Computer Networking

Lent Term
M/W/F 11:00-12:00
LT1 in Gates Building

Handout 4 (Topic 6)

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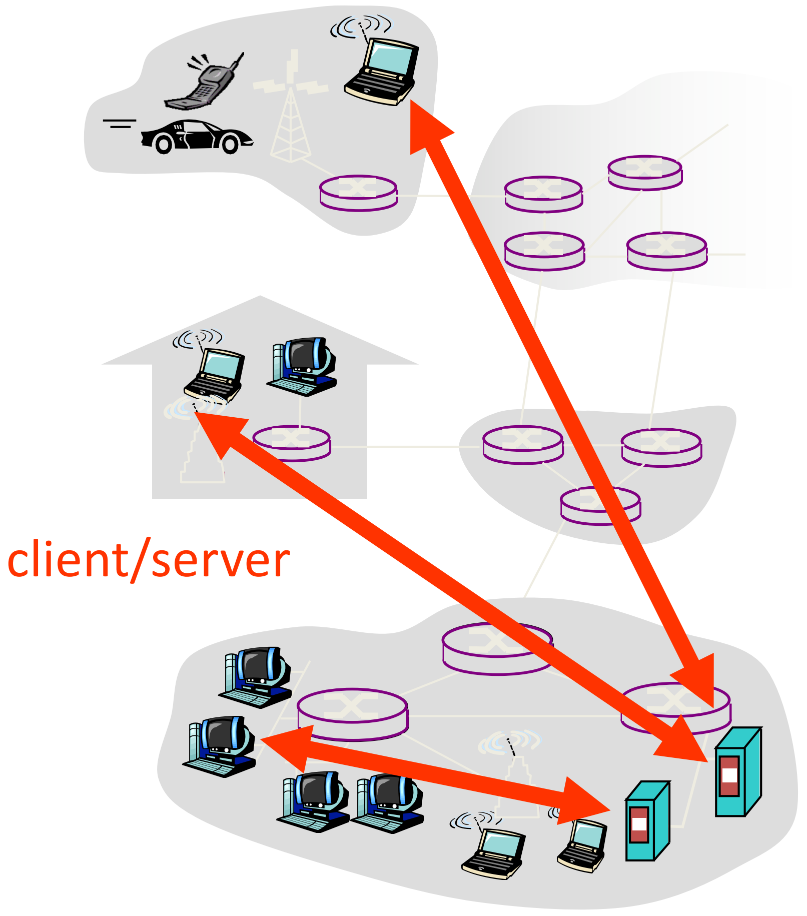
Topic 6 – Applications

- Overview
- Infrastructure Services (DNS)
- Traditional Applications (web)
- Multimedia Applications (SIP)
- P2P Networks

Client-server paradigm



server:

- always-on host
- permanent IP address
- server farms for scaling

clients:

- communicate with server
- may be intermittently connected
- may have dynamic IP addresses
- do not communicate directly with each other

Relationship Between Names&Addresses

- Addresses can change underneath
  - Move www.bbc.co.uk to 212.58.246.92
  - Humans/Apps should be unaffected

- Name could map to multiple IP addresses
  - www.bbc.co.uk to multiple replicas of the Web site
  - Enables
    - Load-balancing
    - Reducing latency by picking nearby servers

- Multiple names for the same address
  - E.g., aliases like www.bbc.co.uk and bbc.co.uk
  - Mnemonic stable name, and dynamic canonical name
    - Canonical name = actual name of host

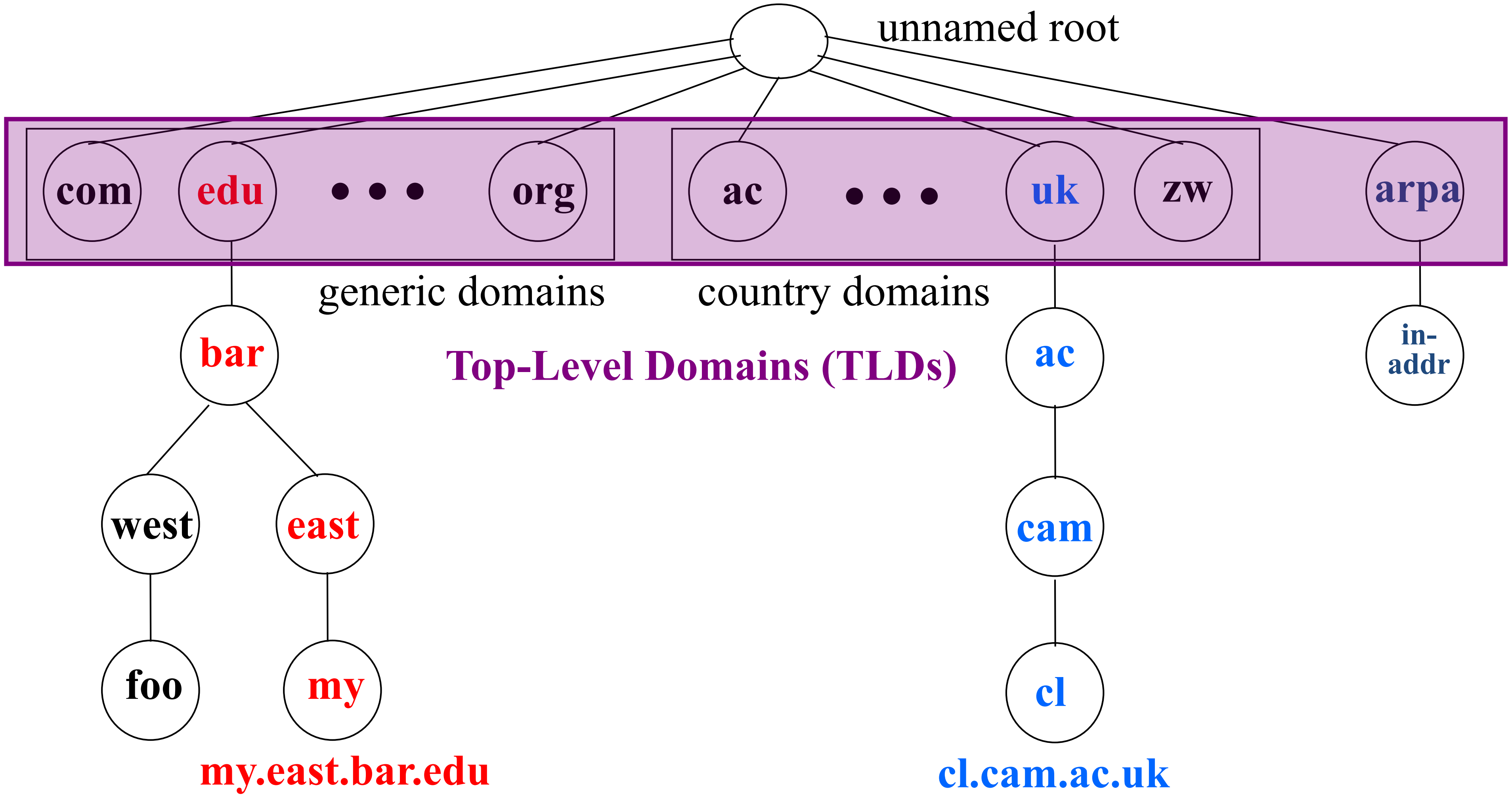
Mapping from Names to Addresses

- Originally: per-host file /etc/hosts
  - SRI (Menlo Park) kept master copy
  - Downloaded regularly
  - Flat namespace
- Single server not resilient, doesn’t scale
  - Adopted a distributed hierarchical system
- Two intertwined hierarchies:
  - Infrastructure: hierarchy of DNS servers
  - Naming structure: www.bbc.co.uk

Domain Name System (DNS)

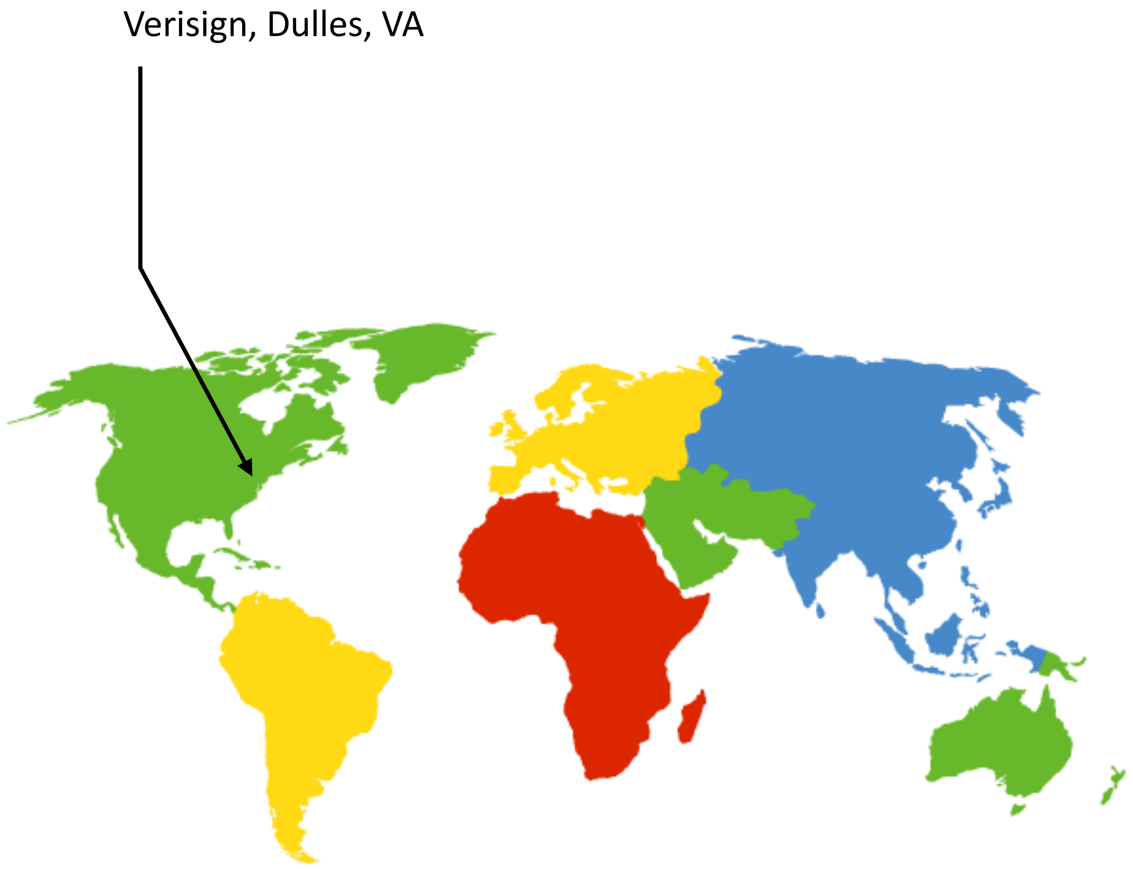
- Top of hierarchy: Root
  - Location hardwired into other servers
- Next Level: Top-level domain (TLD) servers
  - .com, .edu, etc.
  - .uk, .au, .to, etc.
  - Managed professionally
- Bottom Level: Authoritative DNS servers
  - Actually do the mapping
  - Can be maintained locally or by a service provider

Distributed Hierarchical Database



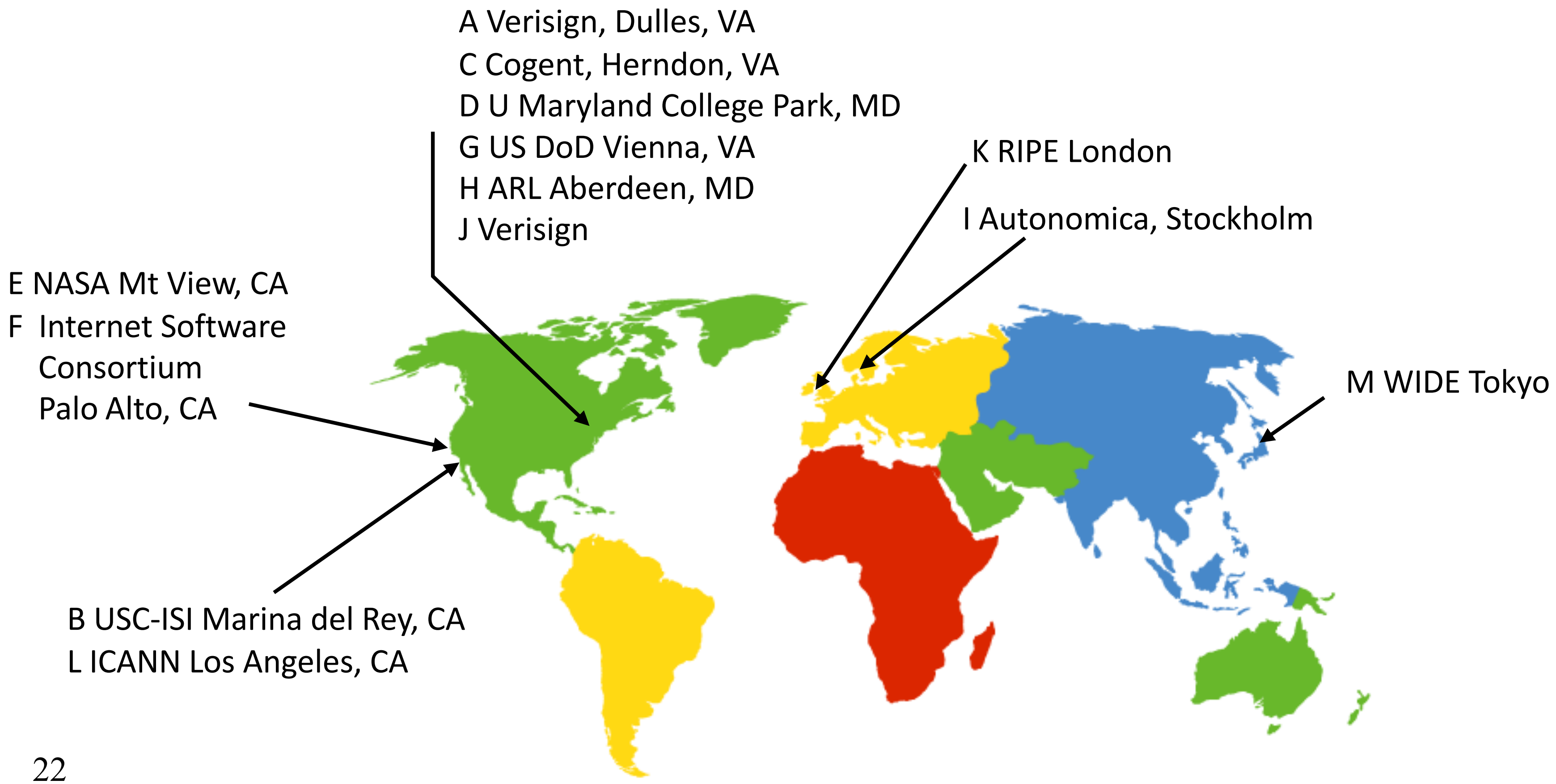
DNS Root

- Located in Virginia, USA
- How do we make the root scale?



