Application Layer

CS5700 Fall 2019

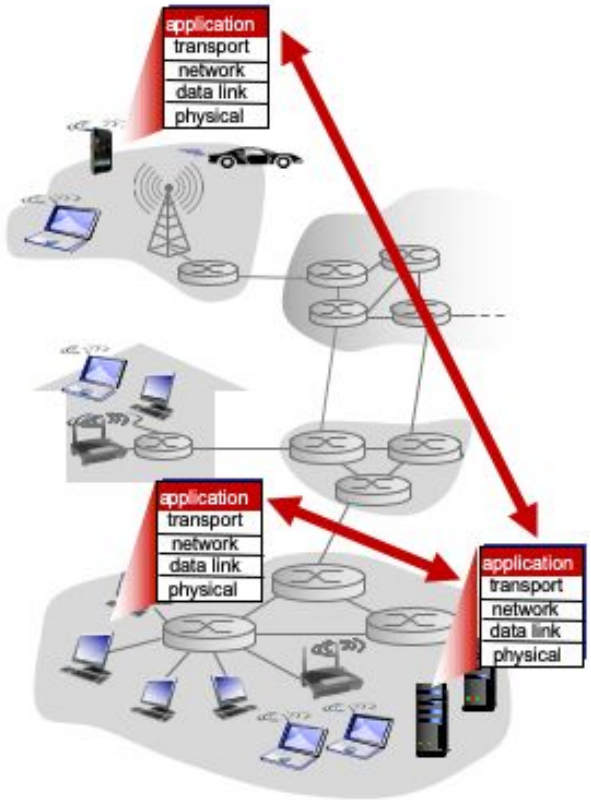
Agenda

- Principles of network applications
- DNS
- Web and HTTP
- CDN
- SMTP
- DHCP

Principles of network applications

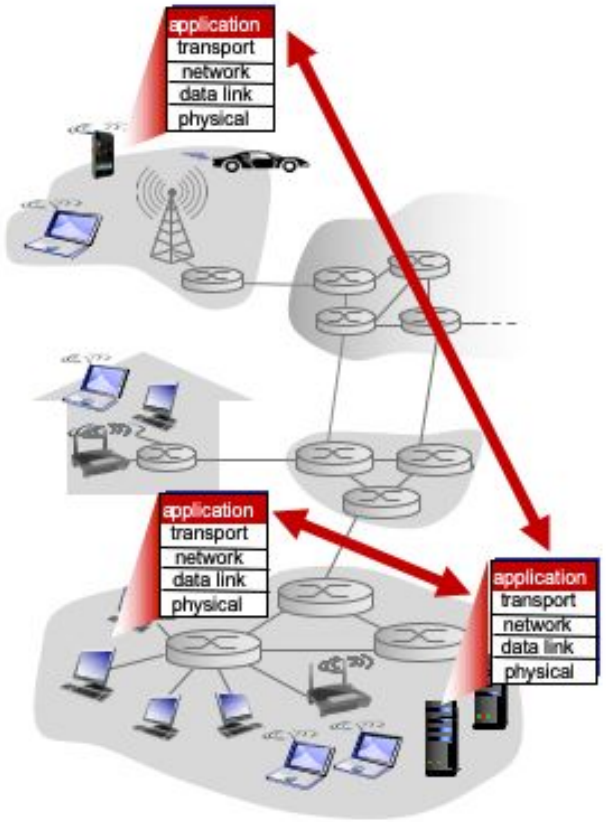
Principle - intelligence at the edge

- Internet does not provide services. It only provides communication.
- Application programs provide all services.



Principle - intelligence at the edge

- Write application programs that
  - Run on hosts
  - Communicate over network
- No need to change network core
  - Network core devices do not run user applications



Principle - intelligence at the edge

- Web
- Email
- Network games
- Streaming videos (Youtube, Netflix, Hulu, etc.)
- Realtime video conferencing
- Social networking
- ...
- All require no change at the network core

Why is it a good principle?

How long does it take us to adopt IPv6?

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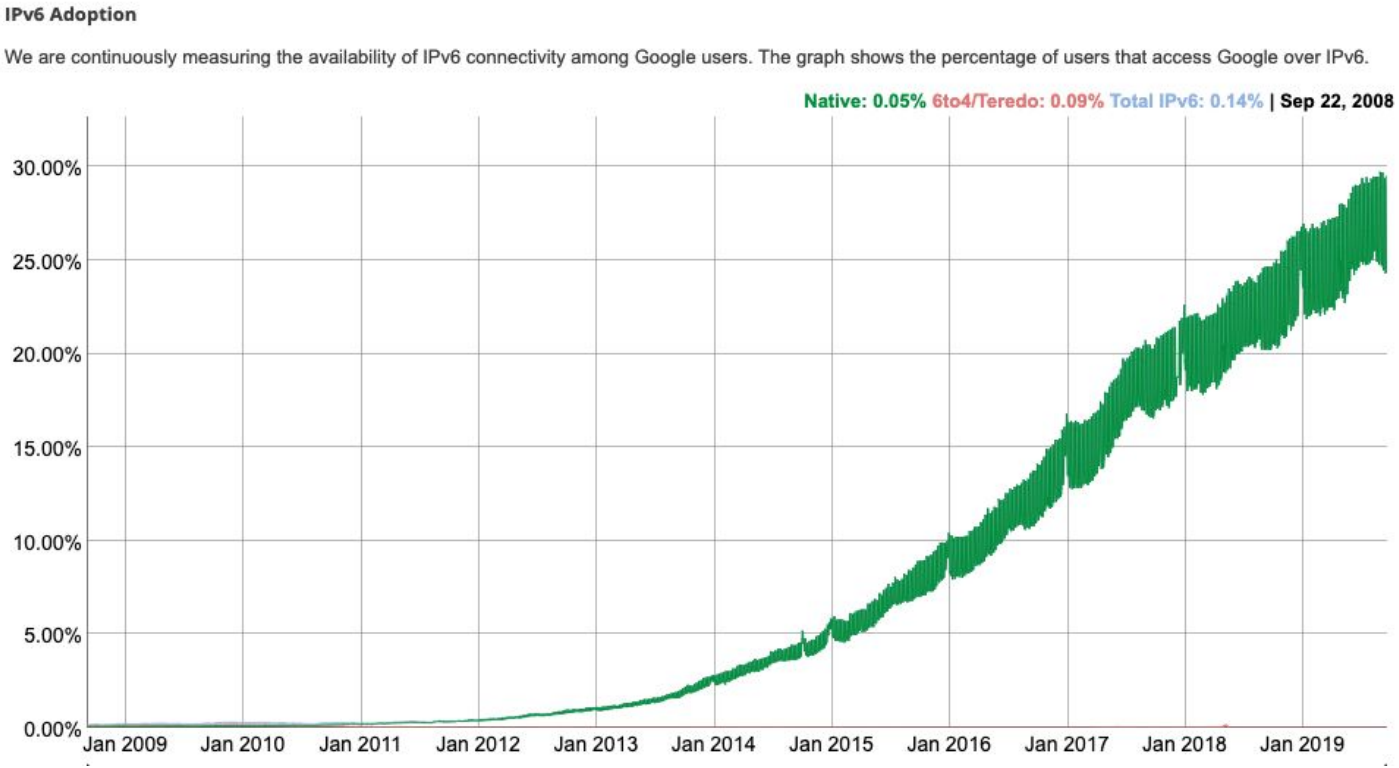
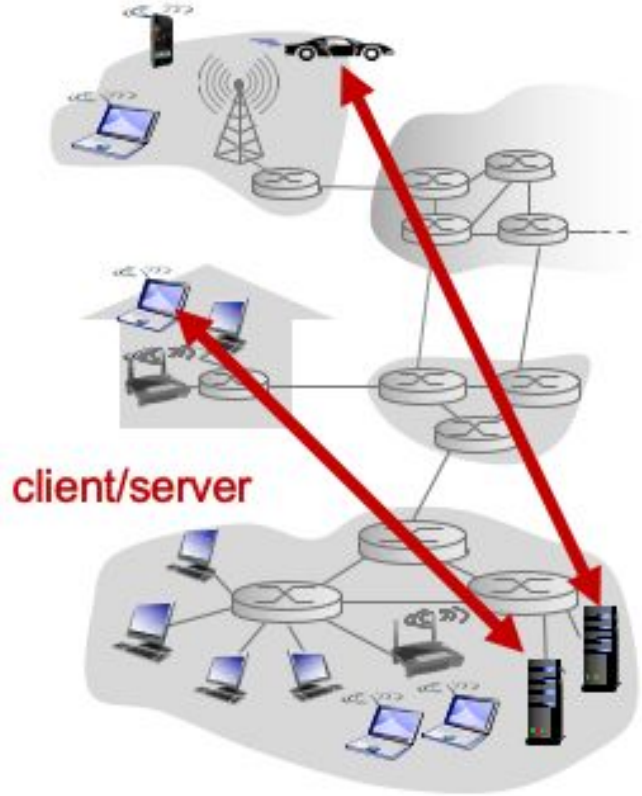


Client-server architecture

- Server
  - Always-on host
  - Permanent IP address
  - Data center for scaling
- Client
  - Communicate with server
  - May have dynamic IP address
  - Do not communicate directly with each other



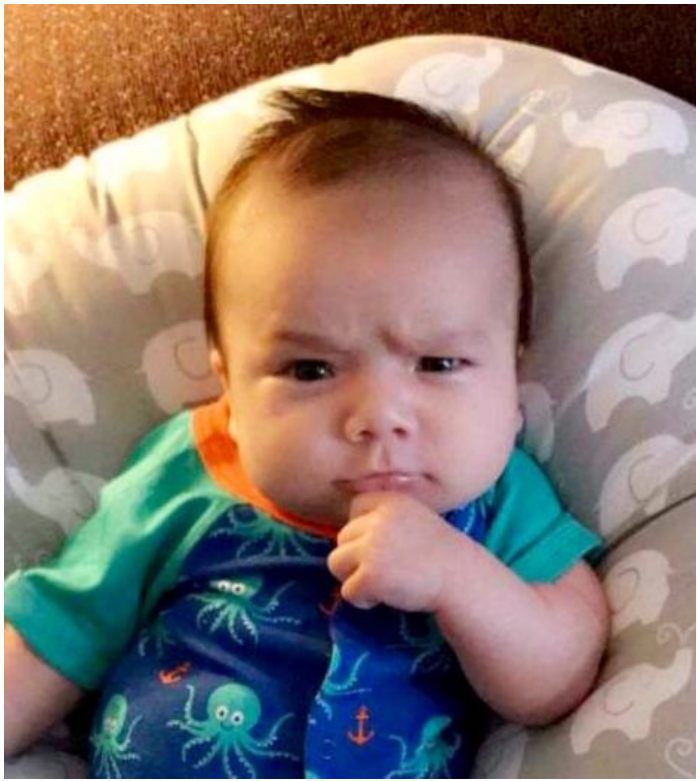
Transport layer service model - TCP

- Reliable data transfer
  - No loss, in-order
- Flow control: sender won’t overwhelm receiver
- Congestion control: throttle sender when network is overloaded
- Connection oriented: setup required between client and server

Transport layer service model - UDP

- Unreliable data transfer
  - Loss, out-of-order, duplicate
- That’s it!

Any service you'd like transport layer to have?



