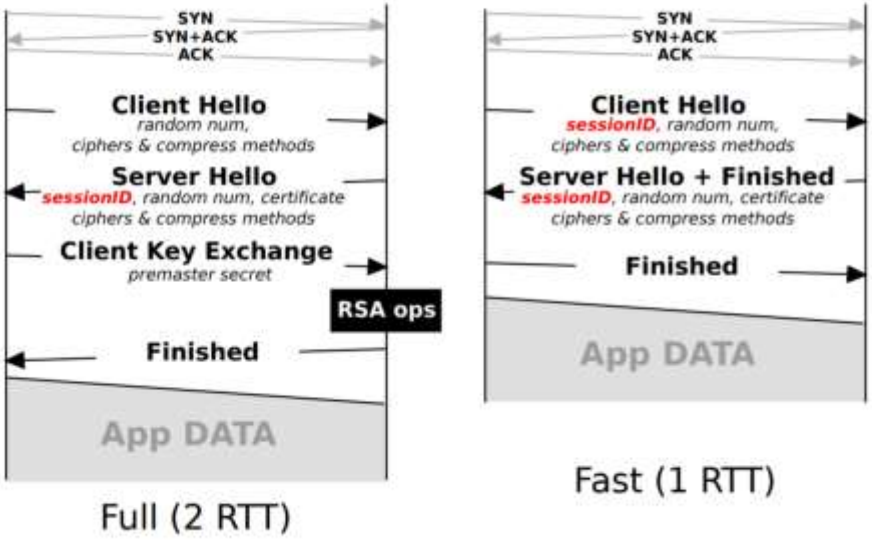


Figure 1: The HTTPS adoption impact chain.



Full (2 RTT)

Fast (1 RTT)

Figure 2: SSL/TLS negotiation.

- Middle-boxes on the delivery chain cannot act on data anymore – data is encrypted, transparent to the middle-boxes
- Before worrying, we first need to check how much S in HTTPs is out there?