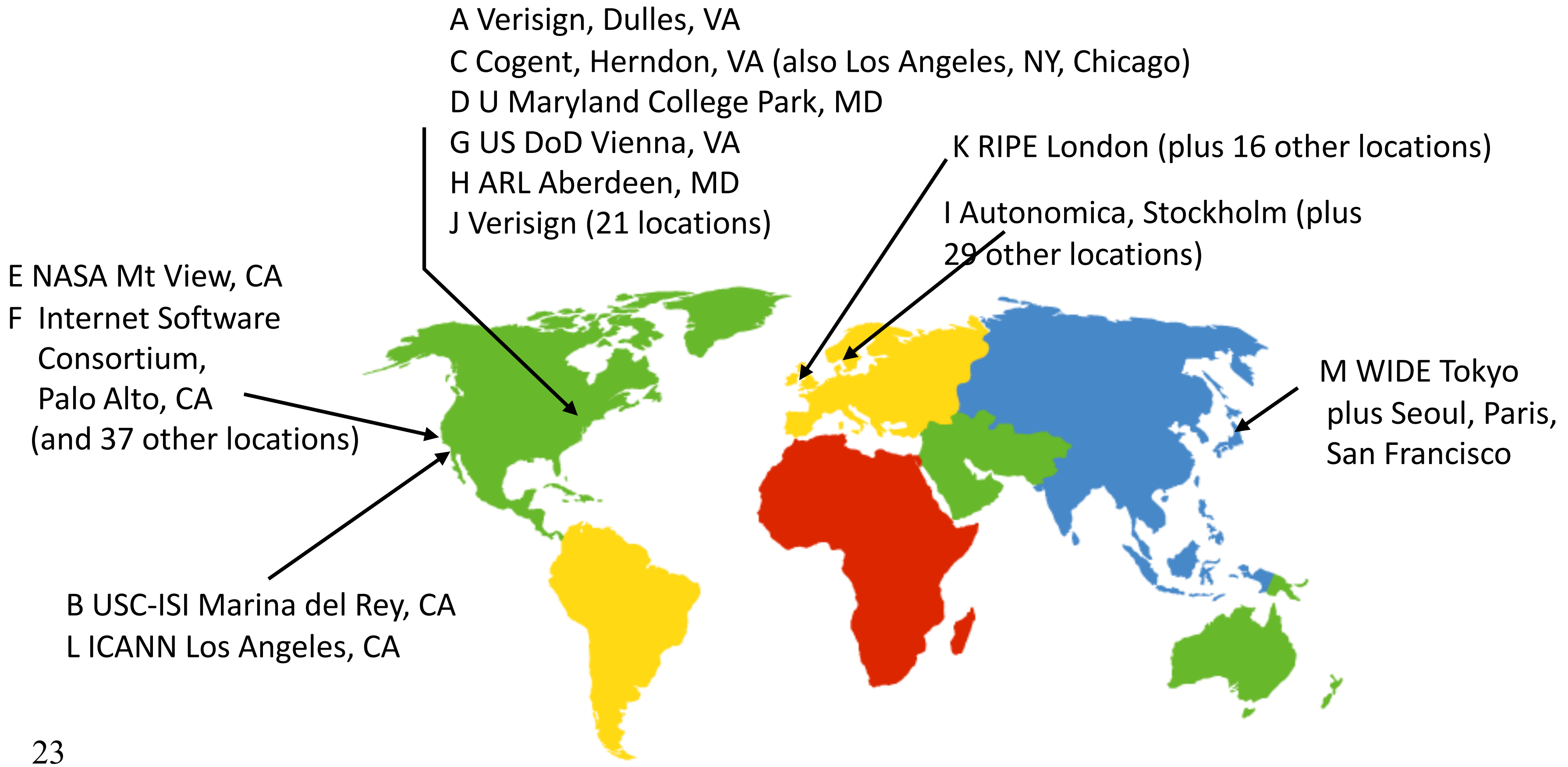
DNS Root Servers

- 13 root servers (see http://www.root-servers.org/)
  - Labeled A through M
- Does this scale?



DNS Root Servers

- 13 root servers (see http://www.root-servers.org/)
  - Labeled A through M
- Replication via any-casting (localized routing for addresses)



A Verisign, Dulles, VA
C Cogent, Herndon, VA (also Los Angeles, NY, Chicago)
D U Maryland College Park, MD
G US DoD Vienna, VA
H ARL Aberdeen, MD
J Verisign (21 locations)

K RIPE London (plus 16 other locations)

I Autonomica, Stockholm (plus 29 other locations)

E NASA Mt View, CA
F Internet Software Consortium, Palo Alto, CA (and 37 other locations)

M WIDE Tokyo plus Seoul, Paris, San Francisco

B USC-ISI Marina del Rey, CA
L ICANN Los Angeles, CA

Using DNS

- Two components
  - Local DNS servers
  - Resolver software on hosts
- Local DNS server ("default name server")
  - Usually near the endhosts that use it
  - Local hosts configured with local server (e.g., /etc/resolv.conf) or learn server via DHCP
- Client application
  - Extract server name (e.g., from the URL)
  - Do gethostbyname() to trigger resolver code

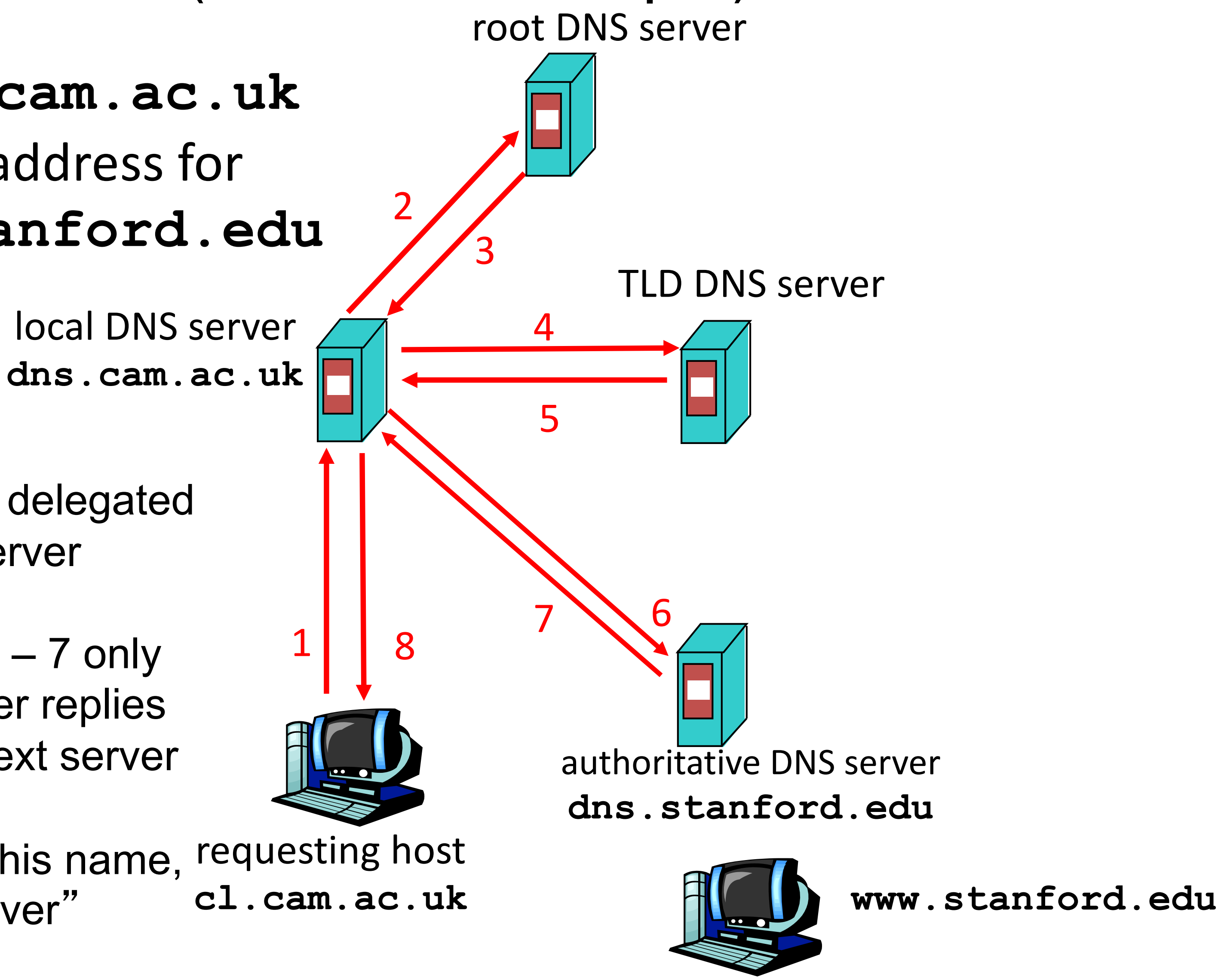
How Does Resolution Happen?

(**Iterative** example)

Host at **`cl.cam.ac.uk`**

wants IP address for

`www.stanford.edu`



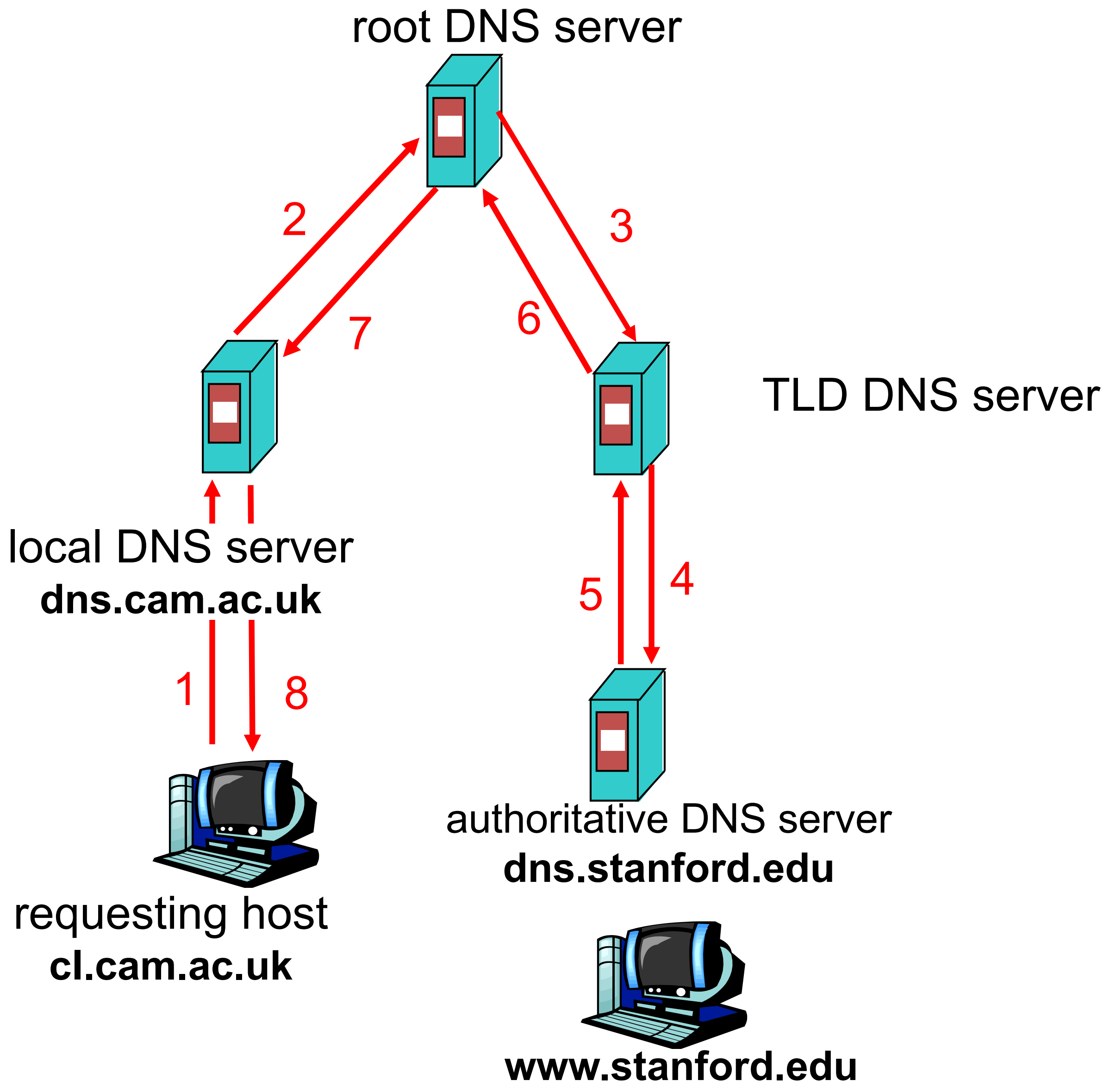
iterated query:

- Host enquiry is delegated to local DNS server
- Consider transactions 2 – 7 only
- contacted server replies with name of next server to contact
- "I don't know this name, but ask this server"

DNS name resolution **recursive** example

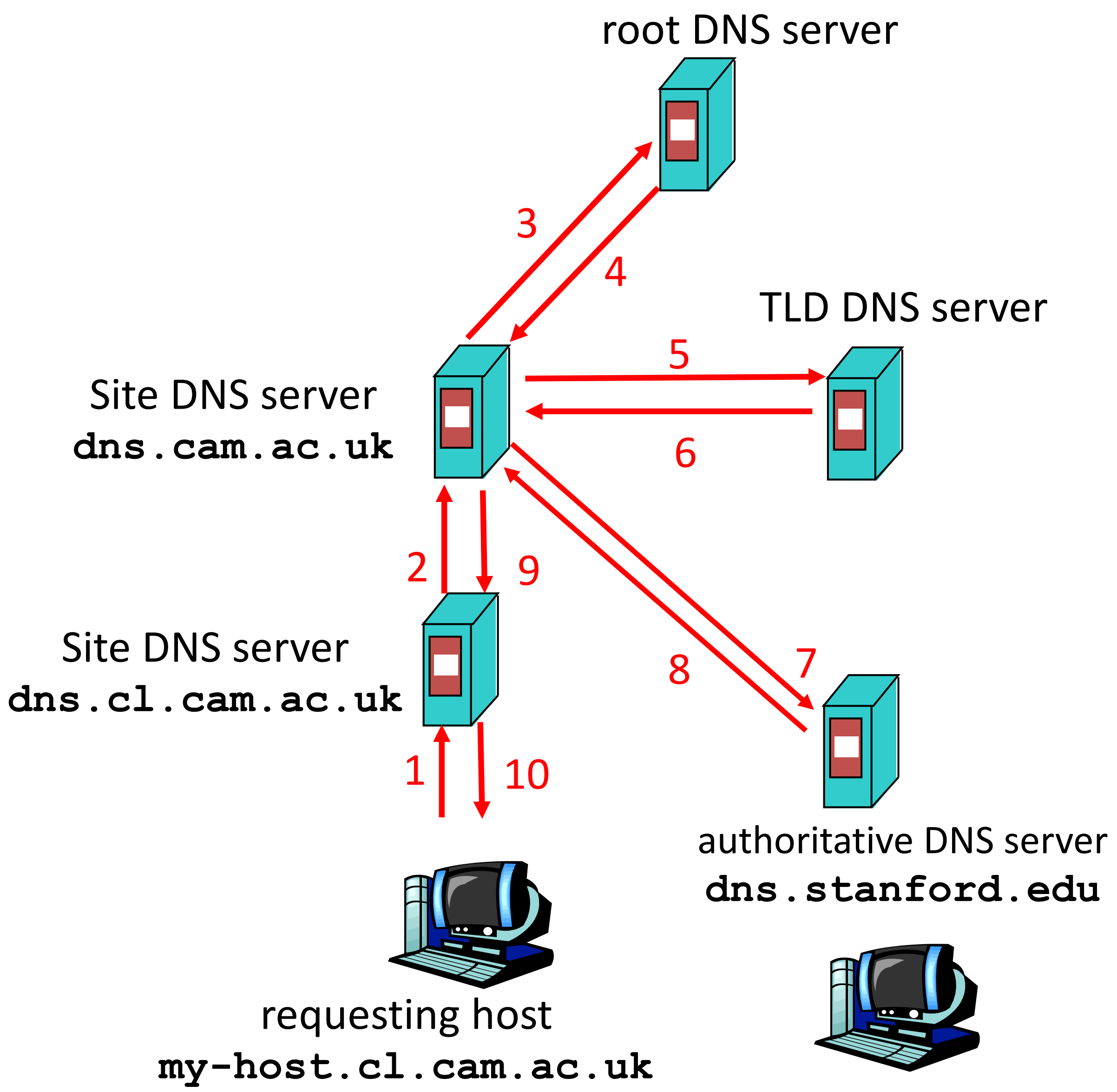
recursive query:

- puts burden of name resolution on contacted name server
- heavy load?



Recursive and Iterative Queries - **Hybrid** case

- Recursive query
  - Ask server to get answer for you
  - E.g., requests 1,2 and responses 9,10
- Iterative query
  - Ask server who to ask next
  - E.g., all other request-response pairs



DNS Caching

- Performing all these queries takes time
  - And all this before actual communication takes place
  - E.g., 1-second latency before starting Web download
- Caching can greatly reduce overhead
  - The top-level servers very rarely change
  - Popular sites (e.g., www.bbc.co.uk) visited often
  - Local DNS server often has the information cached
- How DNS caching works
  - DNS servers cache responses to queries
  - Responses include a "time to live" (TTL) field
  - Server deletes cached entry after TTL expires

Negative Caching

- Remember things that don' t work
  - Misspellings like *bbcc.co.uk* and *www.bbc.com.uk*
  - These can take a long time to fail the first time
  - Good to remember that they don't work
  - … so the failure takes less time the next time around

- But: negative caching is optional
  - And not widely implemented

Reliability

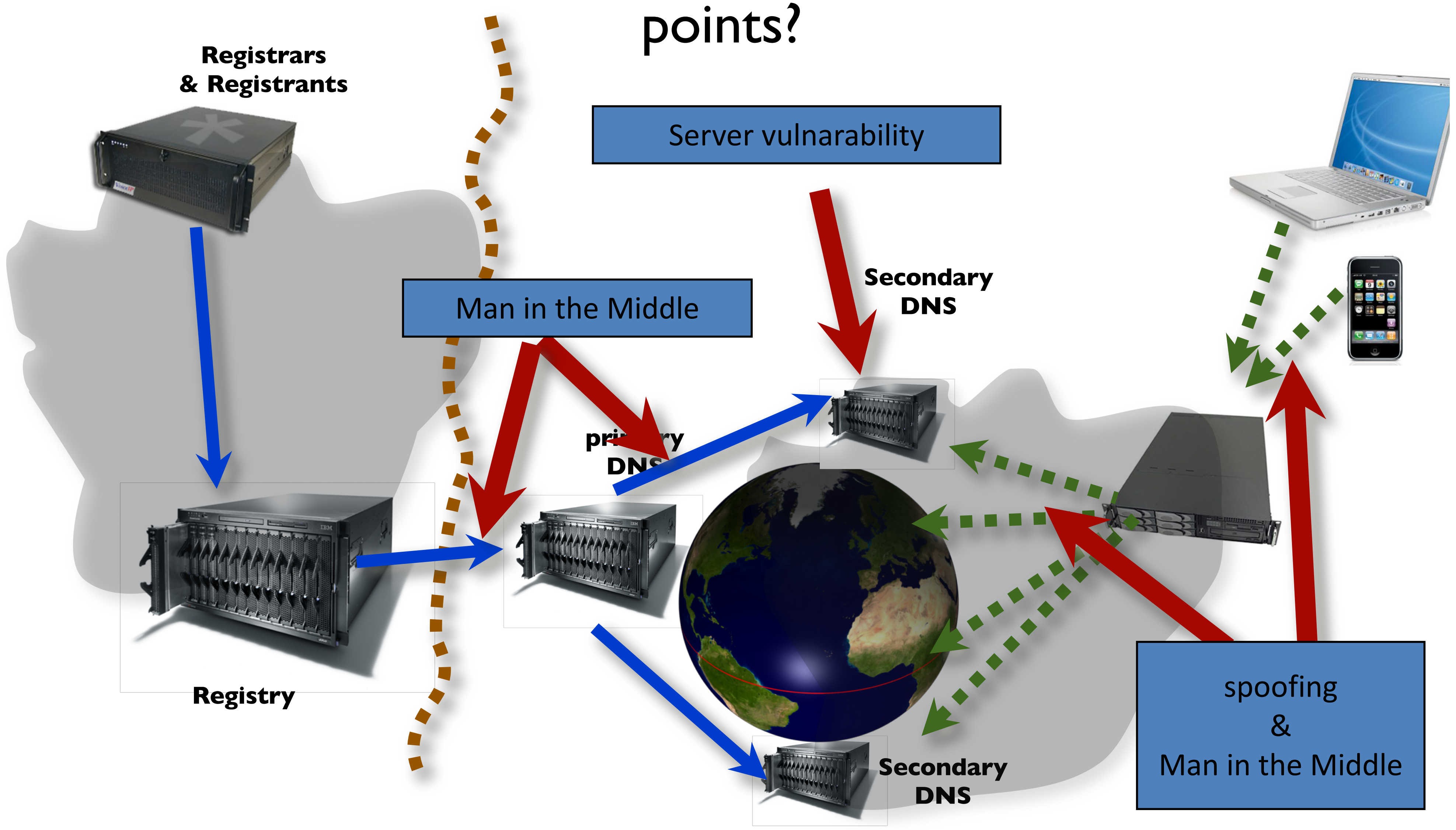
- DNS servers are replicated (primary/secondary)
  - Name service available if at least one replica is up
  - Queries can be load-balanced between replicas
- Usually, UDP used for queries
  - Need reliability: must implement this on top of UDP
  - Spec supports TCP too, but not always implemented
- Try alternate servers on timeout
  - Exponential backoff when retrying same server
- Same identifier for all queries
  - Don’t care which server responds

DNS and Security

- No way to verify answers
  - Opens up DNS to many potential attacks
  - DNSSEC fixes this
- Most obvious vulnerability: recursive resolution
  - Using recursive resolution, host must trust DNS server
  - When at Starbucks, server is under their control
  - And can return whatever values it wants
- More subtle attack: Cache poisoning
  - Those “additional” records can be anything!

Data flow through the DNS

Where are the vulnerable points?



DNSSEC protects all these end-to-end

- provides message authentication and integrity verification through cryptographic signatures
  - You know who provided the signature
  - No modifications between signing and validation

- It does **not** provide authorization
- It does **not** provide confidentiality
- It does **not** provide protection against DDOS

DNSSEC in practice

- Scaling the key signing and key distribution

Solution: Using the DNS to Distribute Keys

- Distributing keys through DNS hierarchy:
  - Use one trusted key to establish authenticity of other keys
  - Building chains of trust from the root down
  - Parents need to sign the keys of their children

- Only the root key needed in ideal world
  - Parents always delegate security to child

Why is the web so successful?

- What do the web, youtube, facebook, twitter, instagram, ….. have in common?
  - The ability to self-publish

- Self-publishing that is easy, independent, *free*

- No interest in collaborative and idealistic endeavor
  - People aren’t looking for Nirvana (or even Xanadu)
  - People also aren’t looking for technical perfection

- Want to make their mark, and find something neat
  - Two sides of the same coin, creates synergy
  - “Performance” more important than dialogue….

Web Components

- Infrastructure:
  - Clients
  - Servers
  - Proxies
- Content:
  - Individual objects (files, etc.)
  - Web sites (coherent collection of objects)
- Implementation
  - HTML: formatting content
  - URL: naming content
  - HTTP: protocol for exchanging content

    Any content not just HTML!

HTML: HyperText Markup Language

- A *Web page* has:
  - Base HTML file
  - Referenced objects (*e.g.*, images)
- HTML has several functions:
  - Format text
  - Reference images
  - Embed *hyperlinks* (HREF)

URL Syntax

protocol : / /hostname[:port] /directorypath /resource

protocol	http, ftp, https, smtp, rtsp, *etc*.
hostname	DNS name, IP address
port	Defaults to protocol's standard port *e.g.* http: 80 https: 443
directory path	Hierarchical, reflecting file system
resource	Identifies the desired resource Can also extend to program executions: `http://us.f413.mail.yahoo.com/ym/ShowLetter?box=%40B%40Bulk&MsgId=2604_1744106_29699_1123_1261_0_28917_3552_1289957100&Search=&Nhead=f&YY=31454&order=down&sort=date&pos=0&view=a&head=b`

HyperText Transfer Protocol (HTTP)

- Request-response protocol
- Reliance on a global namespace
- Resource *metadata*
- *Stateless*
- ASCII format (ok this changed….)

```
$ telnet www.cl.cam.ac.uk 80
GET /win HTTP/1.0
<blank line, i.e., CRLF>
```

Steps in HTTP Request

- HTTP Client initiates TCP connection to server
  - SYN
  - SYNACK
  - ACK
- Client sends HTTP request to server
  - Can be piggybacked on TCP's ACK
- HTTP Server responds to request
- Client receives the request, terminates connection
- TCP connection termination exchange

How many RTTs for a single request?