Other important services

- Timing (aka bounded latency)
  - E.g. Internet telephony, interactive games
- Throughput
  - E.g. multimedia
- Security
  - Encryption, data integrity, etc.
- …
- None of the above is provided in transport layer! :(

DNS

DNS - domain name system

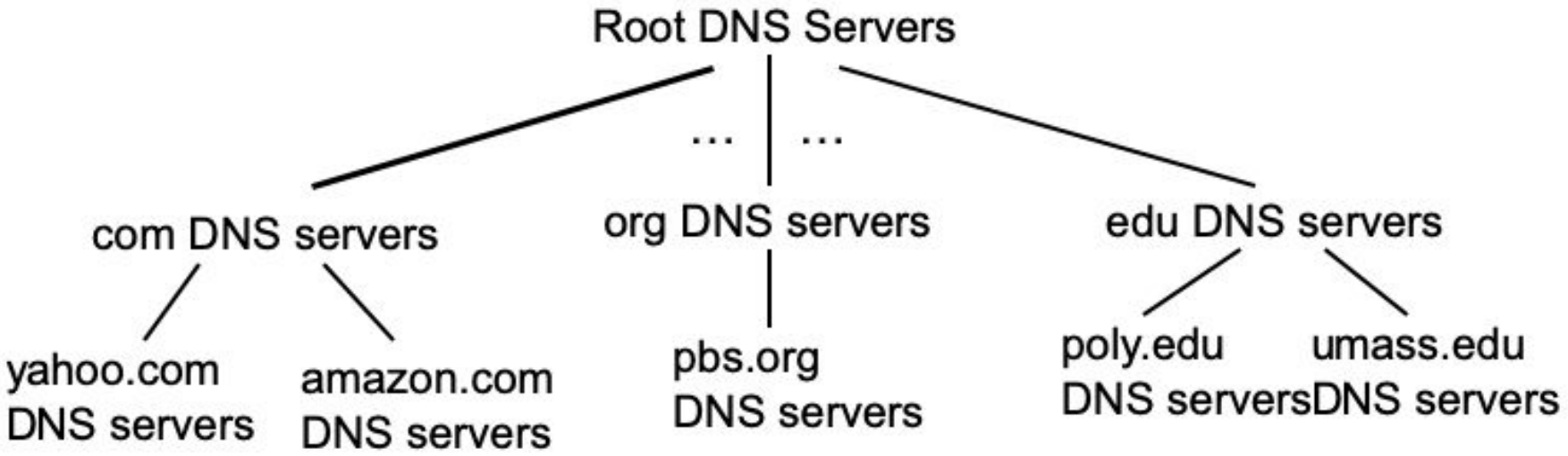
- Important piece of Internet infrastructure
- Runs at the application layer
- Translate human-readable names into IP addresses
- Distributed database
  - Centralized DNS doesn’t scale!

DNS

- Names are hierarchical
- Each name divided into segments by period char
  - Read as “dot”
- Most significant segment is on the right
- Rightmost segment known as a top-level domain (TLD)
- E.g. neu.edu

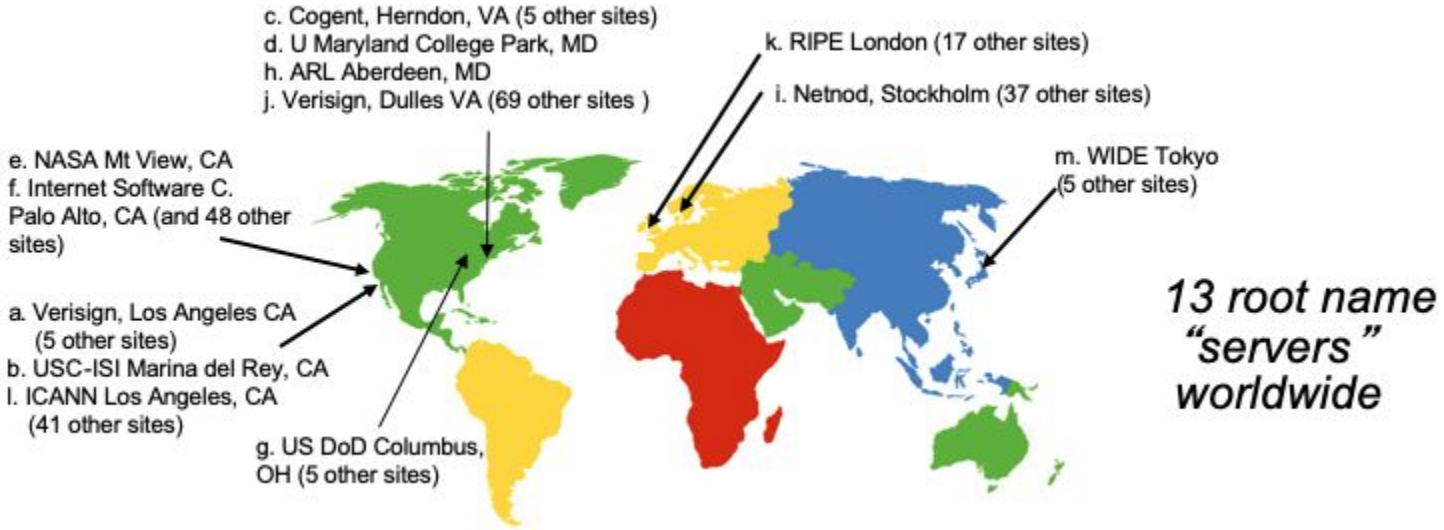
DNS - hierarchical database

- How do you get IP address for www.neu.edu?



DNS - root name servers

- 13 logical root name servers. ([a-m].root-servers.net)
- Provide which TLD name server to ask next



DNS - TLD name servers

- Responsible for com, org, net, edu, ..., and all top-level country domains
- Provide which authoritative name server to ask next

DNS - authoritative name servers

- Organization’s own name servers
- Provide authoritative hostname to IP mappings for organization’s named hosts

Summary so far...

- How many DNS queries you need?
  - 1 for root name server
  - 1 for TLD name server
  - 1 for authoritative name server
- Is there any issue?

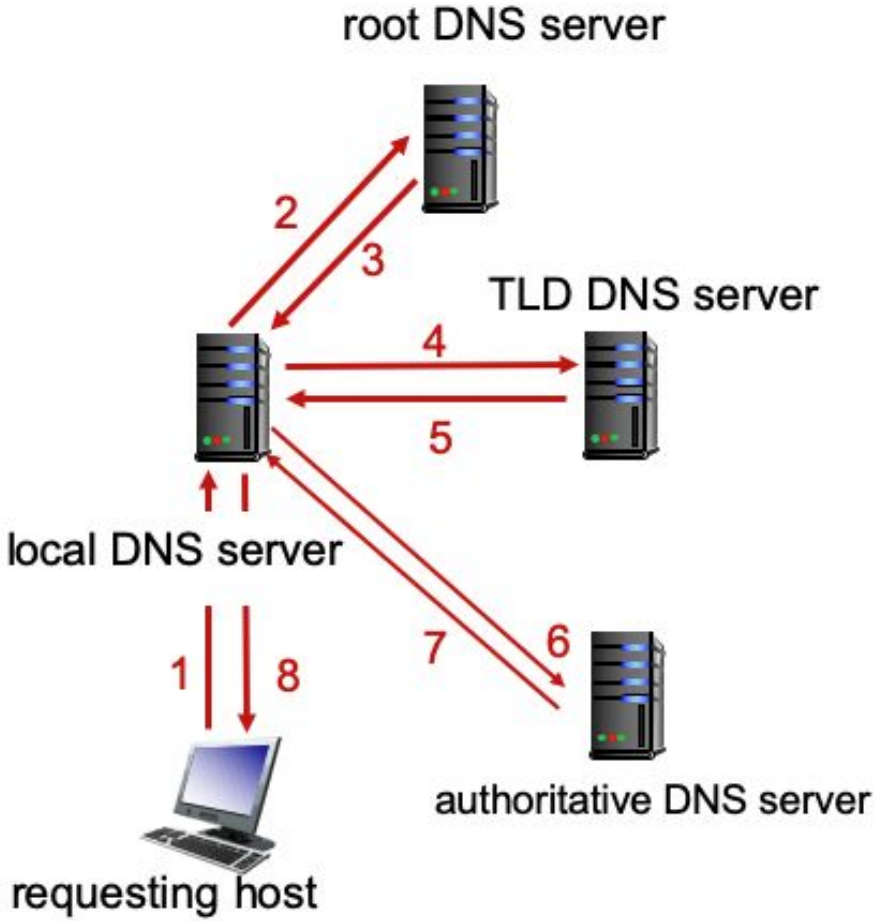
Too slow!!

DNS - local name server

- Does not belong to hierarchy
- Each ISP (residential ISP, company, university) has one
- When host makes DNS query, query is sent to its local name server
  - Acts as proxy, forwards query into hierarchy
  - Has local cache of recent name-to-address map

Put all together

- Can you see this is more efficient?



DNS - caching

- Cache entries timeout after TTL
  - What is reasonable TTL? Who decide?
- TLD name servers typically cached in local name servers
  - Thus root name servers not often visited
- Cached entries may be out-of-date

DNS records

DNS: distributed db storing resource records (RR)

RR format: `(name, value, type, ttl)`

type=A

- **name** is hostname
- **value** is IP address

type=NS

- **name** is domain (e.g., foo.com)
- **value** is hostname of authoritative name server for this domain

type=CNAME

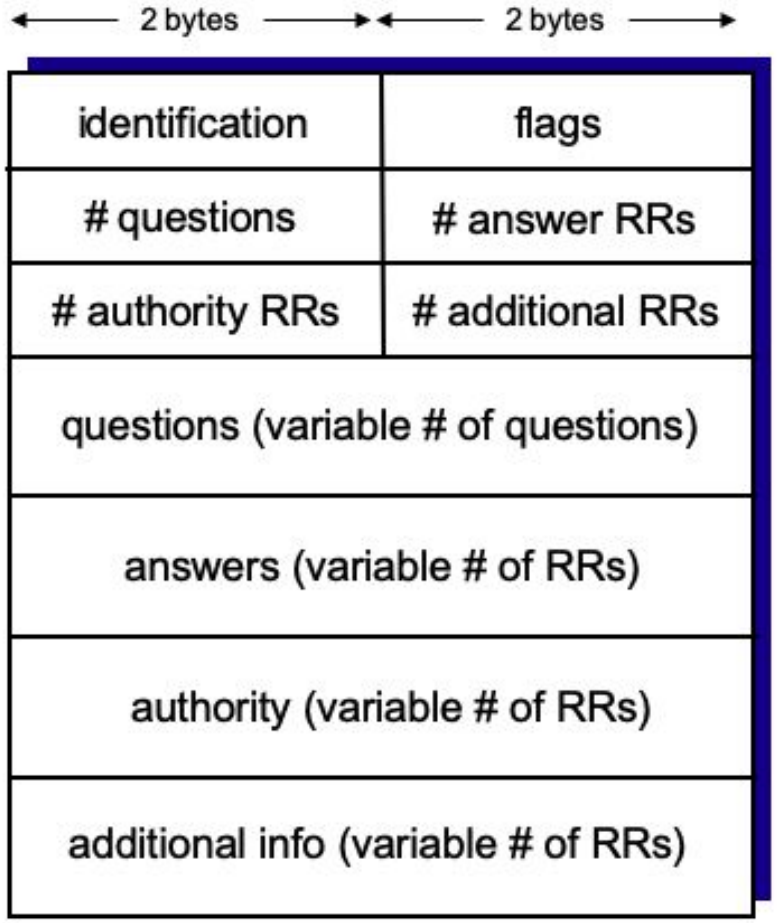
- **name** is alias name for some "canonical" (the real) name
- `www.ibm.com` is really `servereast.backup2.ibm.com`
- **value** is canonical name

type=MX

- **value** is name of mailserver associated with **name**

DNS - message format

- Both query and reply messages have the same format
- Flags:
  - Query or reply
  - Recursion desired
  - Recursion available
  - Reply is authoritative



DNS

- Is DNS using TCP or UDP as transport layer protocol?