How much S in HTTPS

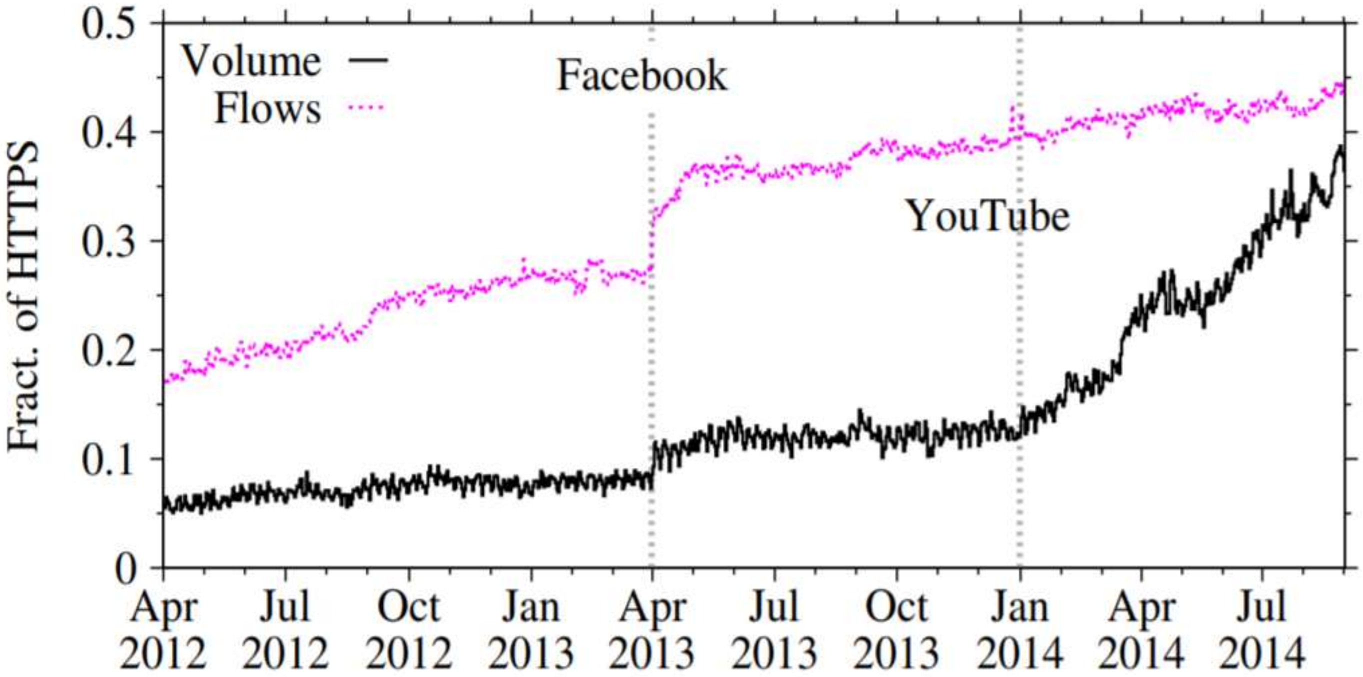


Figure 3. Evolution of HTTPS volume and flow shares over 2.5 years. Vertical lines show the transition to HTTPS for Facebook and YouTube

How much S in HTTPS

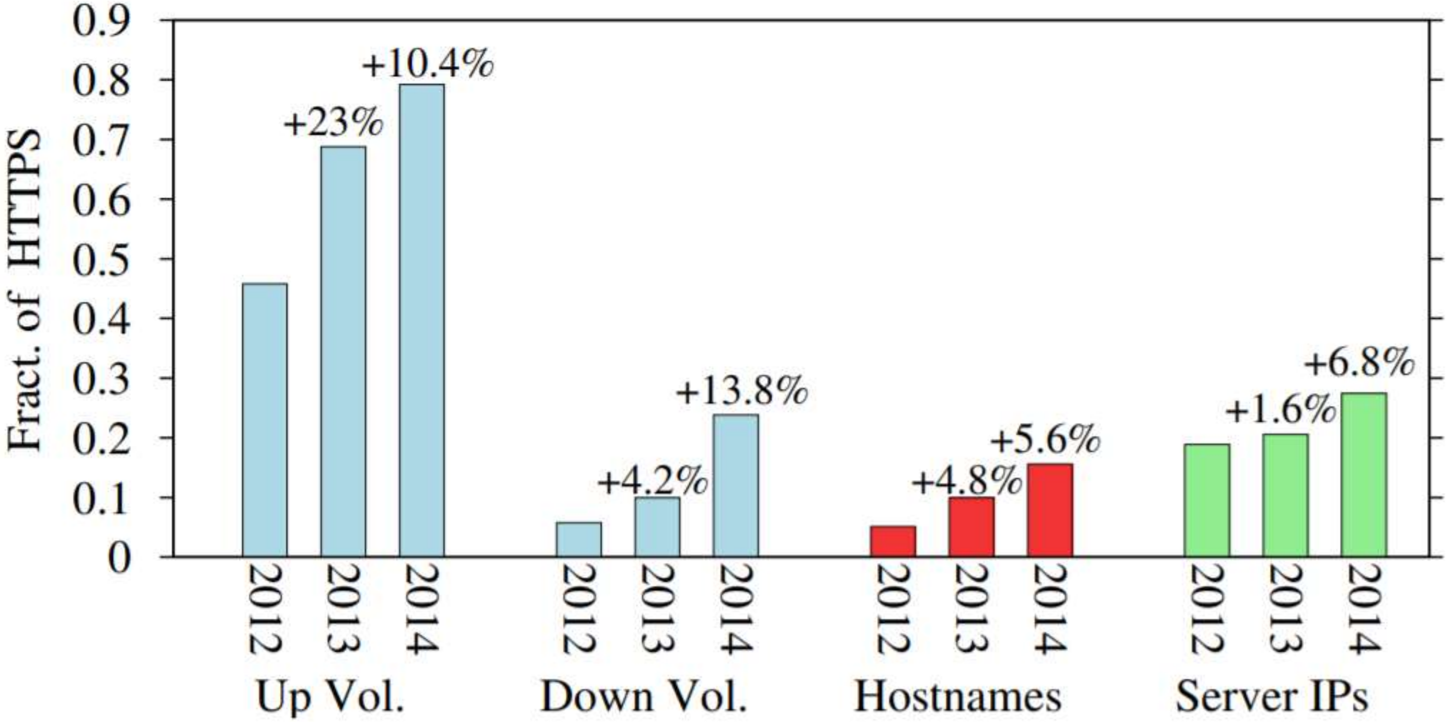


Figure 4. Comparing HTTPS shares over three one-week periods in the Res-ISP dataset. Percentages in the bars highlight year-to-year growth.