Client-Server Communication

- two types of HTTP messages: *request, response*
- HTTP request message: (GET POST HEAD ….)

request line (GET, POST, HEAD commands)

header lines

```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
User-agent: Mozilla/4.0
Connection: close
Accept-language:fr
```

(extra carriage return, line feed)

Carriage return, line feed indicates end of message

HTTP response message

status line (protocol status code status phrase)

header lines

```
HTTP/1.1 200 OK
Connection close
Date: Thu, 06 Aug 1998 12:00:15 GMT
Server: Apache/1.3.0 (Unix)
Last-Modified: Mon, 22 Jun 1998 …...
Content-Length: 6821
Content-Type: text/html

data data data data data ...
```

data, e.g., requested HTML file

Different Forms of Server Response

- Return a file
  - URL matches a file (*e.g.,* `/www/index.html`)
  - Server returns file as the response
  - Server generates appropriate response header

- Generate response dynamically
  - URL triggers a program on the server
  - Server runs program and sends output to client

- Return meta-data with no body

HTTP Resource Meta-Data

- Meta-data
  - Info *about* a resource, stored as a separate entity
- Examples:
  - Size of resource, last modification time, type of content
- Usage example: Conditional GET Request
  - Client requests object "**`If-modified-since`**"
  - If unchanged, "**`HTTP/1.1 304 Not Modified`**"
  - No body in the server's response, only a header

HTTP is *Stateless*

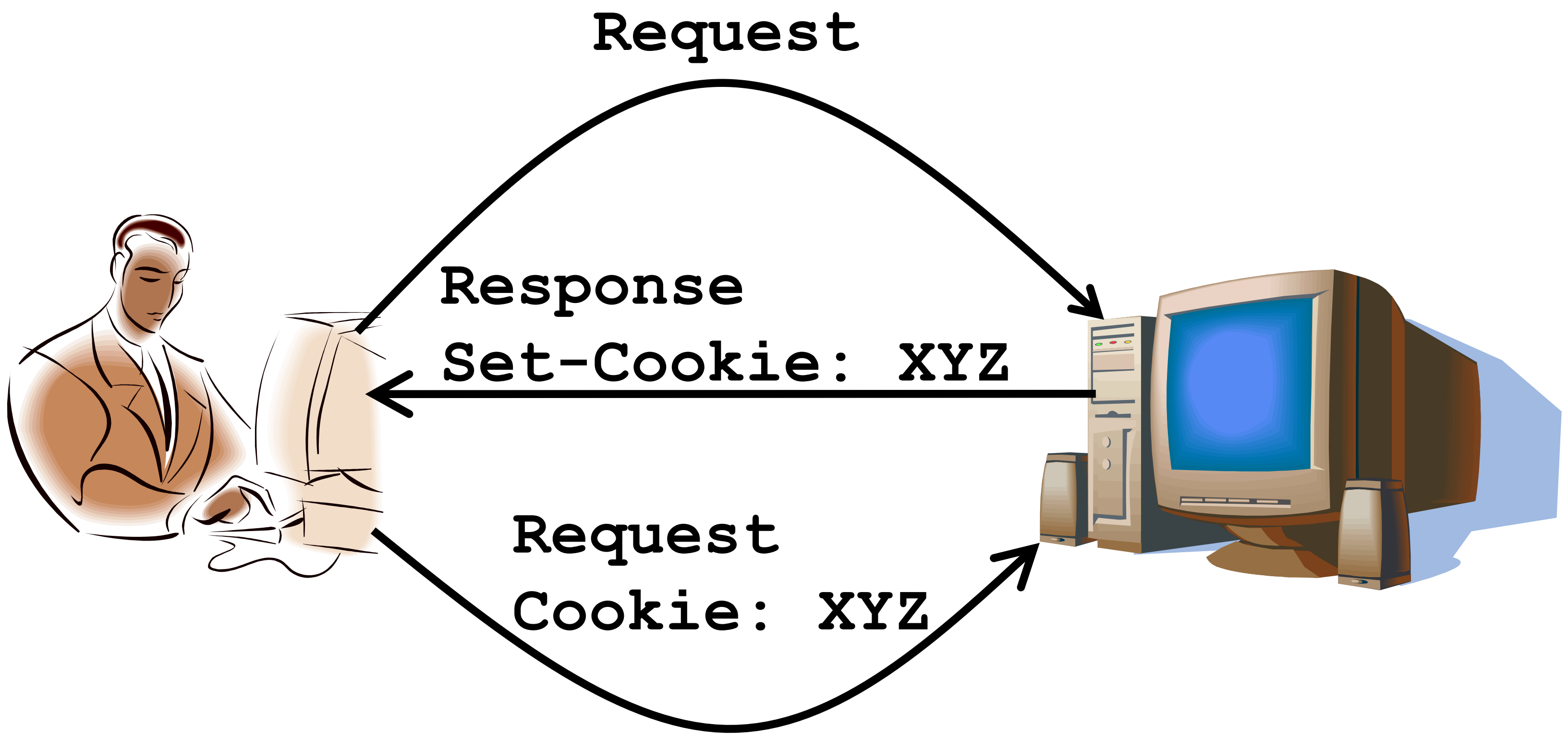
- Each request-response treated independently
  - Servers *not* required to retain state

- **Good**: Improves scalability on the server-side
  - Failure handling is easier
  - Can handle higher rate of requests
  - Order of requests doesn‘t matter

- **Bad**: Some applications need persistent state
  - Need to uniquely identify user or store temporary info
  - *e.g.*, Shopping cart, user profiles, usage tracking, …

State in a Stateless Protocol:
Cookies

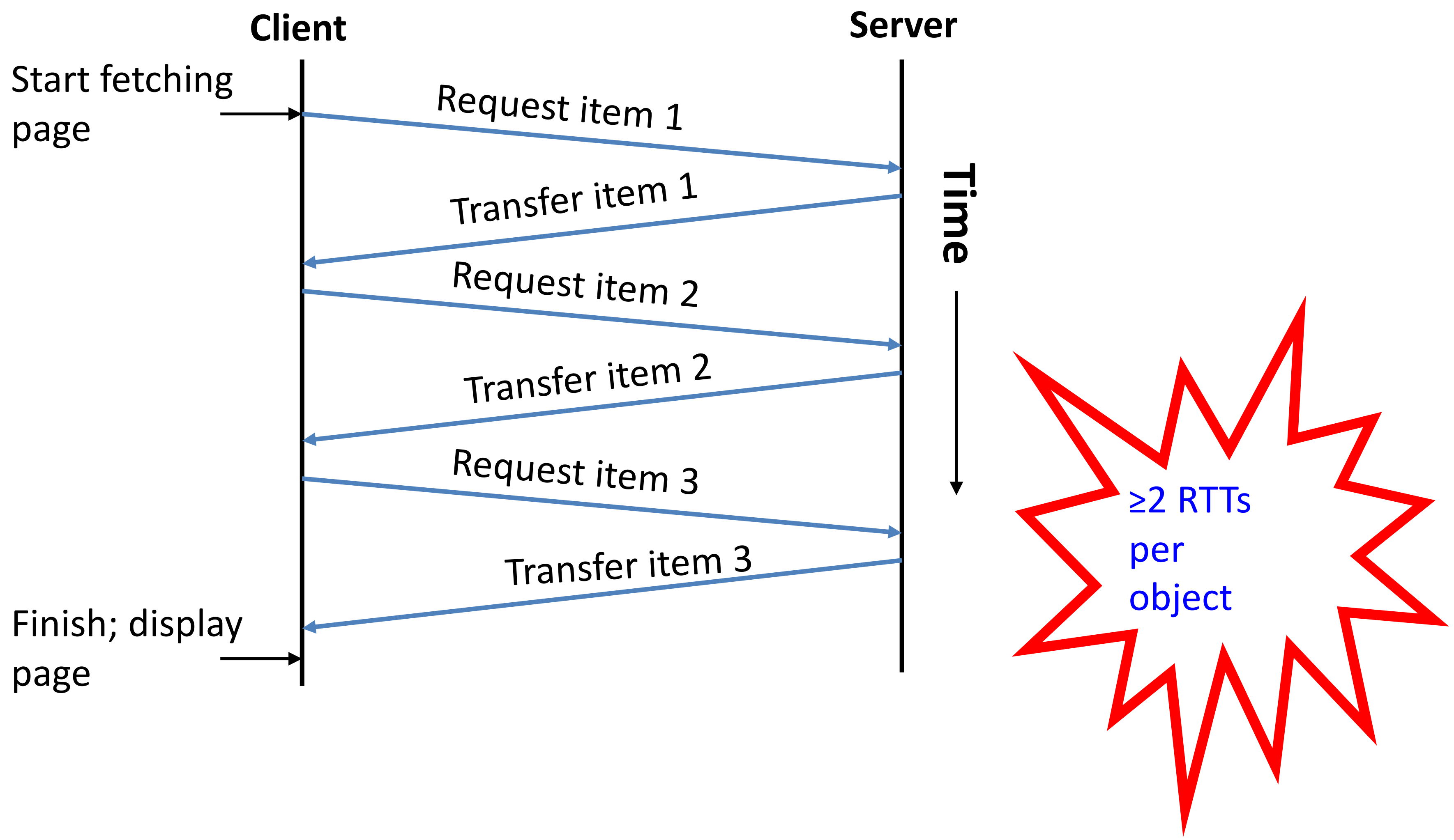
- *Client-side* state maintenance
  - Client stores small(?) state on behalf of server
  - Client sends state in future requests to the server
- Can provide authentication



HTTP Performance

- Most Web pages have multiple objects
  - *e.g.,* HTML file and a bunch of embedded images
- How do you retrieve those objects (naively)?
  - *One item at a time*
- Put stuff in the optimal place?
  - *Where is that precisely?*
    - ***Enter the Web cache and the CDN***

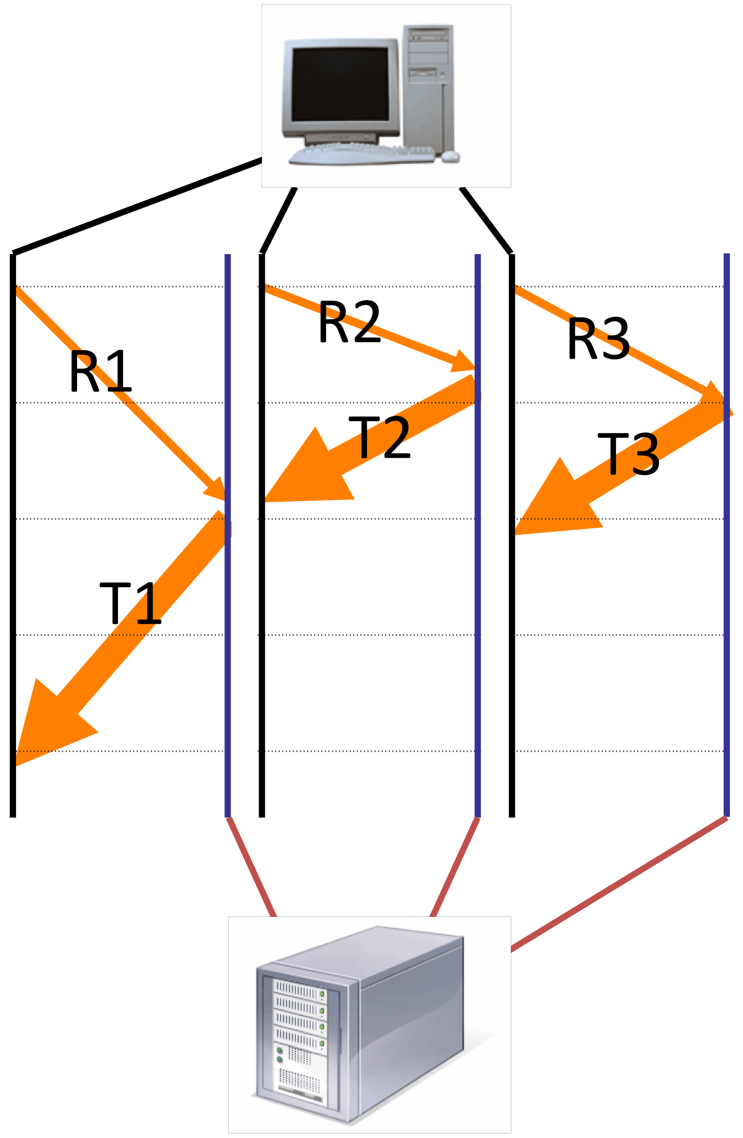
Fetch HTTP Items: Stop & Wait



Improving HTTP Performance:
Concurrent Requests & Responses

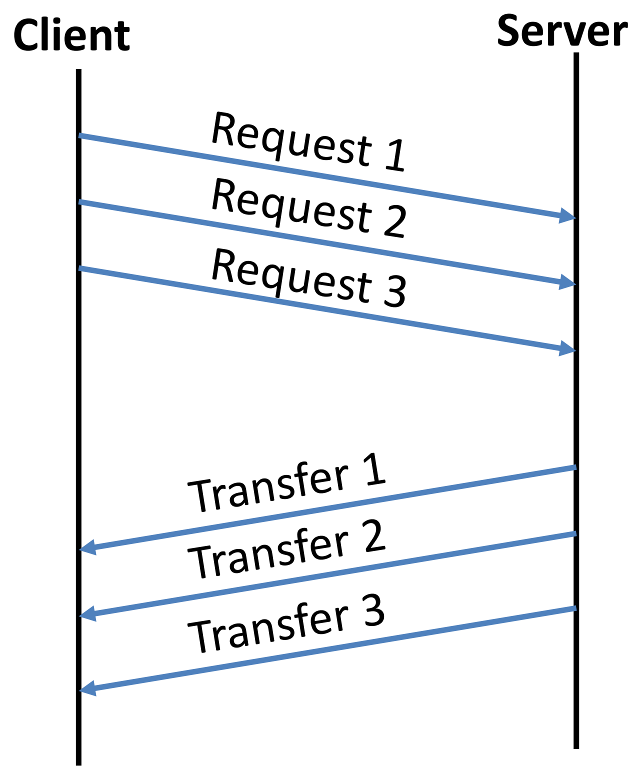
- Use multiple connections *in parallel*
- Does not necessarily maintain order of responses

- Client = ☺
- Server = ☺
- Network = ☹ Why?



Improving HTTP Performance: Pipelined Requests & Responses

- *Batch* requests and responses
  - Reduce connection overhead
  - Multiple requests sent in a single batch
  - Maintains order of responses
  - Item 1 always arrives before item 2
- How is this different from concurrent requests/responses?
  - Single TCP connection



Improving HTTP Performance: Persistent Connections

- Enables multiple transfers per connection
  - Maintain TCP connection across multiple requests
  - Including transfers subsequent to current page
  - Client or server can tear down connection
- Performance advantages:
  - Avoid overhead of connection set-up and tear-down
  - Allow TCP to learn more accurate RTT estimate
  - Allow TCP congestion window to increase
  - i.e., leverage previously discovered bandwidth
- Default in HTTP/1.1

HTTP *evolution*

- 1.0 – one object per TCP: simple but slow
- Parallel connections - multiple TCP, one object each: wastes b/w, may be svr limited, out of order
- 1.1 pipelining – aggregate retrieval time: ordered, multiple objects sharing single TCP
- 1.1 persistent – aggregate TCP overhead: lower overhead in time, increase overhead at ends (e.g., when should/do you close the connection?)