Demo wireshark

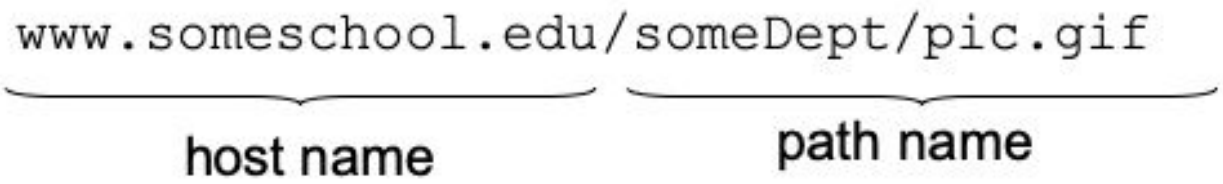
Inserting records into DNS

- New startup “Network Utopia”
- Register name networkutopia.com at DNS registrar
  - Provide names, IP addresses of authoritative name server (primary and secondary)
  - Registrar inserts two RRs into .com TLD name server (networkutopia.com, dns1.networkutopia.com, NS) (dns1.networkutopia.com, 10.1.1.1, A)
- Create type A record for www.networkutopia.com in authoritative name server.

Web and HTTP

What's in a web page?

- Web page consists of objects
- Object can be HTML file, JPEG image, JS file, etc.
- Web page consists of base HTML file which includes several referenced objects
- Each object is addressable by a URL



HTTP overview

- HyperText Transfer Protocol
- Client: browser requests, receives, and display Web objects
- Server: Web server sends objects in response to requests

HTTP overview

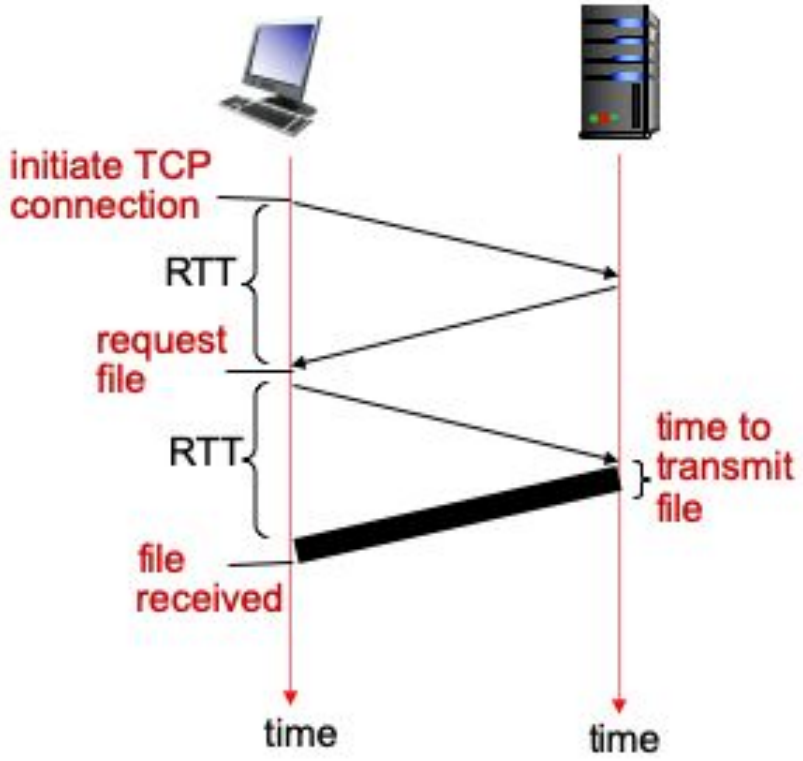
- Uses TCP as transport layer protocol
- Server uses well-known port 80
- HTTP is “stateless”
  - Server maintains no information about past client requests

HTTP connections

- Non-persistent HTTP
  - At most one object sent over a TCP connection
    - Connection then closed
  - Downloading multiple objects required multiple connections
- Persistent HTTP
  - Multiple objects can be sent over single TCP connection

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

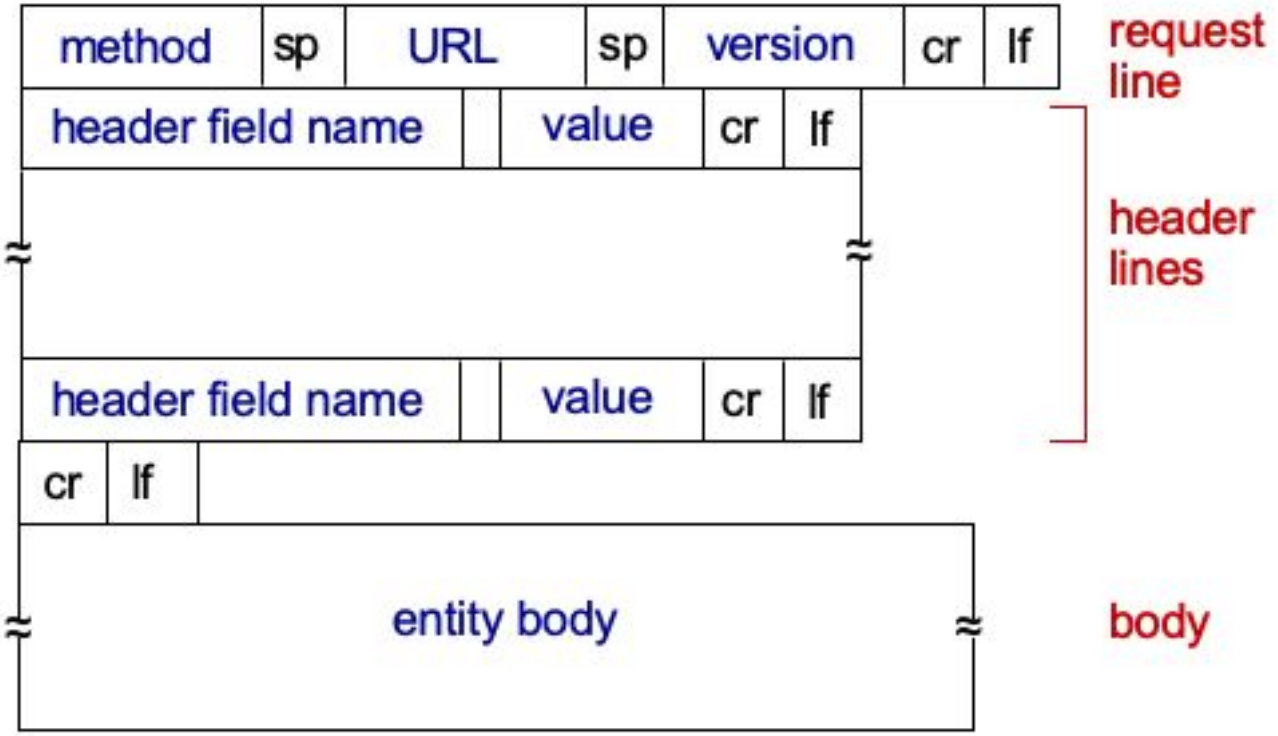


What's the response time using persistent HTTP?

HTTP request message

- ASCII (human-readable format)

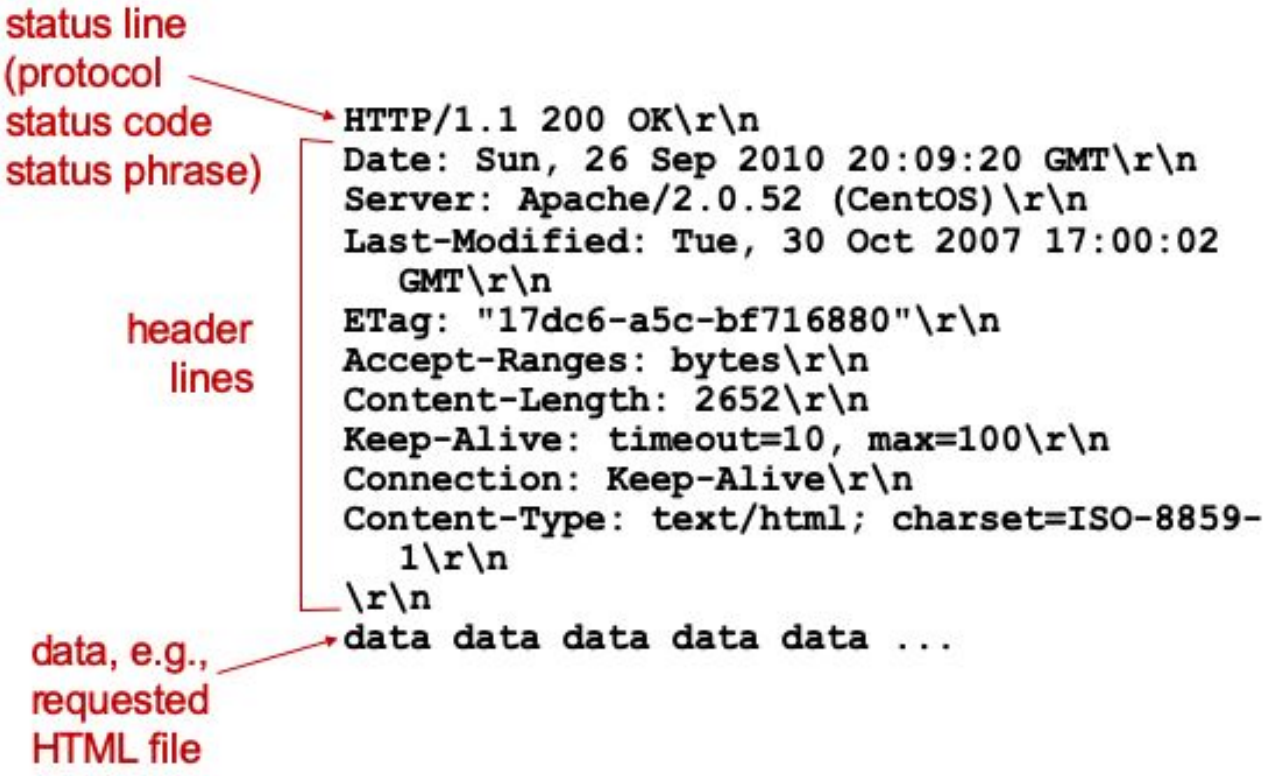
HTTP request message



Method types

- ***GET***: request a document; server responds by sending status information followed by a copy of the document
- ***HEAD***: request status information; server responds by sending status information, but not the document
- ***POST***: sends data to a server; the server appends the data to a specified item
- ***PUT***: sends data to a server; the server uses the data to completely replace the specified item