Quantifying the Impact of S

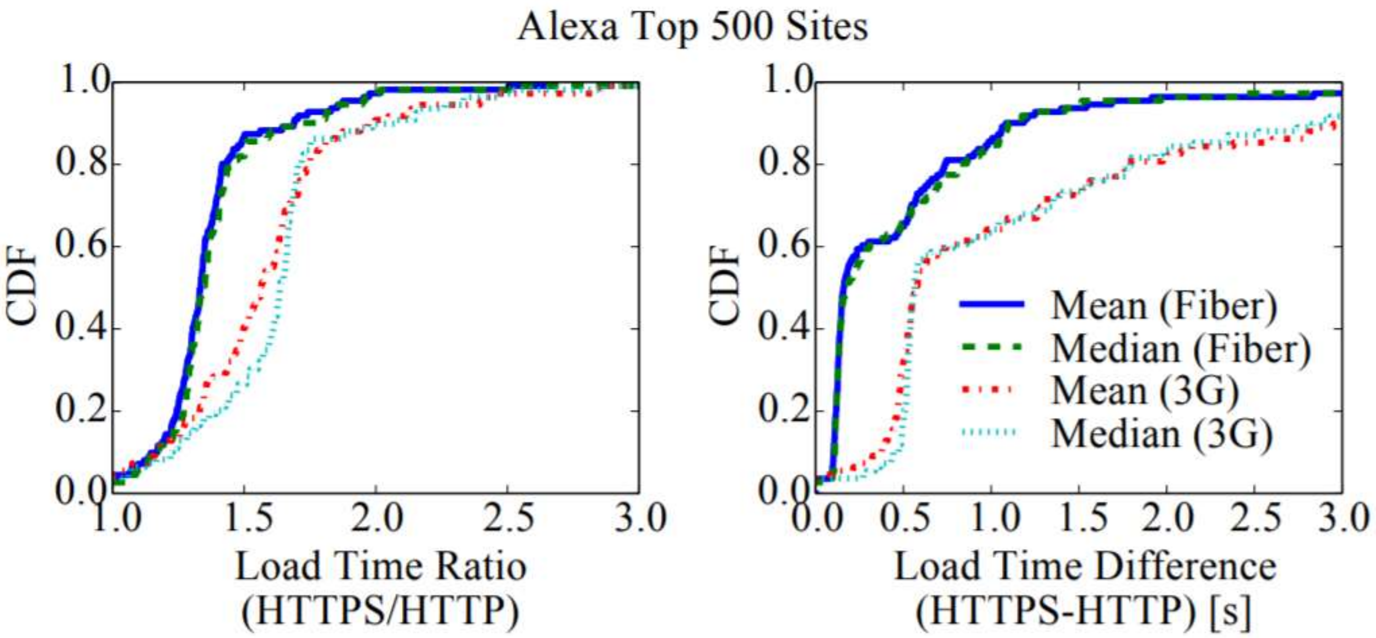


Figure 5: Webpage load time inflation for the Alexa top 500.