Scorecard: Getting n Small Objects

Time dominated by latency

- One-at-a-time: ~2n RTT
- Persistent: ~ (n+1)RTT
- M concurrent: ~2[n/m] RTT
- Pipelined: ~2 RTT
- Pipelined/Persistent: ~2 RTT first time, RTT later

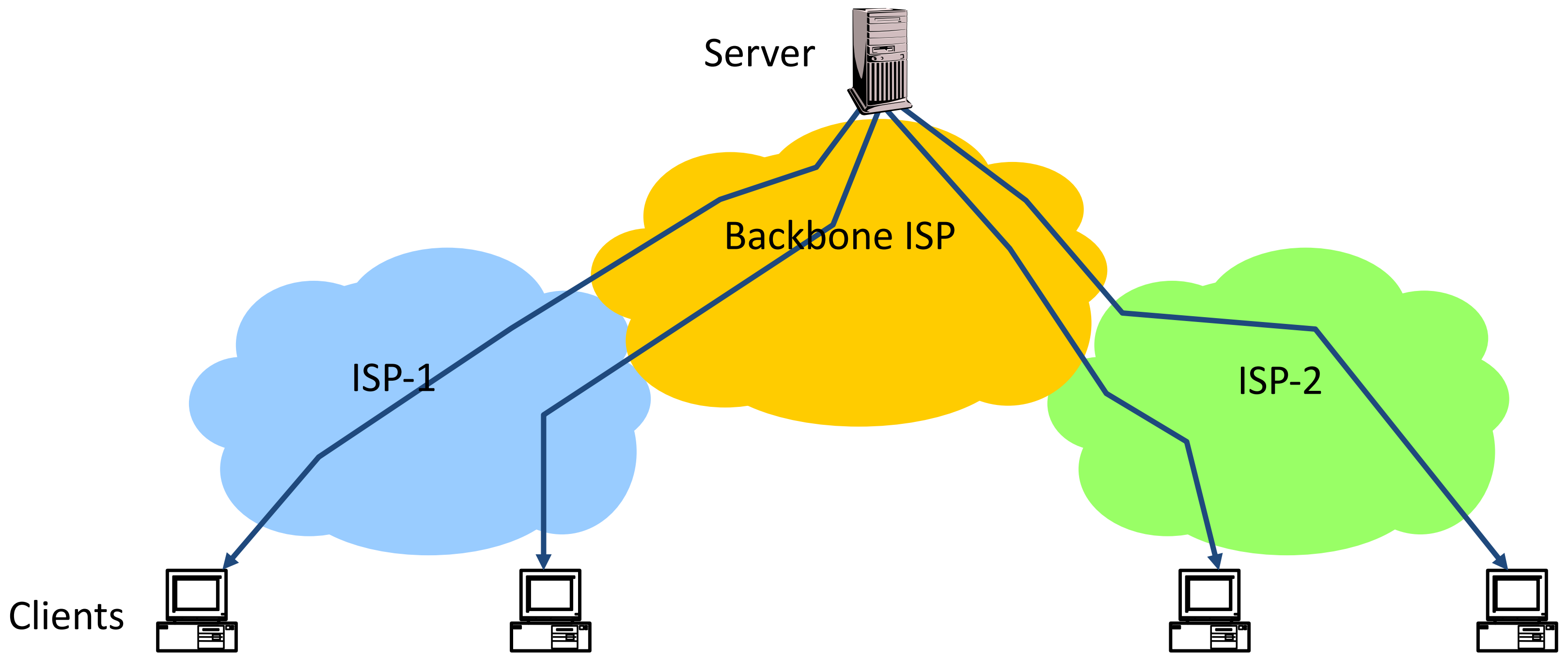
Scorecard: Getting n Large Objects

Time dominated by bandwidth

- One-at-a-time: ~ nF/B
- M concurrent: ~ [n/m] F/B
  – assuming shared with large population of users
- Pipelined and/or persistent: ~ nF/B
  – The only thing that helps is getting more bandwidth..

Improving HTTP Performance: Caching

- Many clients transfer the same information
  - Generates redundant server and network load
  - Clients experience unnecessary latency



Improving HTTP Performance:

Caching: How

- Modifier to GET requests:
  - `If-modified-since` – returns “not modified” if resource not modified since specified time
- Response header:
  - `Expires` – how long it’s safe to cache the resource
  - `No-cache` – ignore all caches; always get resource directly from server

Improving HTTP Performance:

Caching: Why

- Motive for placing content closer to client:
  - User gets better response time
  - Content providers get happier users
    - Time is money, really!
  - Network gets reduced load

- Why does caching work?
  - Exploits *locality of reference*

- How well does caching work?
  - Very well, up to a limit
  - Large overlap in content
  - But many unique requests

Improving HTTP Performance:
Caching on the Client

Example: Conditional GET Request

- Return resource only if it has changed at the server
  - Save server resources!

Request from client to server:

```
GET /~awm22/win HTTP/1.1
Host: www.cl.cam.ac.uk
User-Agent: Mozilla/4.03
If-Modified-Since: Sun, 27 Aug 2006 22:25:50 GMT
<CRLF>
```

- How?
  - Client specifies “if-modified-since” time in request
  - Server compares this against “last modified” time of desired resource
  - Server returns “304 Not Modified” if resource has not changed
  - …. or a “200 OK” with the latest version otherwise

Improving HTTP Performance:

Caching with Reverse Proxies

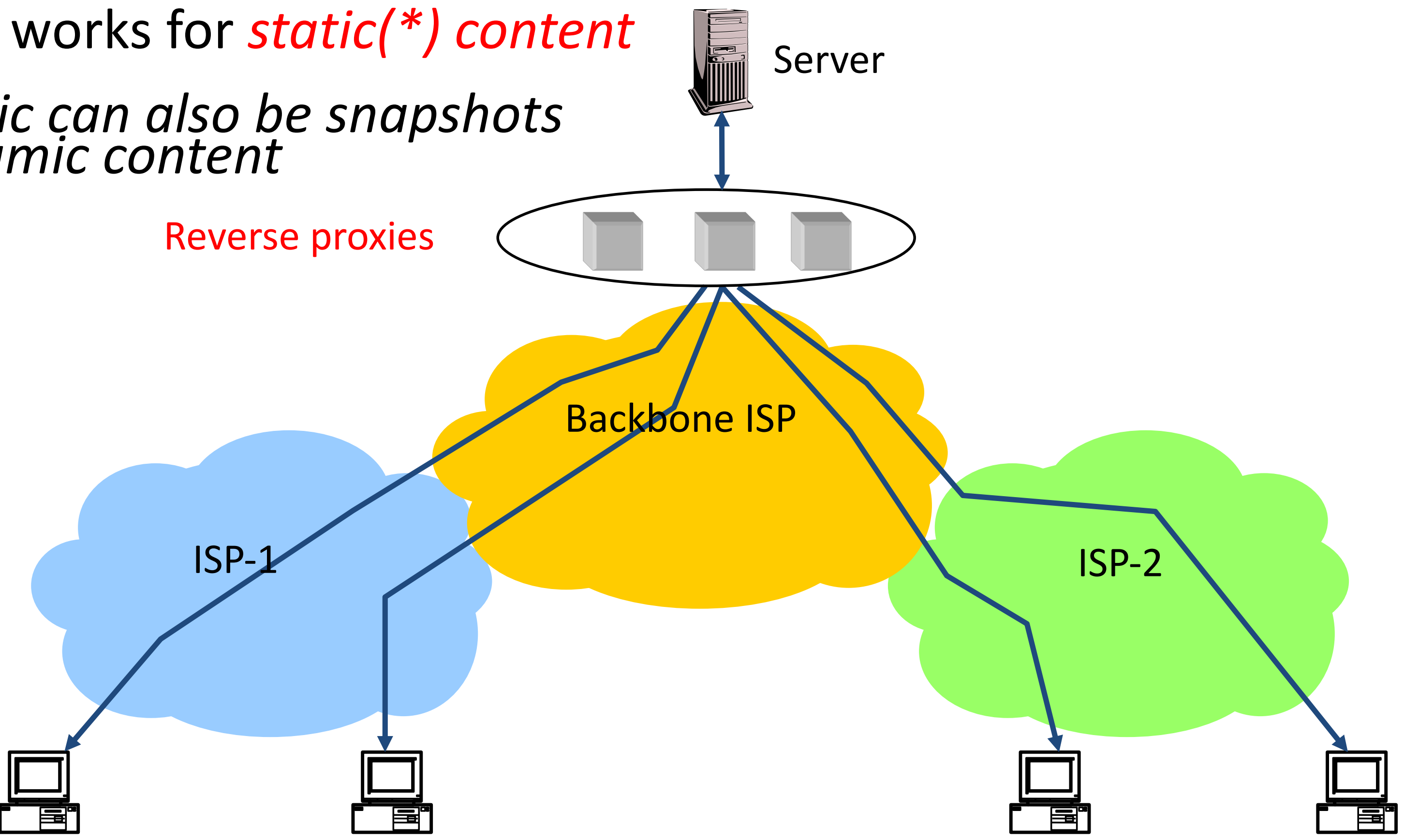
Cache documents close to **server**

→ decrease server load

- Typically done by content providers

- Only works for *static(*) content*

(*) static can also be snapshots of dynamic content

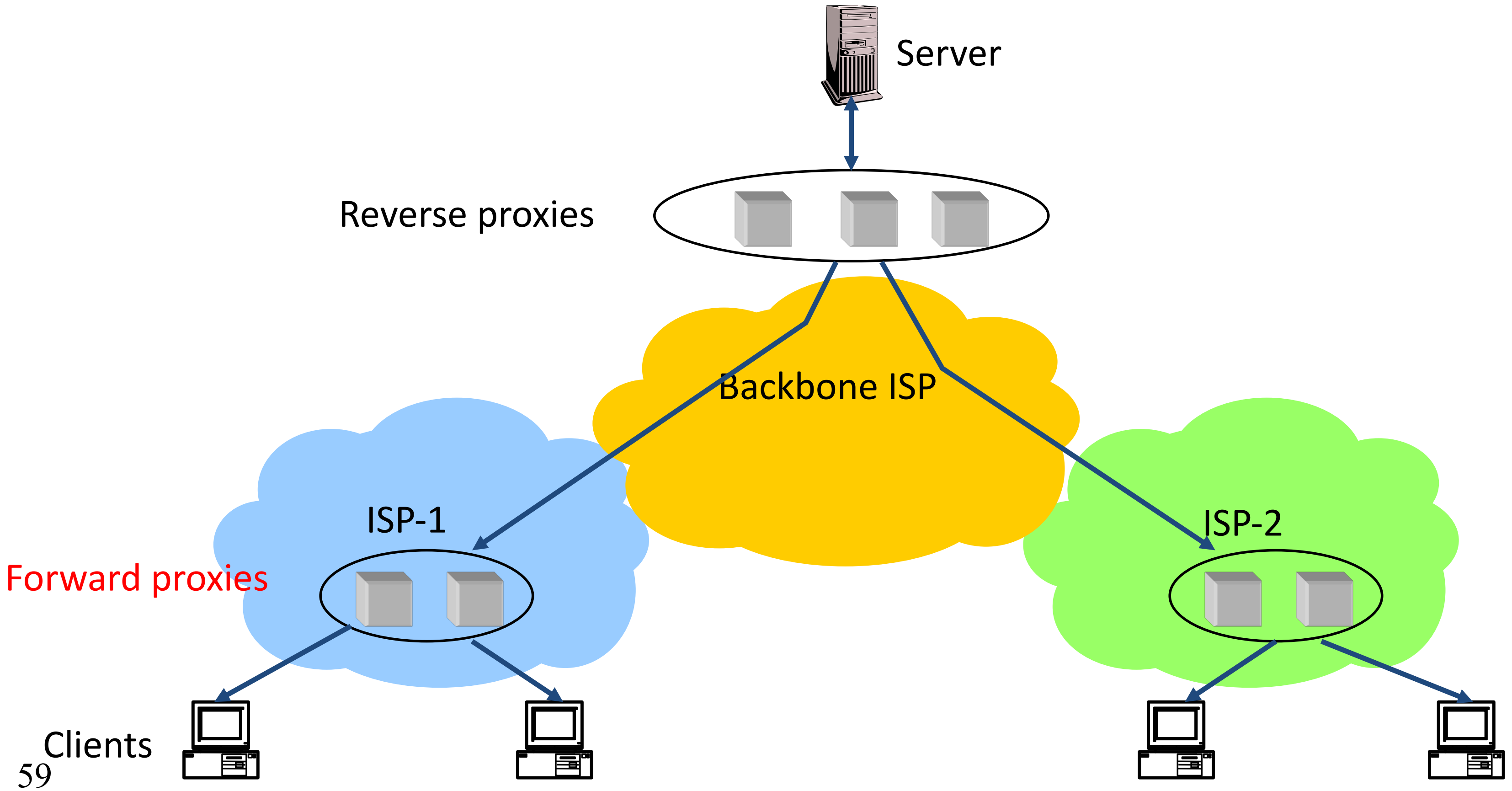


Improving HTTP Performance:

Caching with Forward Proxies

Cache documents close to **clients**
→ reduce network traffic and decrease latency