HTTP response message



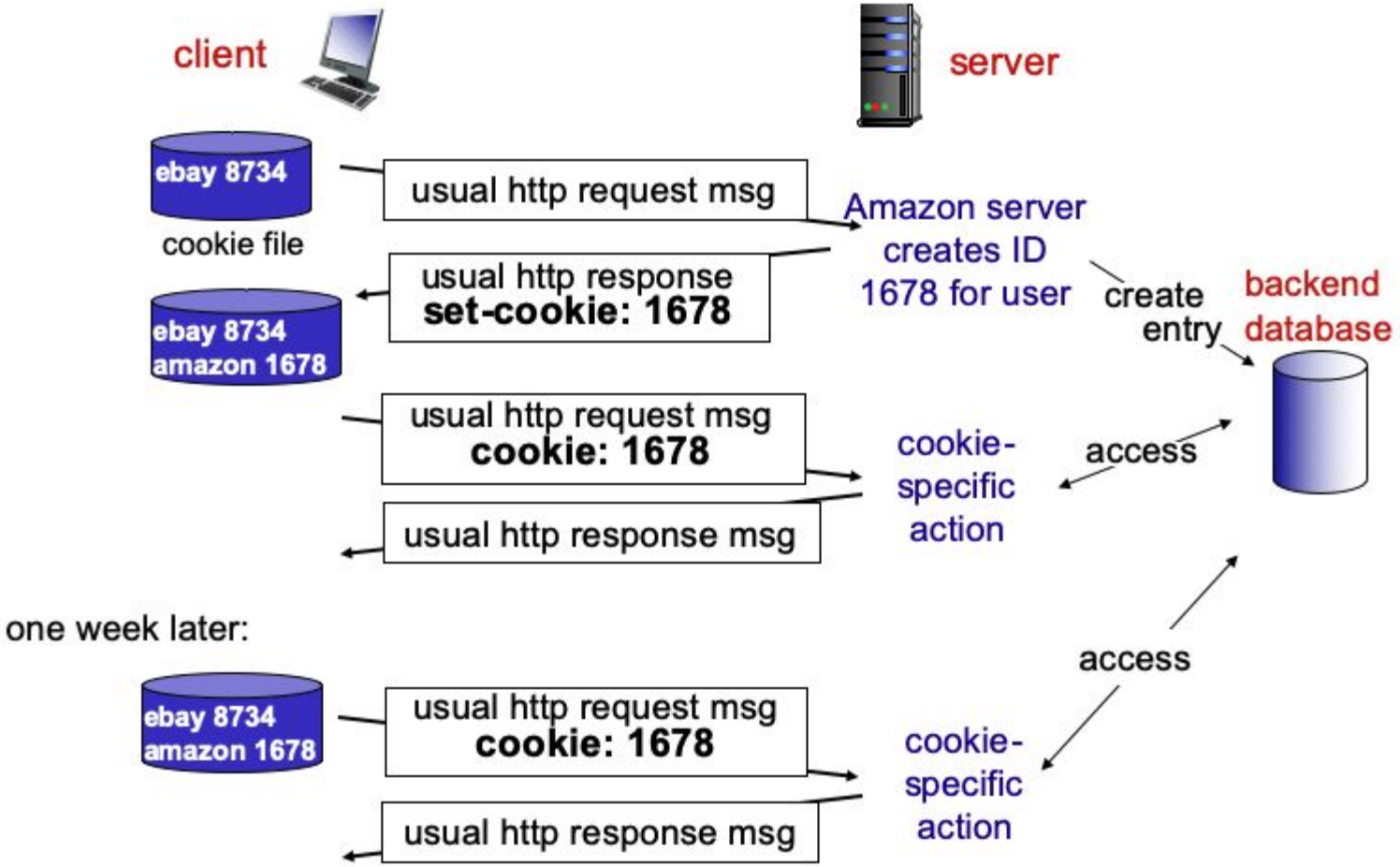
HTTP response status codes

- Appears in the first line
- Some sample codes:
  - 200 OK
  - 301 Moved Permanently
  - 400 Bad Request
  - 404 Not Found
  - 505 HTTP Version Not Supported

Cookies

- Cookie header line of HTTP response message
- Cookie header line in next HTTP request message
- Cookie file kept on user’s host, managed by user’s browser
- Back-end database at server side

Cookies

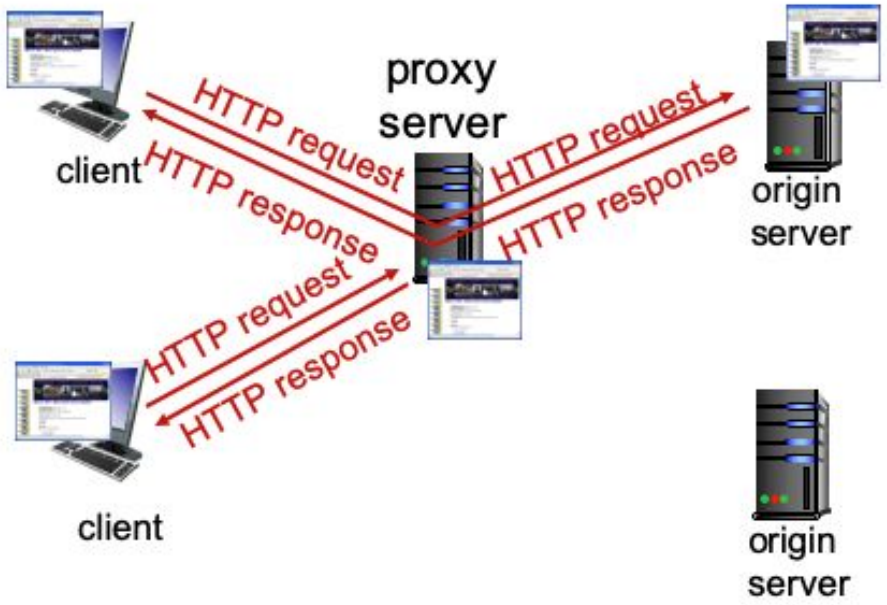

client
server
ebay 8734
usual http request msg
Amazon server creates ID 1678 for user
create entry
backend database
cookie file
usual http response
set-cookie: 1678
ebay 8734
amazon 1678
usual http request msg
cookie: 1678
cookie-specific action
access
usual http response msg
one week later:
access
ebay 8734
amazon 1678
usual http request msg
cookie: 1678
cookie-specific action
usual http response msg

Cookies

- What cookies can be used for
  - Authorization
  - Shopping carts
  - Recommendations
  - Ads
- Privacy
  - Cookies permit sites to learn a lot about you
  - You may supply name and email to sites

Web proxy server

- Goal: satisfy client request without involving origin server
- Browser sends all HTTP requests to proxy
  - Hit, return object.
  - Miss, request from origin server



Web proxy server

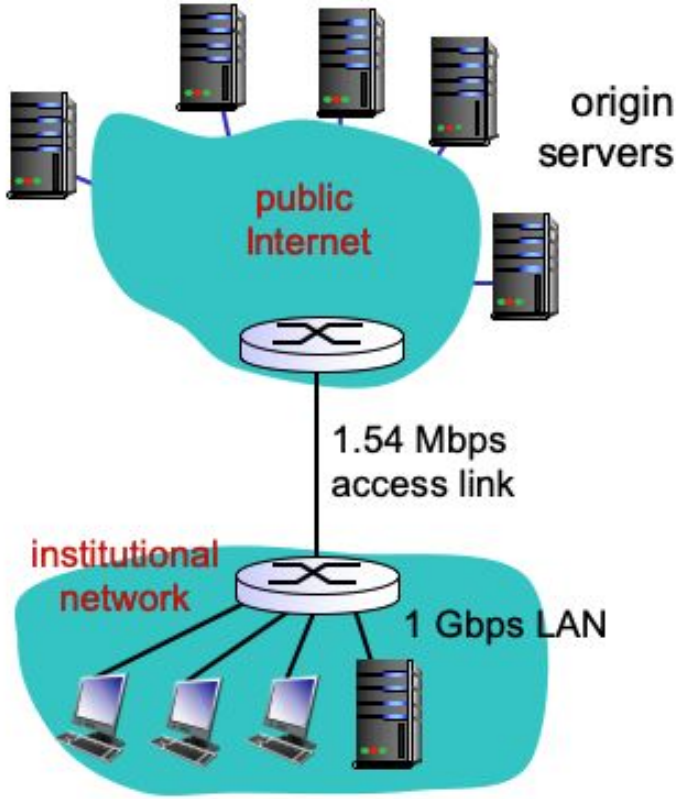
- Proxy acts as both client and server
- Typically proxy is installed by ISP (university, company, etc.)
- What are the benefits?

Web proxy server

- Benefits
  - Reduce response time for client request
  - Reduce traffic on an institution’s access link
  - Better user experience and save money

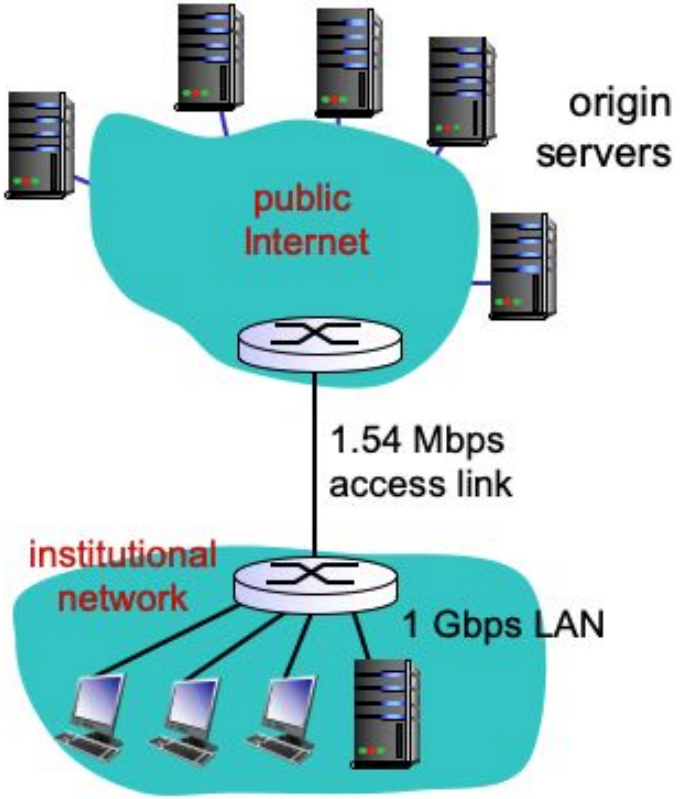
Some calculation

- Assumptions
  - Avg object size: 100K bits
  - Avg request rate from browsers to origin server: 15/sec
  - Avg data rate: 100K bits * 15/sec = 1.50 Mbps
  - RTT from institutional router to origin server: 2 sec
  - Access link data rate: 1.54 Mbps
  - Local network data rate: 1 Gbps



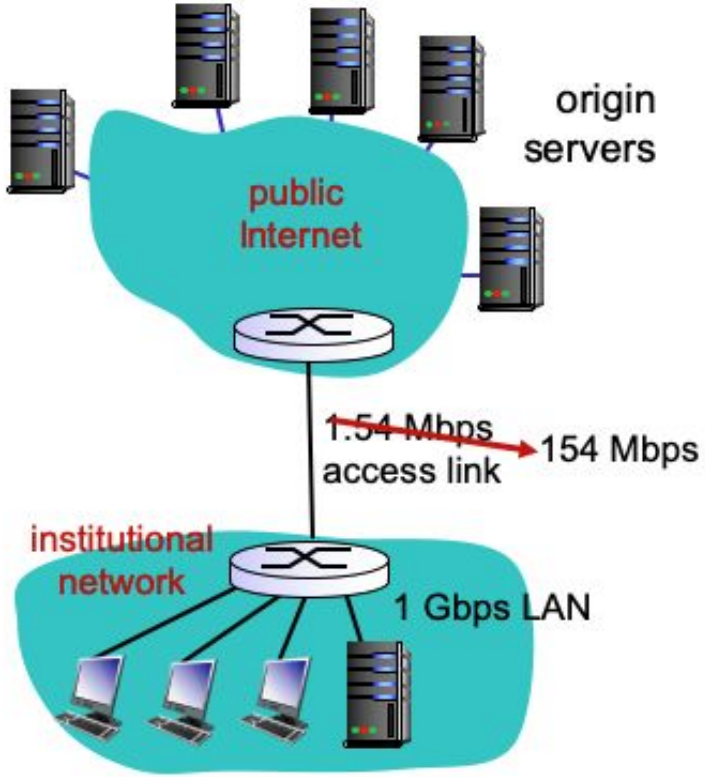
Some calculation

- Consequences
  - LAN utilization
    1.5 Mbps / 1 Gbps = 15%
  - Access link utilization
    1.5 Mbps / 1.54 Mbps = 97%
    - What happens in this case?
  - What is the total delay? Is it good user experience?