Quantifying the Impact of S

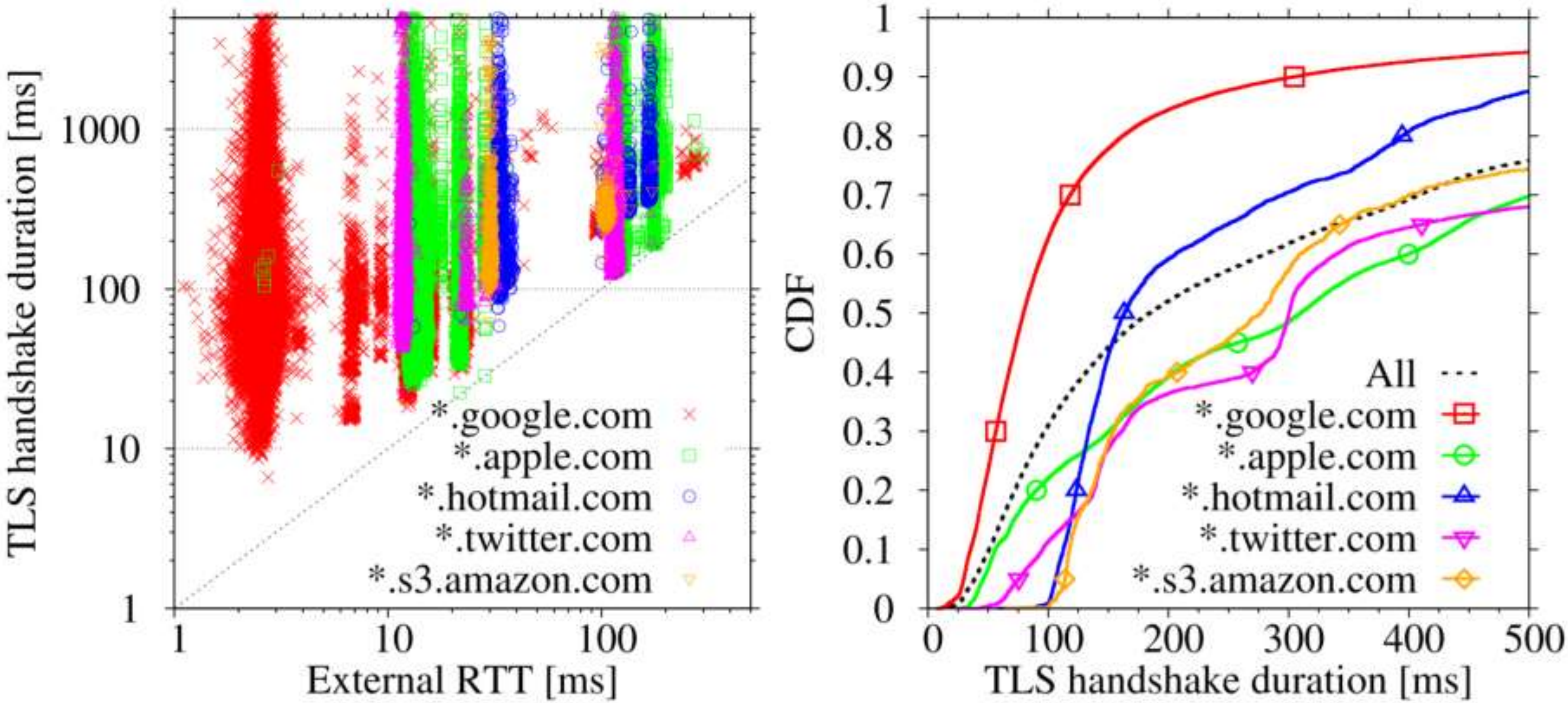


Figure 7: Quantifying TLS handshake costs. Scatter plot of the TLS handshake duration with respect to server distance (left). TLS handshake duration CDF (right).