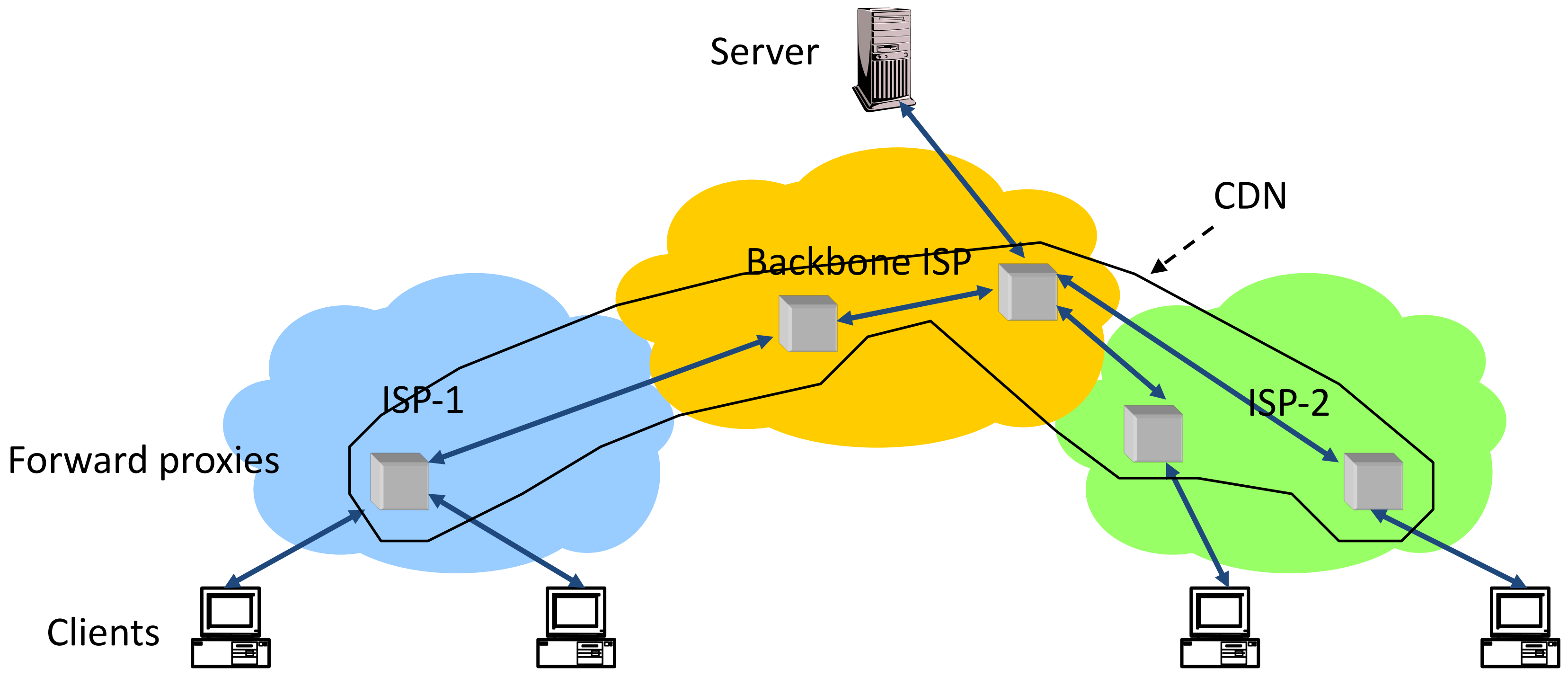
- Typically done by ISPs or corporate LANs



Improving HTTP Performance:
Caching w/ Content Distribution Networks

- Integrate forward and reverse caching functionality
  - One overlay network (usually) administered by one entity
  - *e.g.,* Akamai
- Provide document caching
  - **Pull:** Direct result of clients' requests
  - **Push:** Expectation of high access rate
- Also do some processing
  - Handle *dynamic* web pages
  - *Transcoding*
  - *Maybe do some security function – watermark IP*

Improving HTTP Performance:
Caching with CDNs (cont.)



Improving HTTP Performance:
CDN Example – Akamai

- Akamai creates new domain names for each client content provider.
  - e.g., *a128.g.akamai.net*
- The CDN's DNS servers are authoritative for the new domains
- The client content provider modifies its content so that embedded URLs reference the new domains.
  - "Akamaize" content
  - e.g.: *http://www.bbc.co.uk/popular-image.jpg* becomes *http://a128.g.akamai.net/popular-image.jpg*
- *Requests now sent to CDN's infrastructure…*

Hosting: Multiple Sites Per Machine

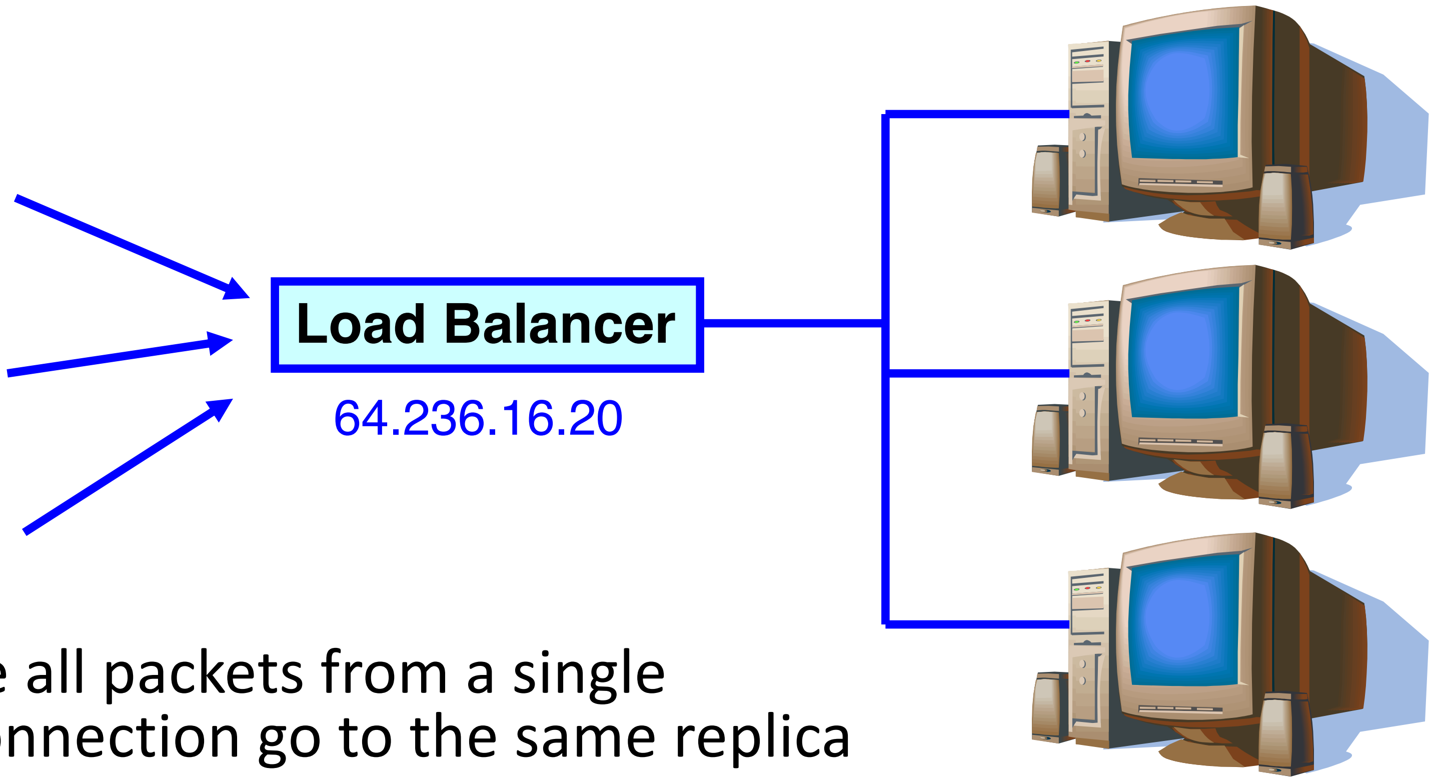
- Multiple Web sites on a single machine
  - Hosting company runs the Web server on behalf of multiple sites (*e.g*., www.foo.com and www.bar.com)
- Problem: `GET /index.html`
  - `www.foo.com/index.html` or `www.bar.com/index.html`?
- Solutions:
  - Multiple server processes on the same machine
    - Have a separate IP address (or port) for each server
  - Include site name in HTTP request
    - Single Web server process with a single IP address
    - Client includes “Host” header (*e.g.,* `Host: www.foo.com`)
    - *Required header* with HTTP/1.1

Hosting: Multiple Machines Per Site

- Replicate popular Web site across many machines
  - Helps to handle the load
  - Places content closer to clients
- Helps when content isn't cacheable
- Problem: Want to direct client to particular replica
  - Balance load across server replicas
  - Pair clients with nearby servers

Multi-Hosting at Single Location

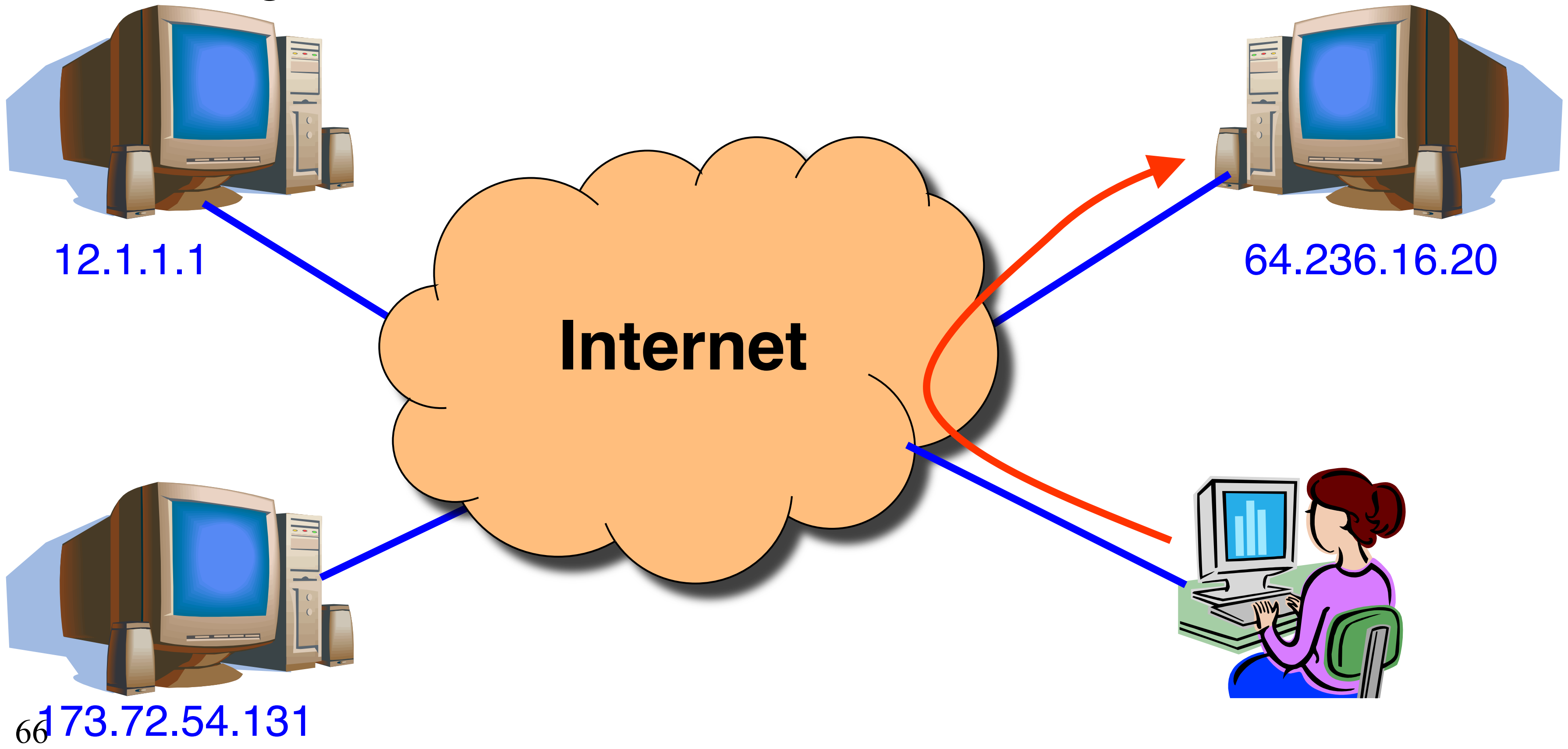
- Single IP address, multiple machines
  - Run multiple machines behind a single IP address



  - Ensure all packets from a single TCP connection go to the same replica

Multi-Hosting at Several Locations

- Multiple addresses, multiple machines
  - Same name but different addresses for all of the replicas
  - Configure DNS server to return *closest* address



CDN examples round-up

- CDN using DNS

  DNS has information on loading/distribution/location

- CDN using anycast

  same address from DNS name but local routes

- CDN based on rewriting HTML URLs

  (akami example just covered – akami uses DNS too)