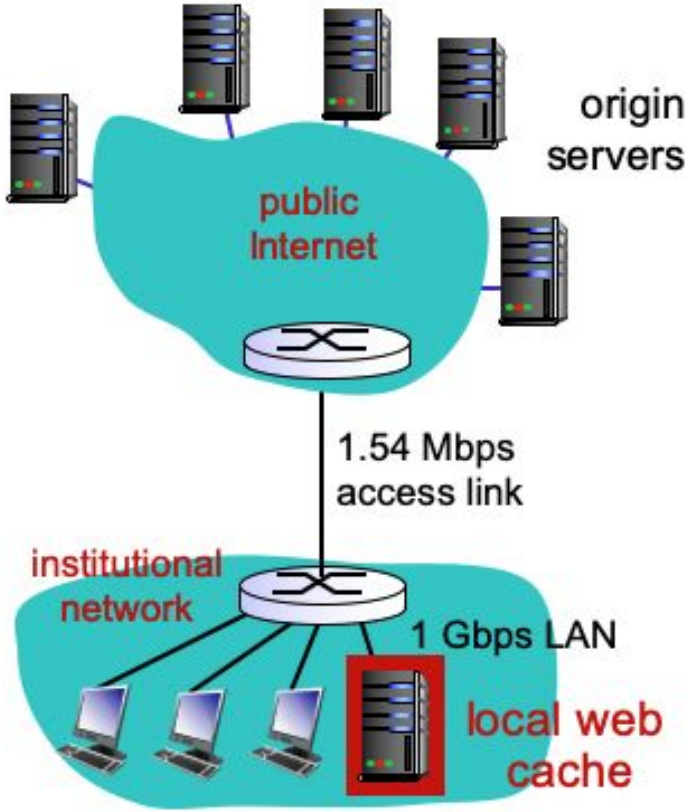
Solution I

- Fatter access link
- Access link utilization:
  1.5 Mbps / 154 Mbps = 9.7%
- What's the total delay? Is it good user experience?
- Money solves everything?



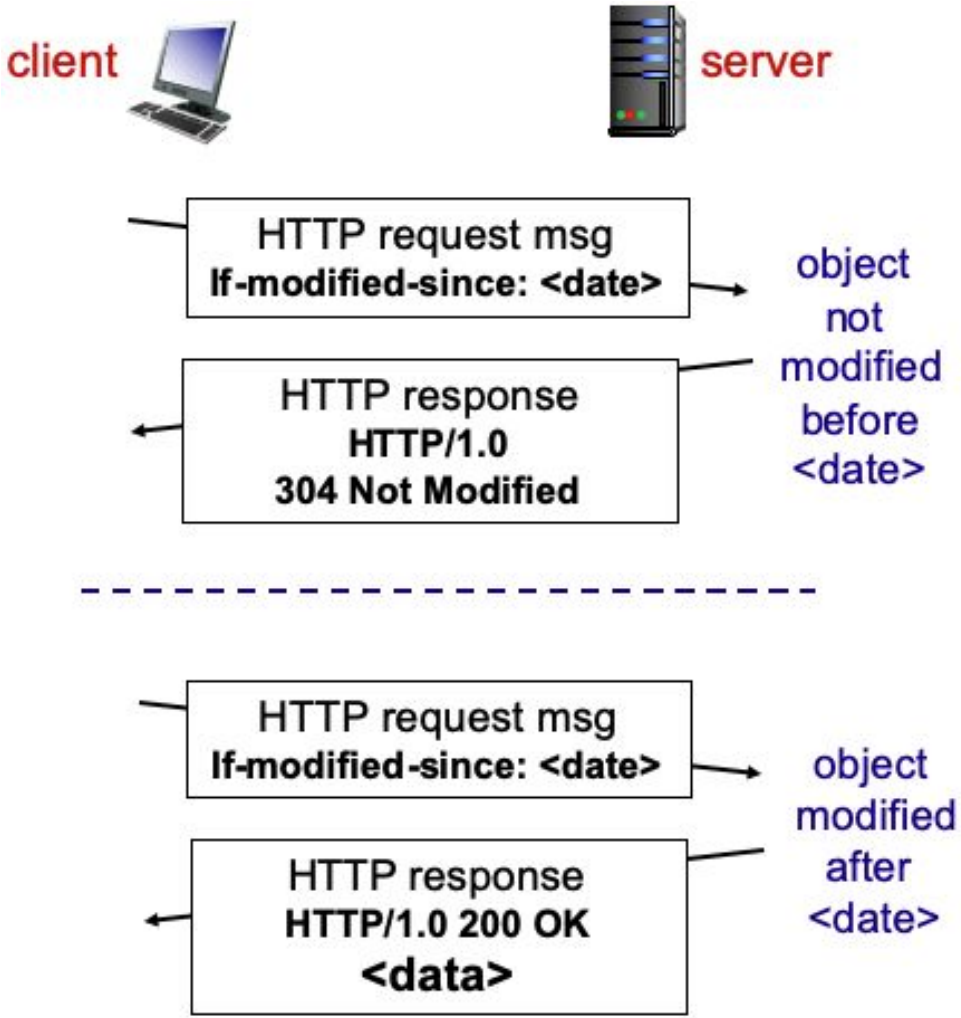
Solution II

- Assume hit rate is 40%
- Access link utilization:
  1.5 Mbps * 60% / 1.54 Mbps = 58%
- What's the total delay?
  60% * (delay from origin server) + 40% * (delay from proxy)



Conditional GET

- Goal: don't send object if cache has up-to-date version




READY FOR HW?
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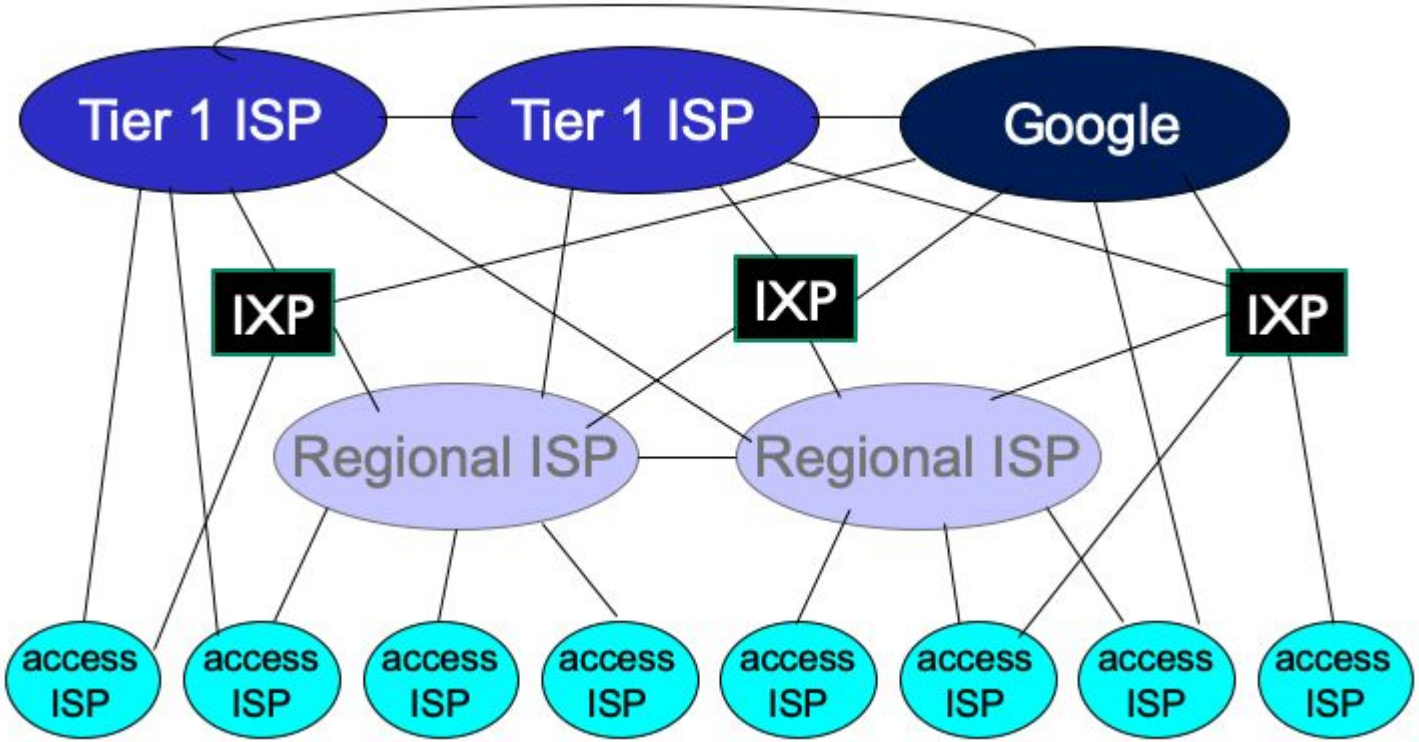
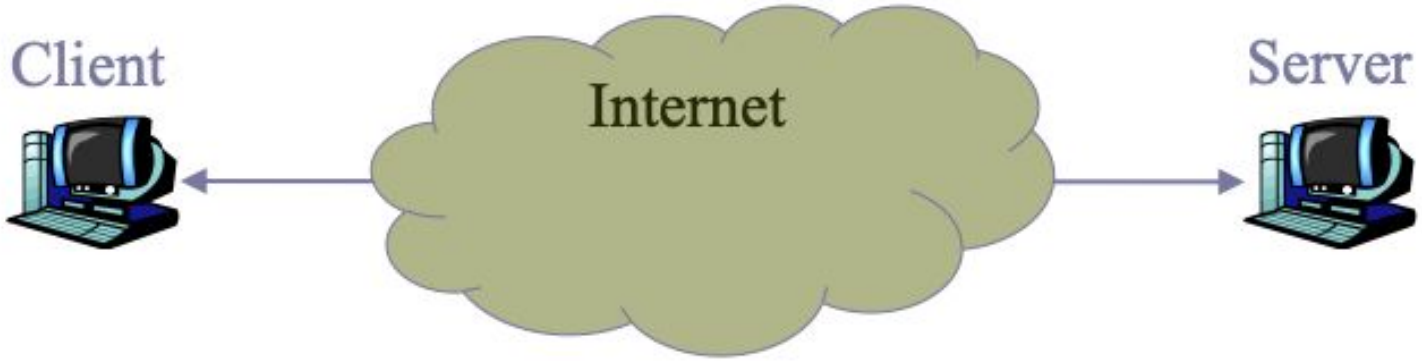
CDN