External RTT: TCP SYN – ACK response

1 Million distinct TLS flows present in the dataset

Quantifying the Impact of S

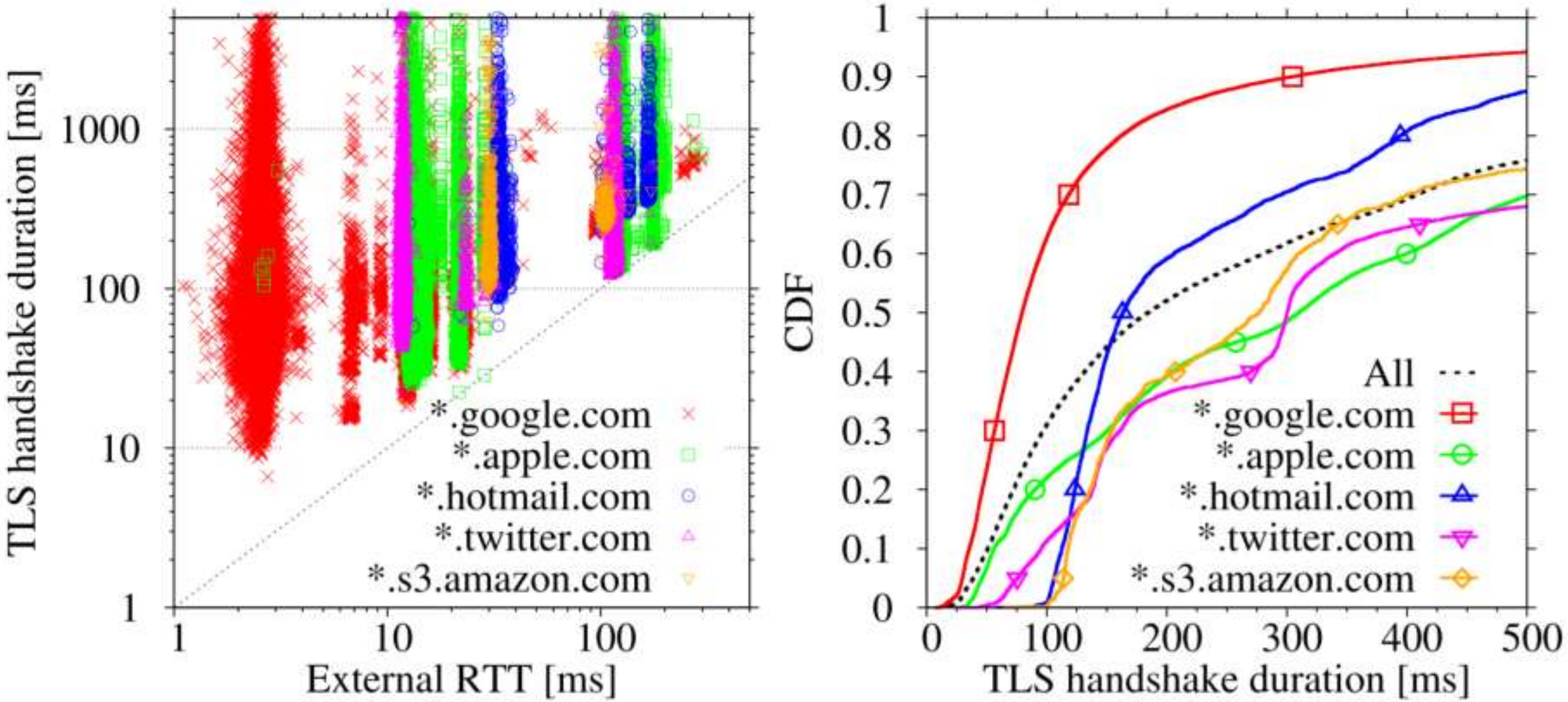


Figure 7: Quantifying TLS handshake costs. Scatter plot of the TLS handshake duration with respect to server distance (left). TLS handshake duration CDF (right).

External RTT: TCP SYN – ACK response

1 Million distinct TLS flows present in the dataset

Considerations

- HTTPS accounts for 50% of all HTTP connections and is no longer used solely for small objects, suggesting that the cost of deployment is justifiable and manageable for many services.
- The extra latency introduced by HTTPS is not negligible, especially in a world where one second could cost 1.6 billion in sales (Amazon case study)
- Most users are unlikely to notice significant jumps in data usage due to loss of compression, but ISPs stand to see a large increase in upstream traffic due to loss of caching

- From a user perspective browser-caching techniques and proactive content push to the edges are feasible
- From and operator (ISP, content provider) viewpoint this poses a burden
  - Sol#1: Secure only essential parts of the communication others through HTTP (privacy?)
  - Sol#2: Split proxy approach for not sensitive information (man-in-the-middle (Deep Packet Inspection)?)
  - This said: Youtube mobile version is on clear HTTP