Review structure of the Internet



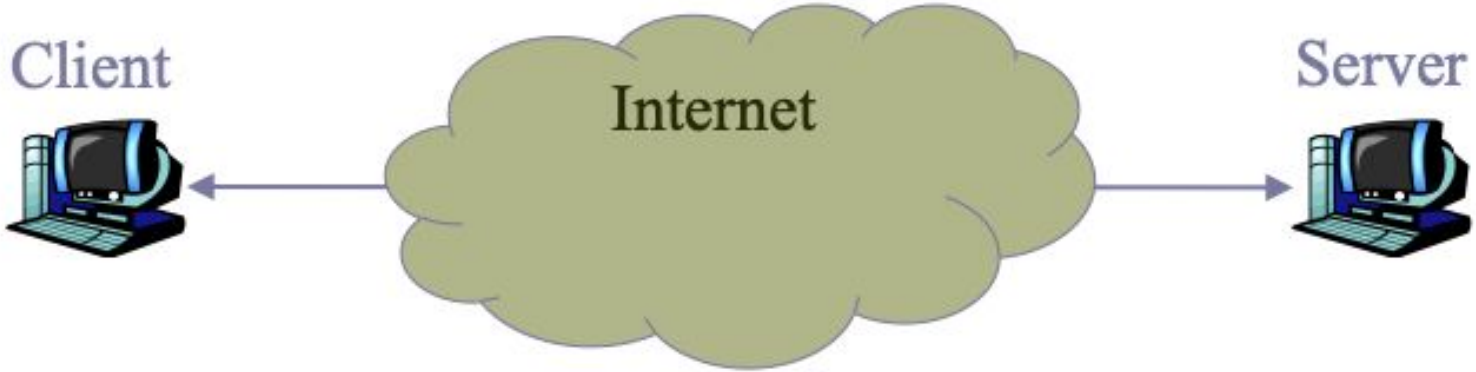
Serve web content

- Why not a single server for web content? (e.g. Google search or Youtube)



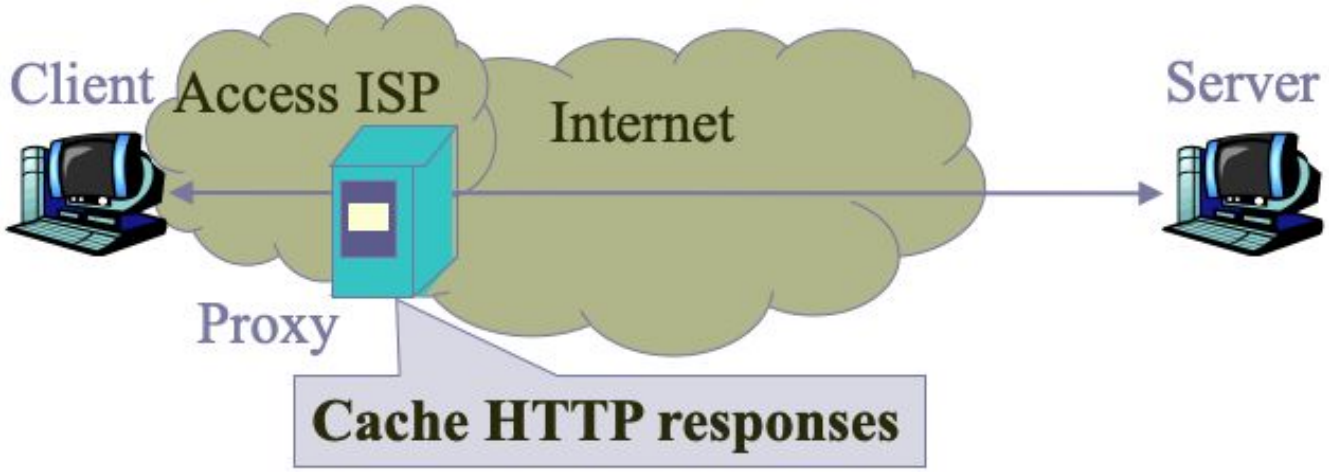
Single web server

- Single point of failure
- Easier to be overloaded
- Long latency
- etc.



What about ISP proxy caching?

- Does this solve the single server issues once for all?



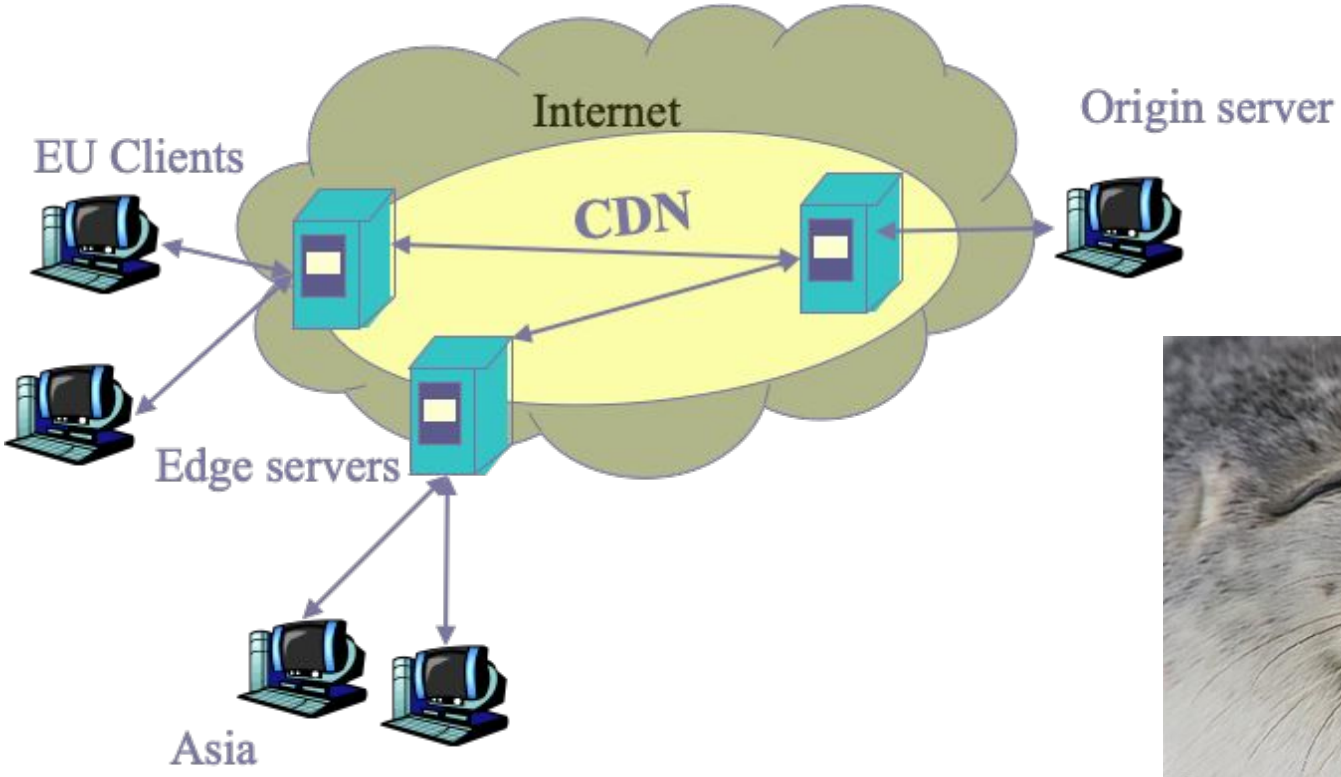
What about ISP proxy caching?

- Pros
  - Reduced latency for cached contents
- Cons
  - Security/authentication
  - Fine-grained control on when and where to cache content
  - Cold start

CDN

- Content delivery networks
- Content providers contract with CDN companies
- CDN companies have servers in lots of networks
- Better coordination between replicas (controlled refresh and removal)
- Proactively content replication on edge servers
- Win-win for both content providers and ISPs

CDN


Internet
Origin server
EU Clients
CDN
Edge servers
Asia


FEEL GOOD
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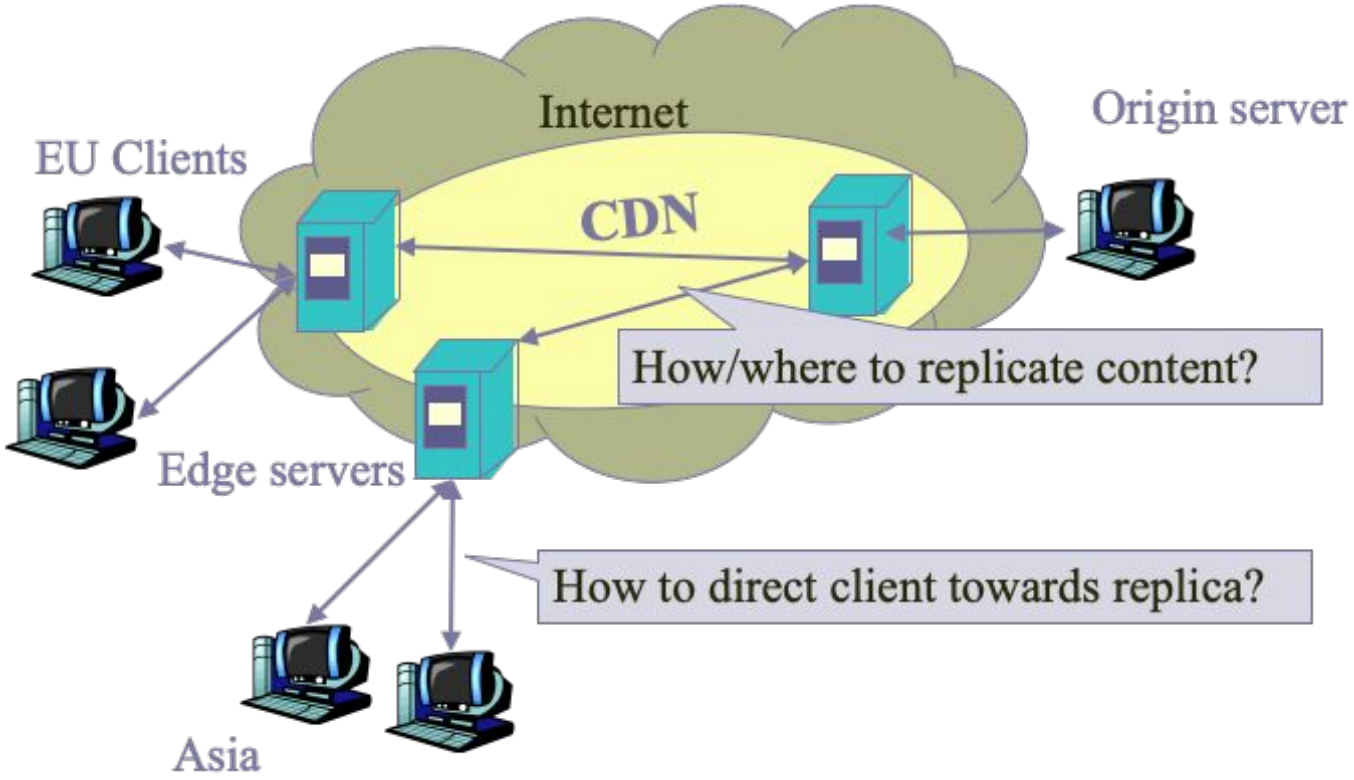
But, ...


Internet
Origin server
EU Clients
CDN
How/where to replicate content?
Edge servers
How to direct client towards replica?
Asia

Akamai

- Distributed servers
  - Over 250,000 servers
  - 137 countries
  - ~1,600 networks
- Scale
  - Over 50 Tbps
  - 15-30% of global traffic

Who is using Akamai?

- 55 percent of the Fortune Global 500

How Akamai works

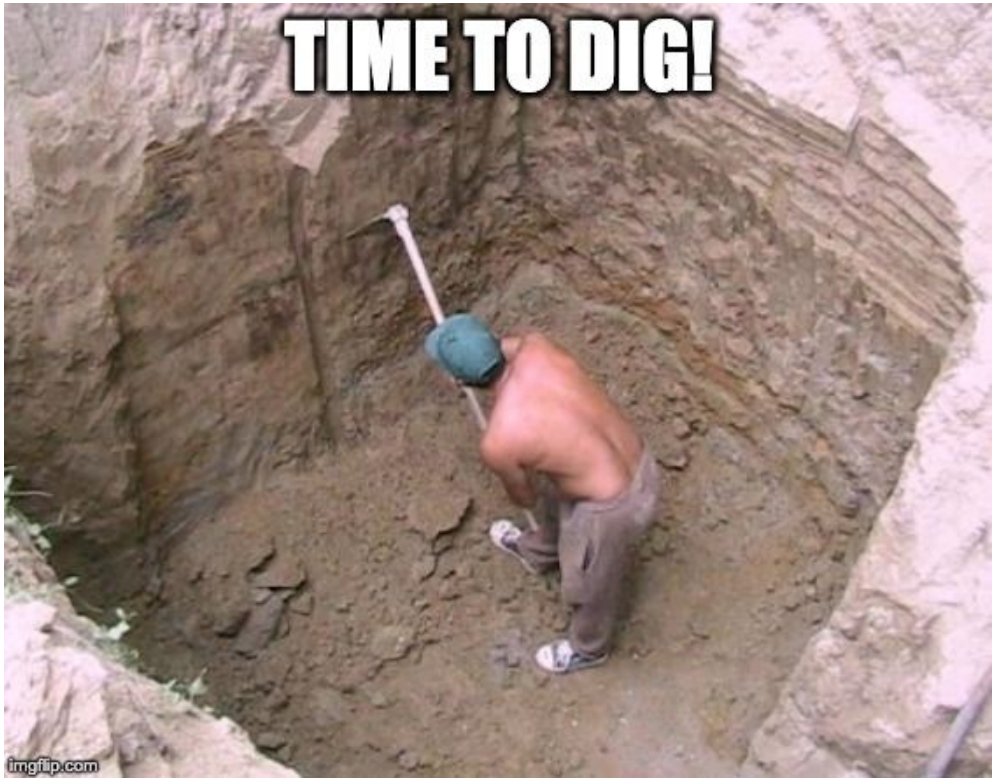
- Clients delegate domain to Akamai

```
mit.edu.                1506    IN      NS      eur5.akam.net.
mit.edu.                1506    IN      NS      ns1-37.akam.net.
mit.edu.                1506    IN      NS      use5.akam.net.
mit.edu.                1506    IN      NS      usw2.akam.net.
mit.edu.                1506    IN      NS      asia1.akam.net.
```

- CNAME chaining

```
www.mit.edu.                1799    IN      CNAME   www.mit.edu.edgekey.net.
www.mit.edu.edgekey.net.    58      IN      CNAME   e9566.dscb.akamaiedge.net.
e9566.dscb.akamaiedge.net.  18      IN      A       184.51.176.128
```

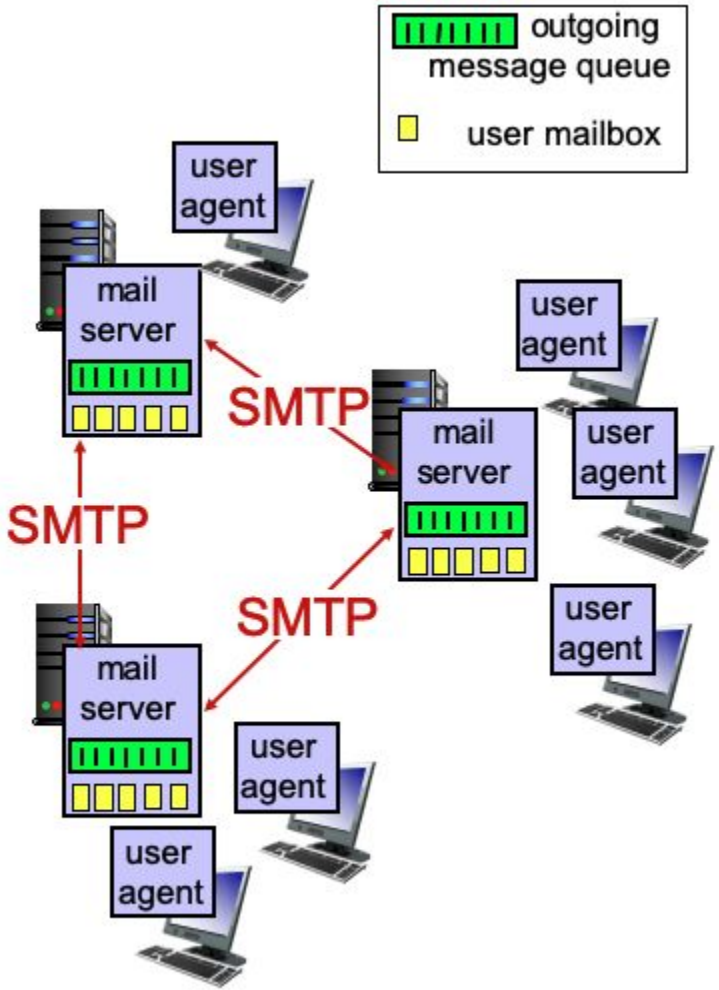
How Akamai works



SMTP

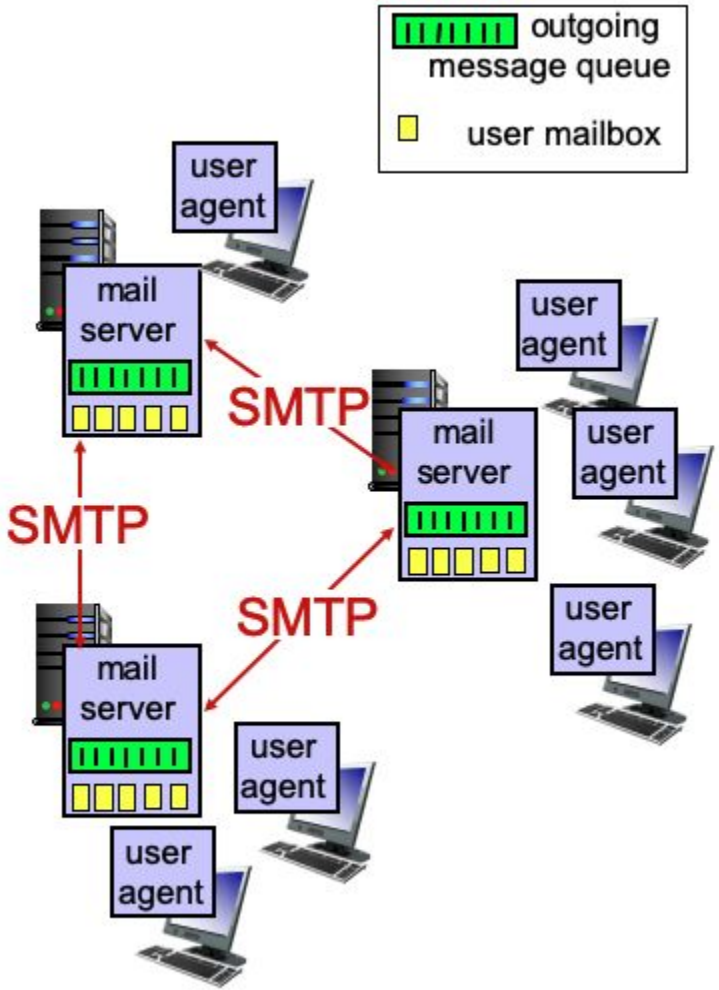
Email

- Three major components
  - User agents
  - Mail servers
  - SMTP (simple mail transfer protocol)



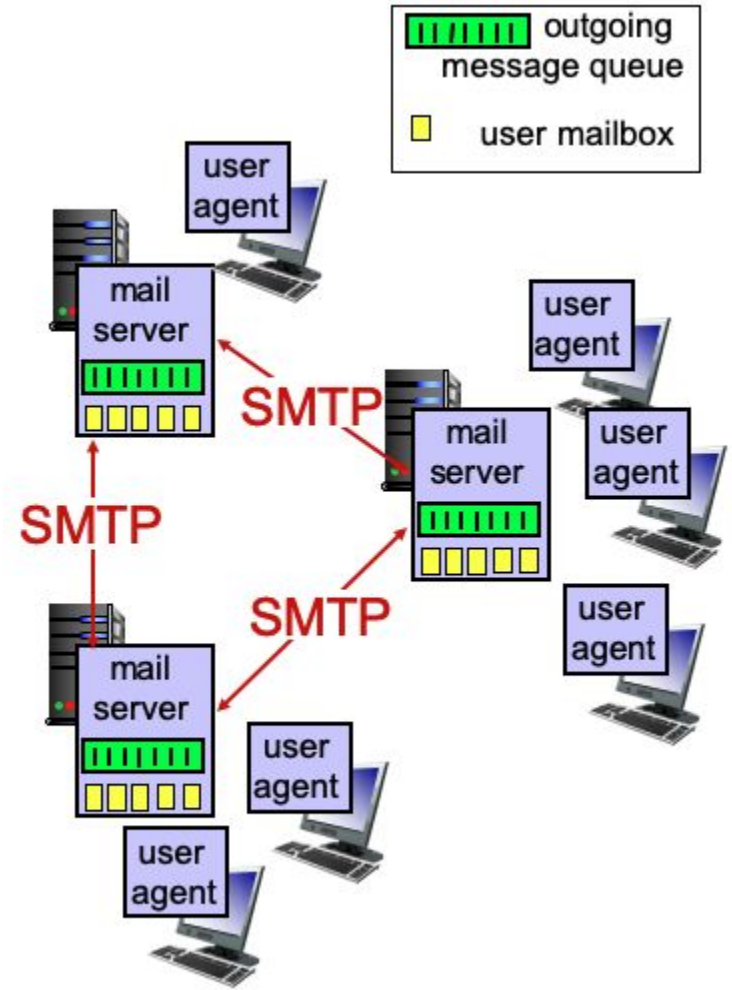
Email

- User agent
  - Aka “mail reader”
  - Composing, editing, reading email messages
  - E.g. outlook, thunderbird
  - Outgoing, incoming messages stored on mail servers



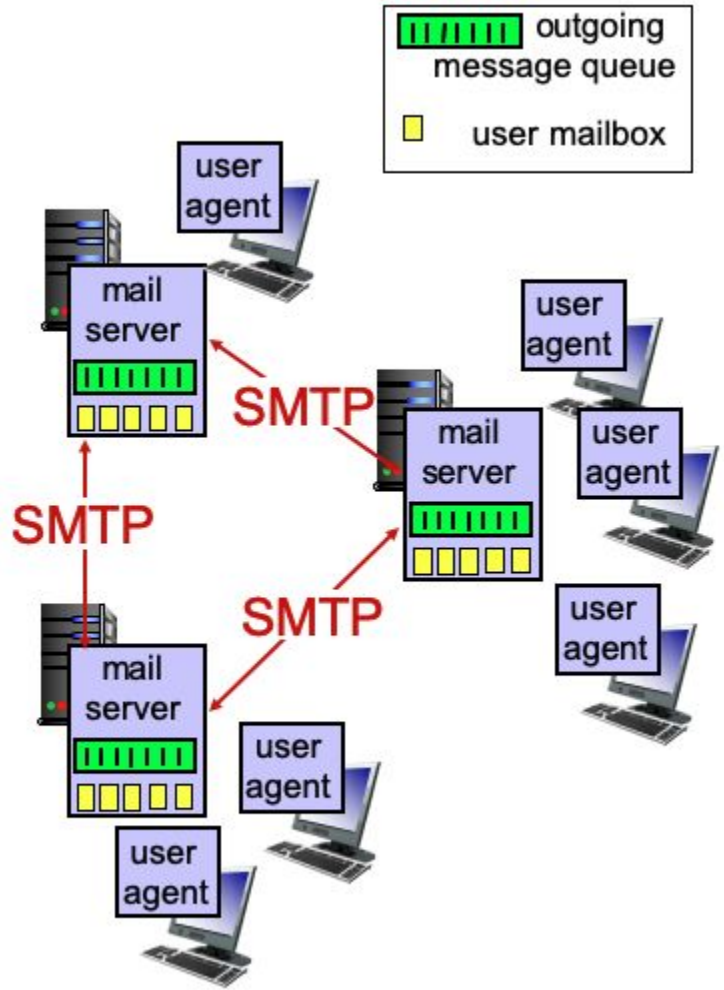
Email

- Mail servers
  - Hold incoming and outgoing email messages for users
  - Use SMTP protocol to send emails messages between mail servers



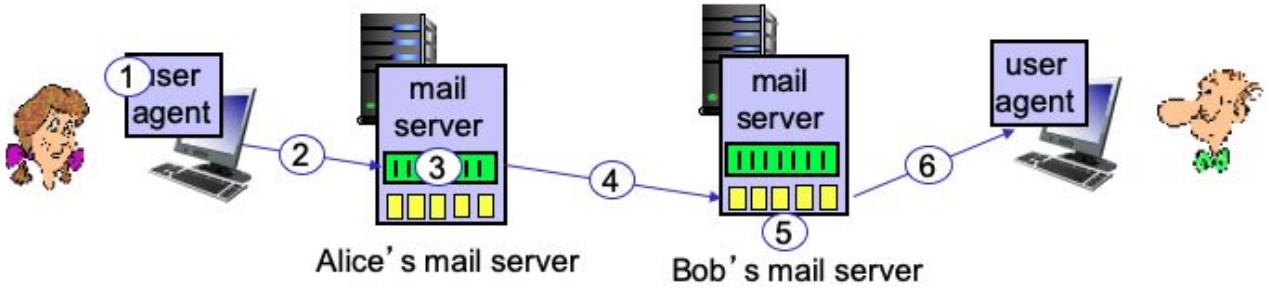
Email

- SMTP
  - Uses TCP to reliably transfer email messages
  - Port number 25
  - Command and response interaction
    - Commands: ASCII text
    - Response: status code and phrase



Alice sends message to Bob!

1) Alice uses UA to compose message "to" `bob@someschool.edu`
2) Alice's UA sends message to her mail server; message placed in message queue
3) client side of SMTP opens TCP connection with Bob's mail server
4) SMTP client sends Alice's message over the TCP connection
5) Bob's mail server places the message in Bob's mailbox
6) Bob invokes his user agent to read message



SMTP interaction

```
S: 220 hamburger.edu
C: HELO crepes.fr
S: 250  Hello crepes.fr, pleased to meet you
C: MAIL FROM: <alice@crepes.fr>
S: 250 alice@crepes.fr... Sender ok
C: RCPT TO: <bob@hamburger.edu>
S: 250 bob@hamburger.edu ... Recipient ok
C: DATA
S: 354 Enter mail, end with "." on a line by itself
C: Do you like ketchup?
C: How about pickles?
C: .
S: 250 Message accepted for delivery
C: QUIT
S: 221 hamburger.edu closing connection
```


DEMO?
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DHCP

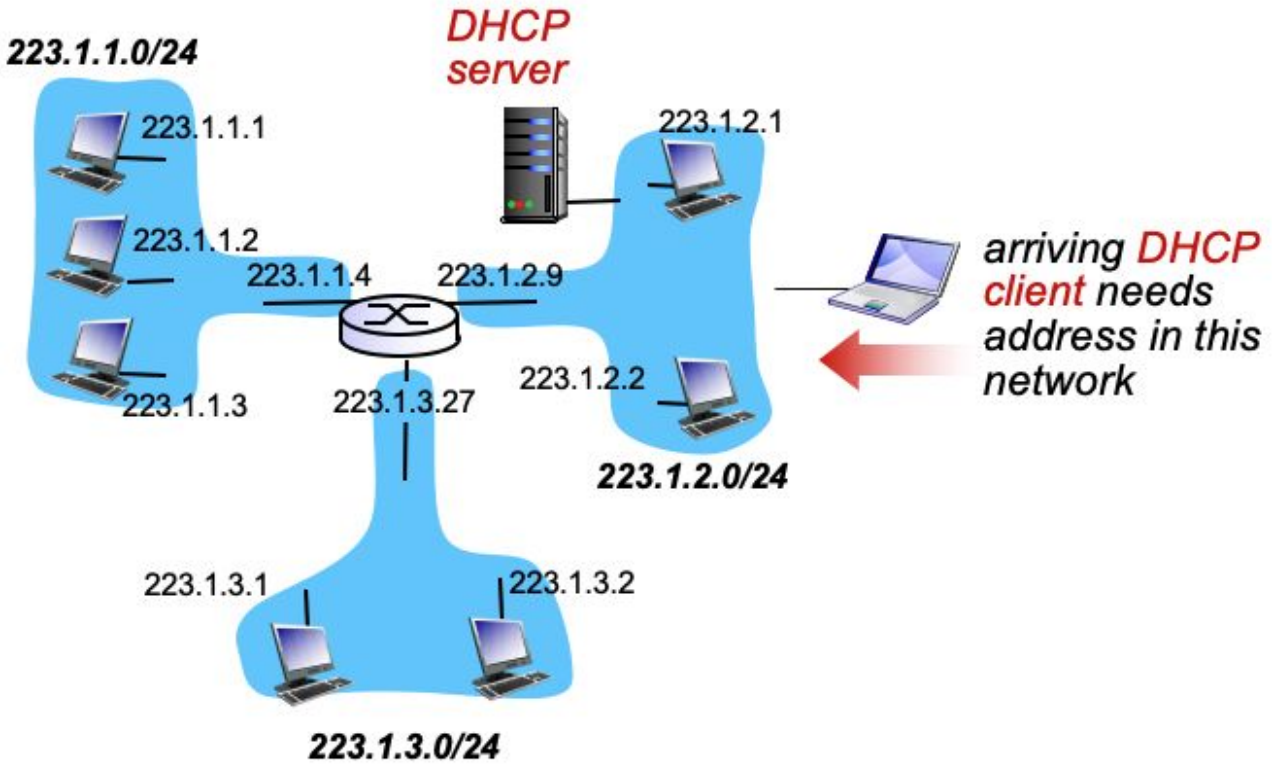
How does a host get IP address?

- Hard-coded by system admin
- DHCP
  - Dynamic Host Configuration Protocol
  - Dynamically get address from a server
  - “Plug-and-play”

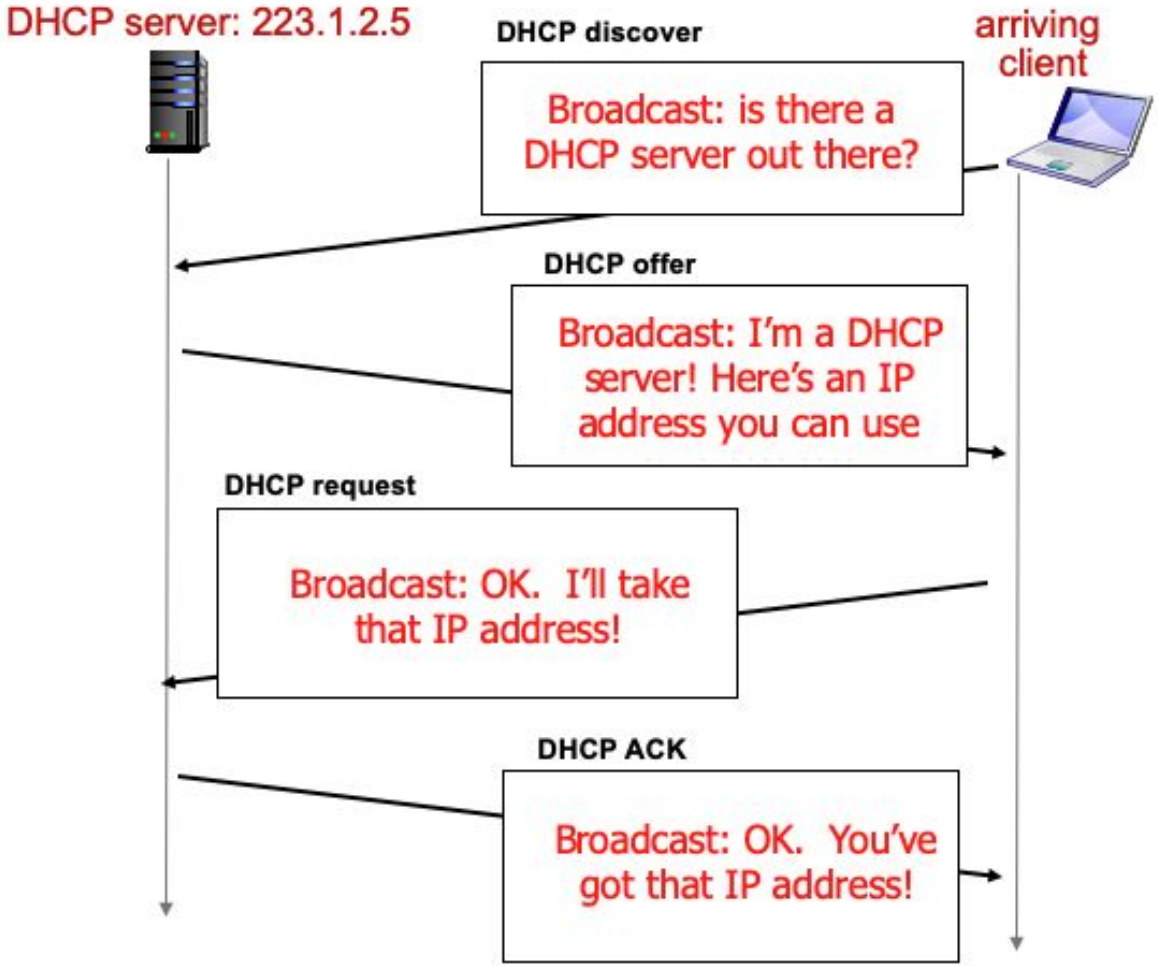
DHCP

- Goal: allow host to dynamically obtain IP address when it joins network
- Overview
  - Host broadcasts “DHCP discover” message
  - DHCP server responds with “DHCP offer” message
  - Host requests IP address with “DHCP request”
  - DHCP server sends address with “DHCP ack” message

DHCP


223.1.1.0/24
DHCP server
223.1.1.1
223.1.2.1
223.1.1.2
223.1.1.4
223.1.2.9
arriving DHCP client needs address in this network
223.1.1.3
223.1.3.27
223.1.2.2
223.1.2.0/24
223.1.3.1
223.1.3.2
223.1.3.0/24

DHCP


DHCP server: 223.1.2.5
DHCP discover
arriving client
Broadcast: is there a DHCP server out there?
DHCP offer
Broadcast: I'm a DHCP server! Here's an IP address you can use
DHCP request
Broadcast: OK. I'll take that IP address!
DHCP ACK
Broadcast: OK. You've got that IP address!

DHCP

- DHCP returns more than just the IP address
  - Network mask (indicating network vs host portion)
  - Name and IP address of local DNS server
  - Address of first-hop router

Is DHCP on TCP or UDP?

Summary

- Application layer principles
  - Intelligence at the edge, client-server architecture
- Service model of TCP and UDP
- Study protocols
  - DNS, HTTP, SMTP, DHCP