After HTTP/1.1

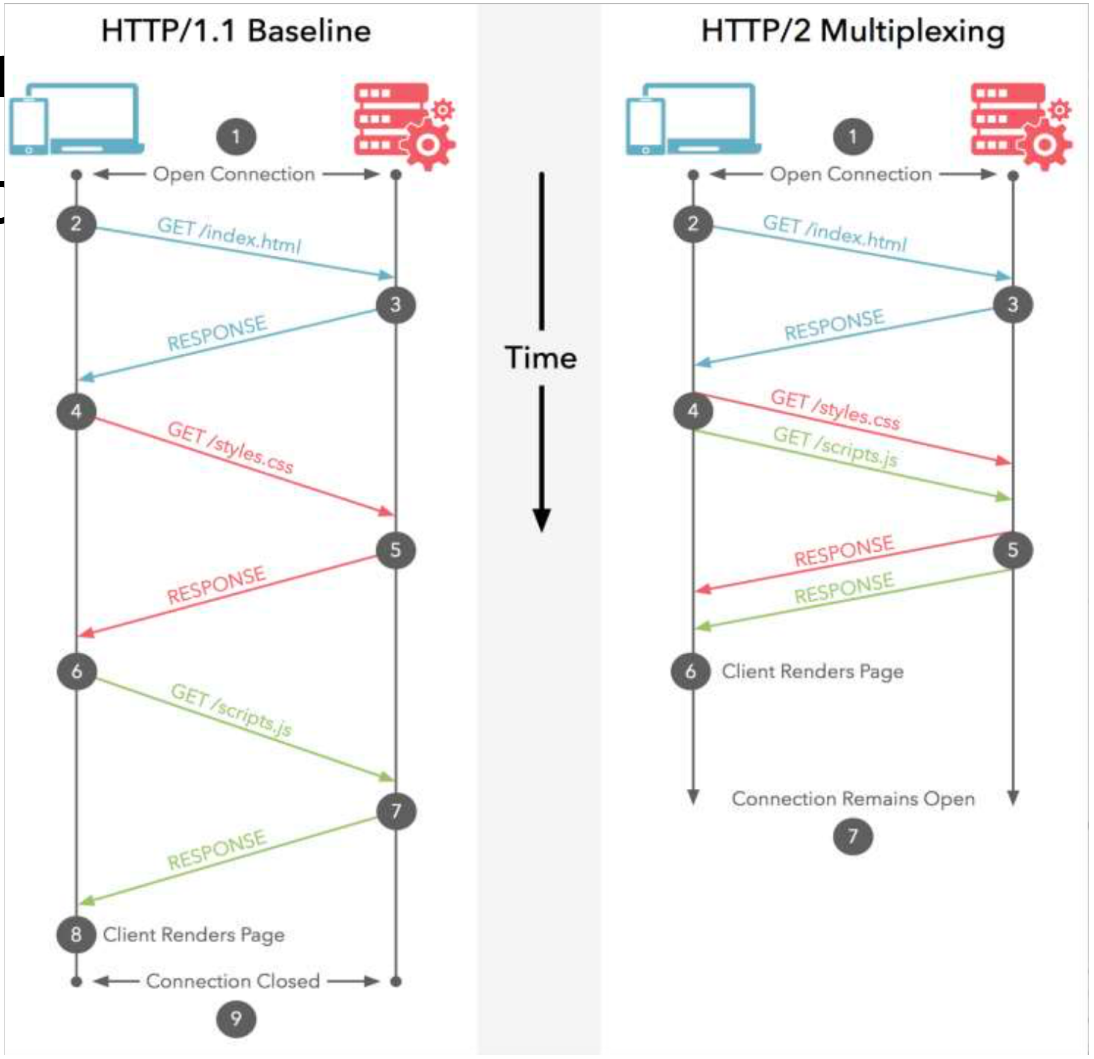
SPDY (speedy) and its moral successor HTTP/2

- Binary protocol
  - More efficient to parse
  - More compact on the wire
  - Much less error prone as compared
  - to textual protocols

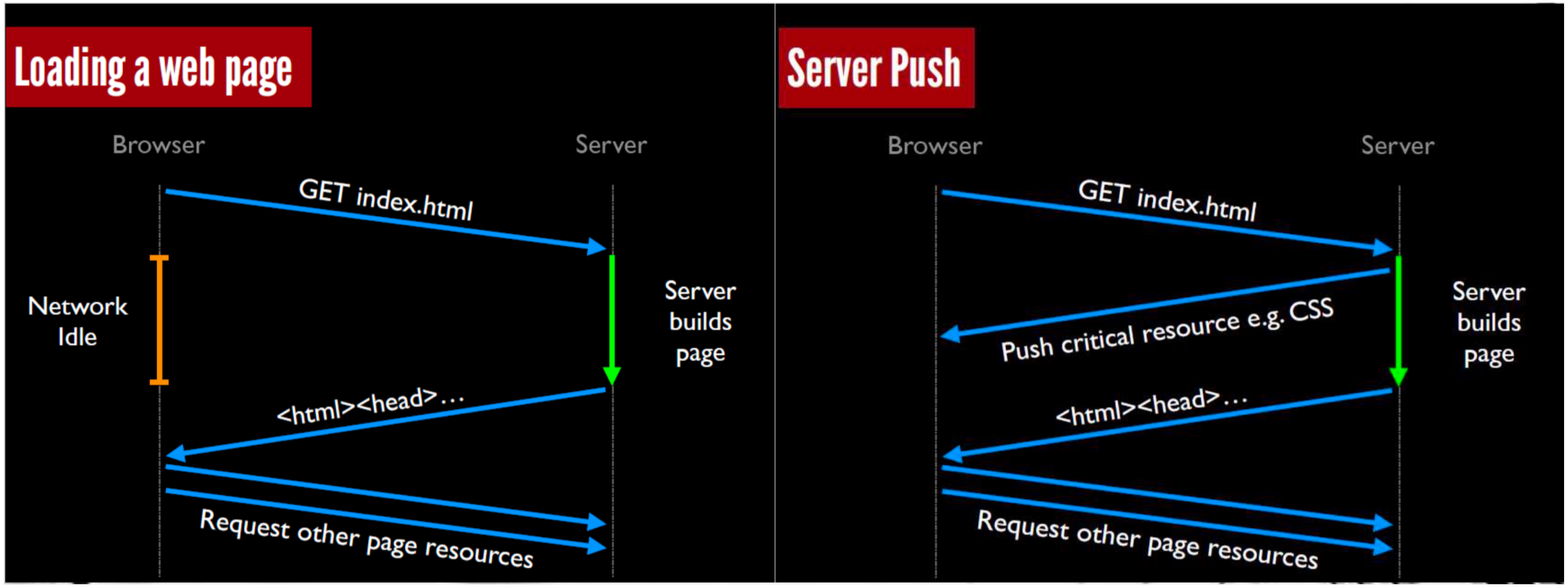
After HTTP/1.1

SPDY (speedy) a

- Binary protoco
- Multiplexing
  - Interleaved



After HTTP/1.1



- Server Push
  - Proactively push stuff to client that it will need

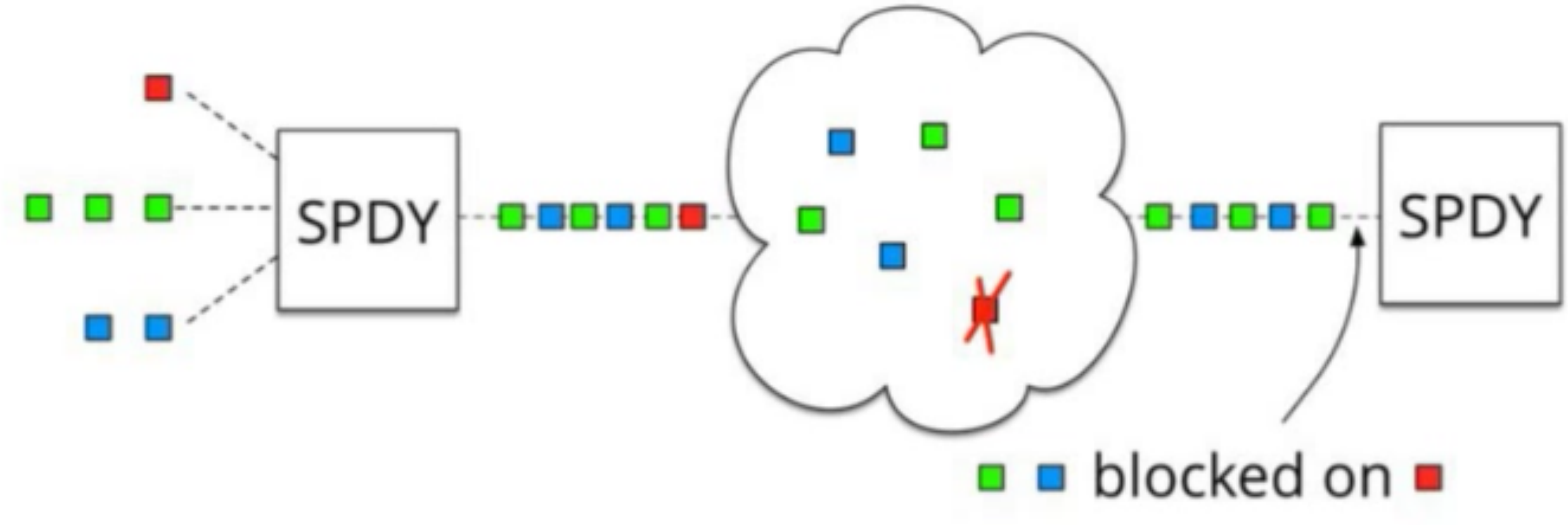
After HTTP/1.1

SPDY (speedy) and its moral successor HTTP/2

- Binary protocol
- Multiplexing
- Priority control over Frames
- Header Compression
- Server Push

SPDY

- SPDY + HTTP/2: One single TCP connection instead of multiple
- Downside: Head of line blocking
- In TCP, packets need to be processed in



Add QUIC and stir…
Quick UDP Internet Connections

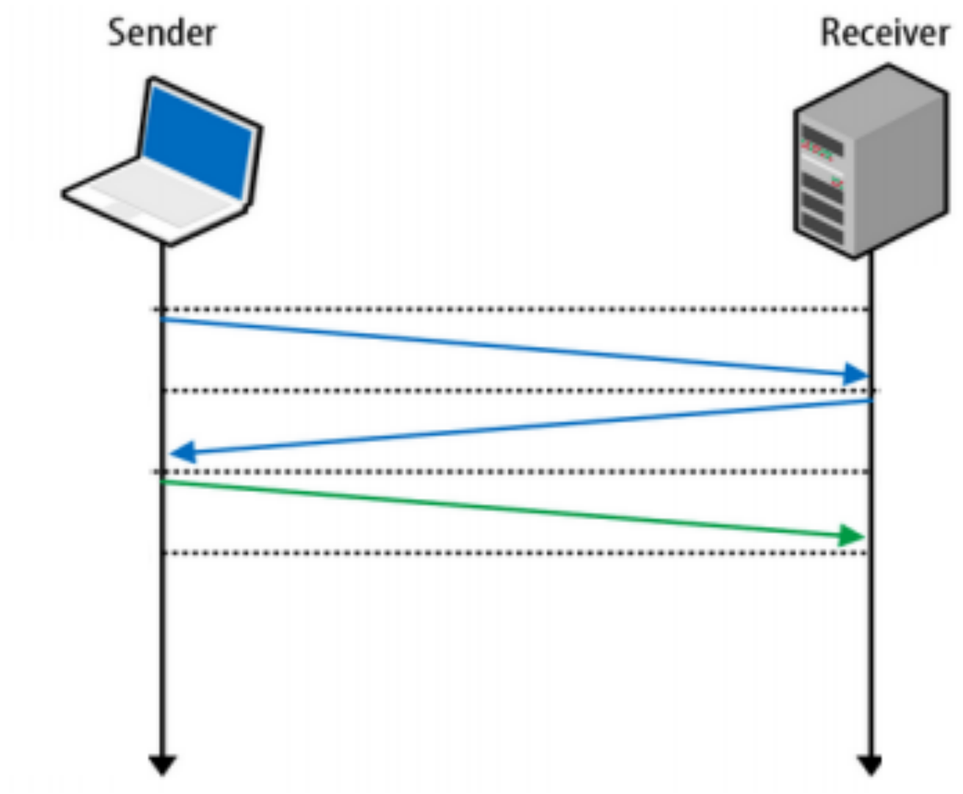
Objective: Combine speed of UDP protocol with TCP’s reliability

- Very hard to make changes to TCP
- *Faster to implement new protocol on top of UDP*
- Roll out features in TCP if they prove theory

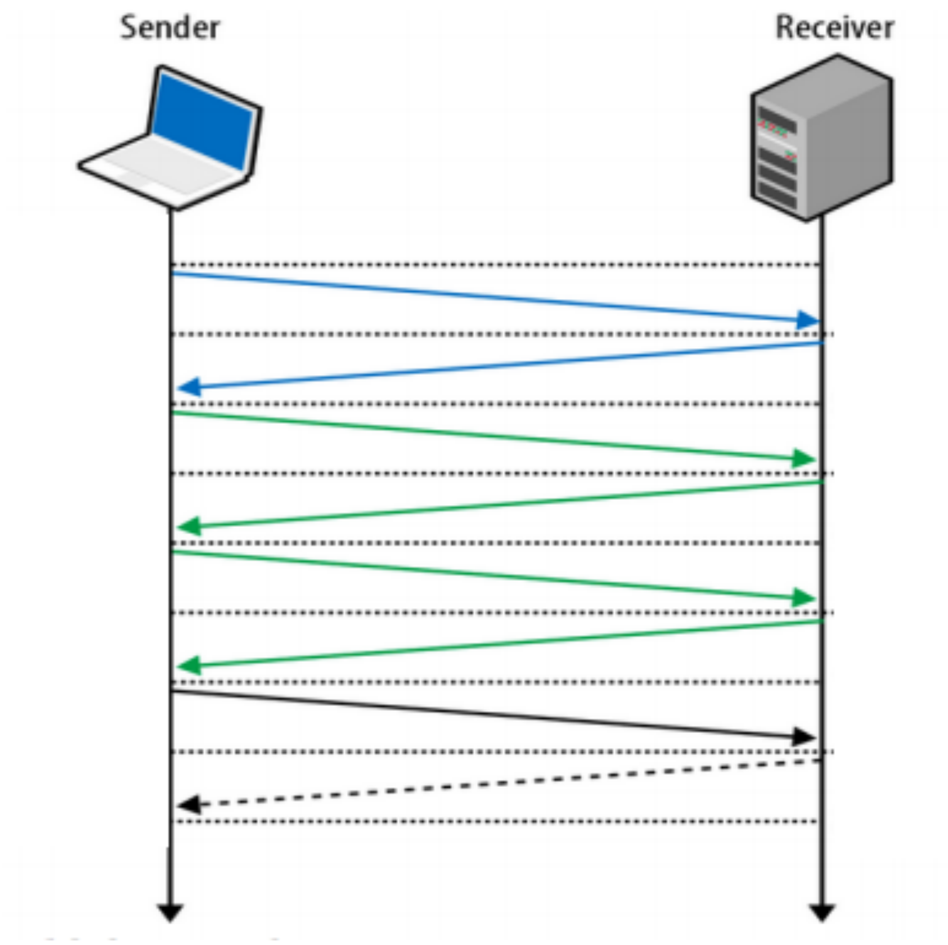
QUIC:

- Reliable transport over UDP (seriously)
- Uses FEC
- Default crypto
- Restartable connections

3-Way Handshake



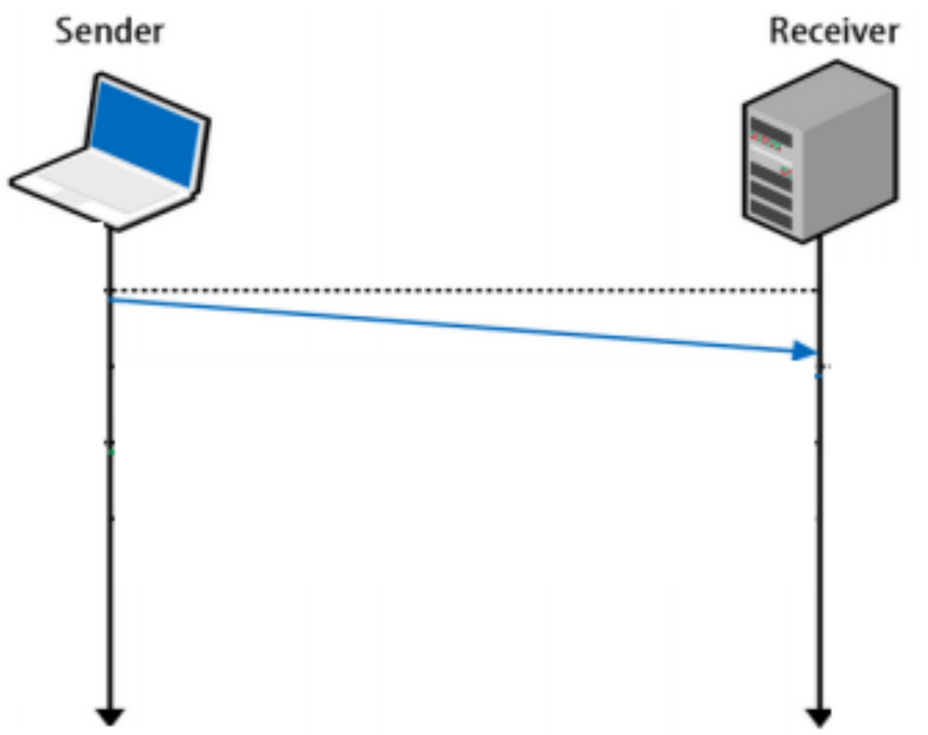
Without TLS



With TLS

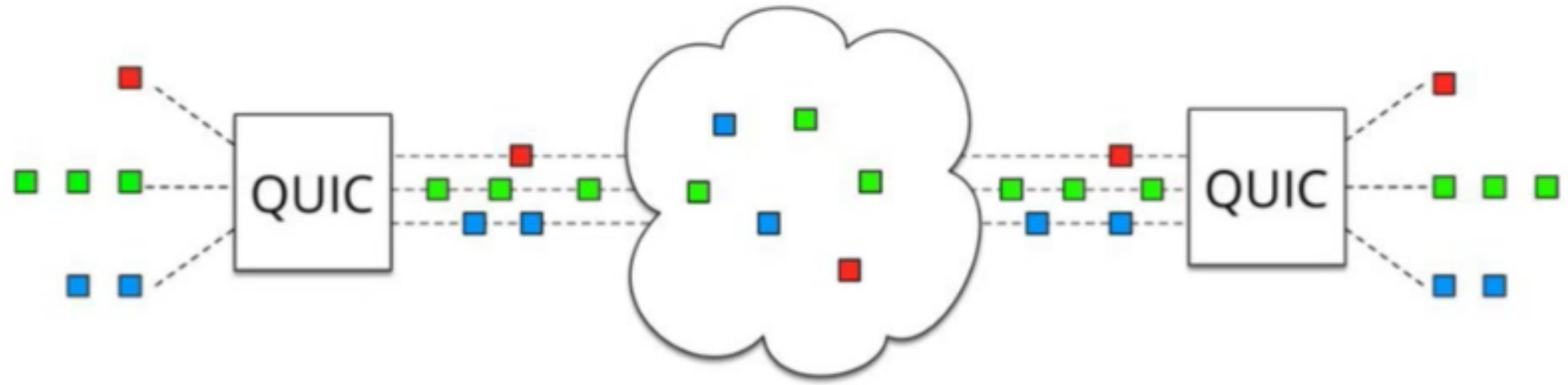
UDP

- Fire and forget
  - Less time spent to validate packets
  - Downside - no reliability, has to be built on top of UDP



QUIC

- UDP does NOT depend on order of arriving packets
- Lost packets will only impact an individual resource, e.g., CSS or JS file.
- QUIC is combining best parts of HTTP/2 over UDP:
  - Multiplexing on top of non-blocking transport protocol



QUIC – more than just UDP

- QUIC outshines TCP under poor network conditions, shaving a full second off the Google Search page load time for the slowest 1% of connections.

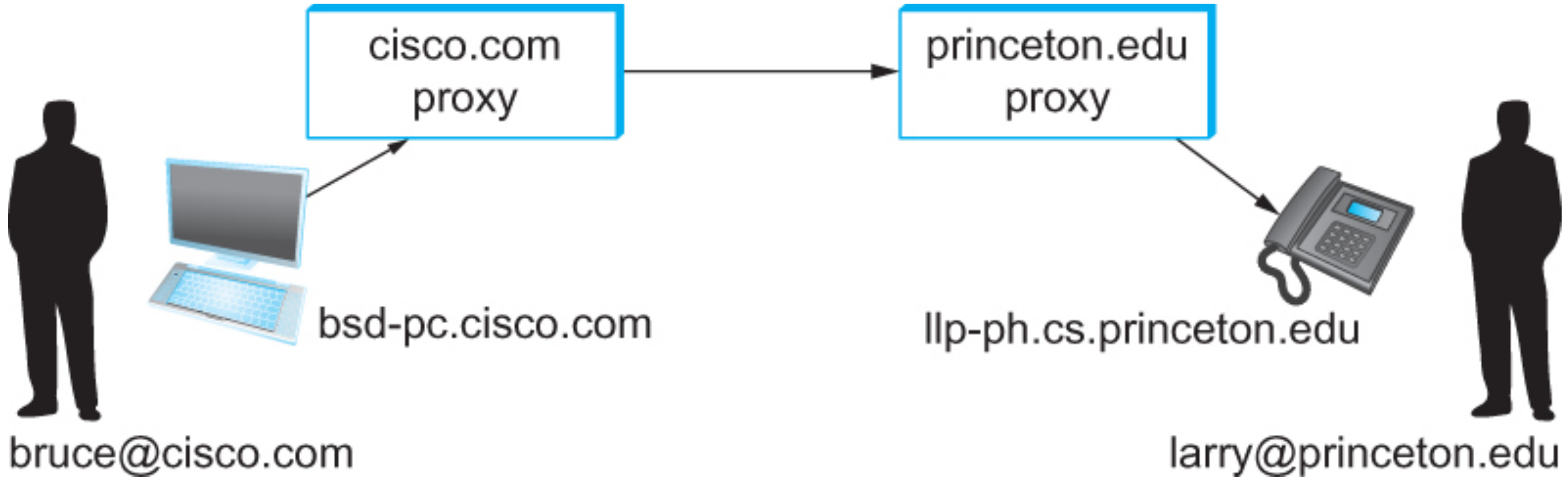
- These benefits are even more apparent for video services like YouTube. Users report 30% fewer rebuffers when watching videos over QUIC.

SIP – Session Initiation Protocol

Session?

Anyone smell an OSI / ISO standards document burning?

SIP - VoIP



Establishing communication through SIP proxies.

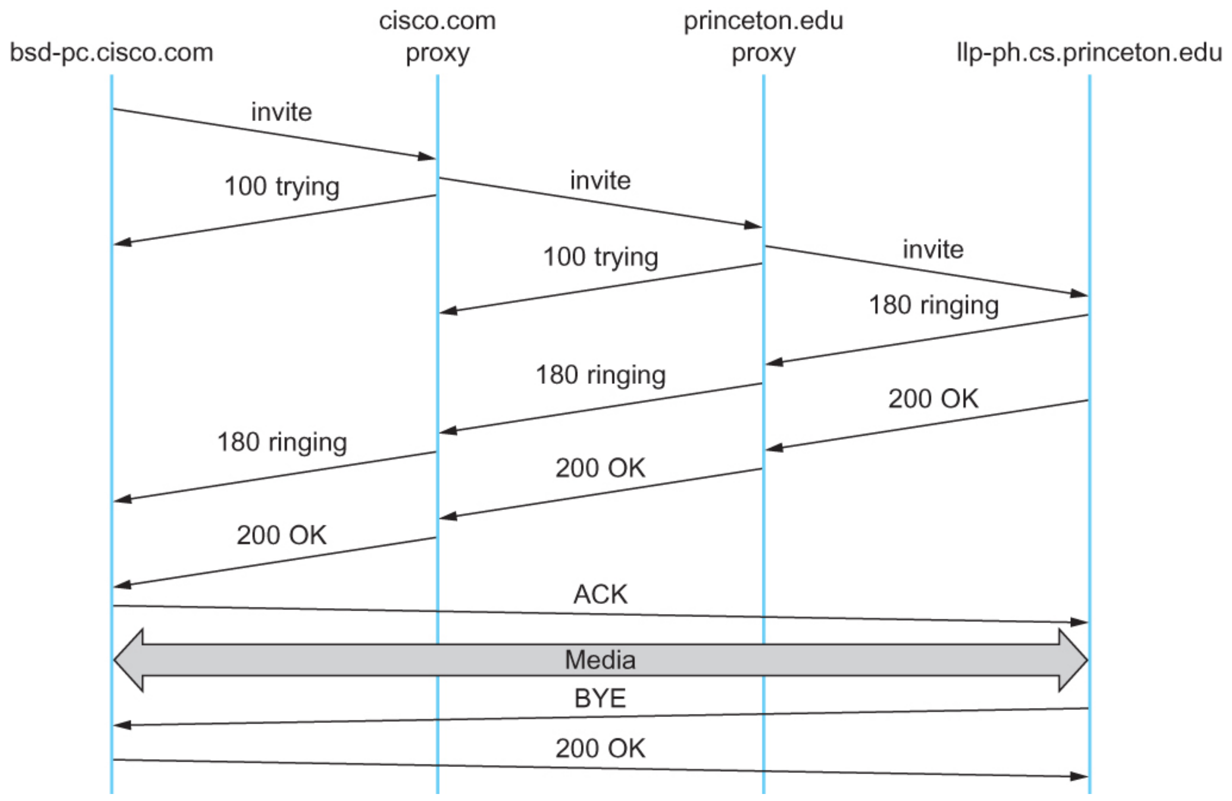
SIP?

- SIP – bringing the fun/complexity of telephony to the Internet
  - User location
  - User availability
  - User capabilities
  - Session setup
  - Session management
    - (e.g. "call forwarding")

H.323 – ITU

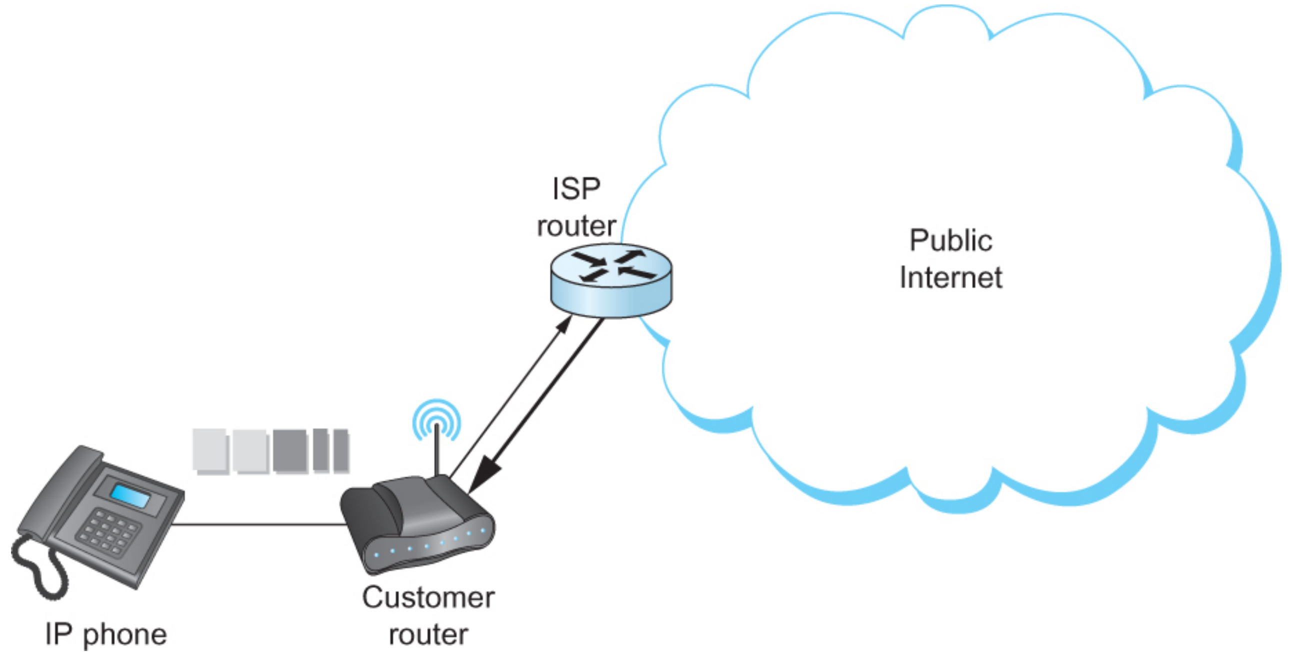
- Why have one standard when there are at least two….
- The full H.323 is hundreds of pages
  - The protocol is known for its complexity – an ITU hallmark
- SIP is not much better
  - IETF grew up and became the ITU….

Multimedia Applications



Message flow for a basic SIP session

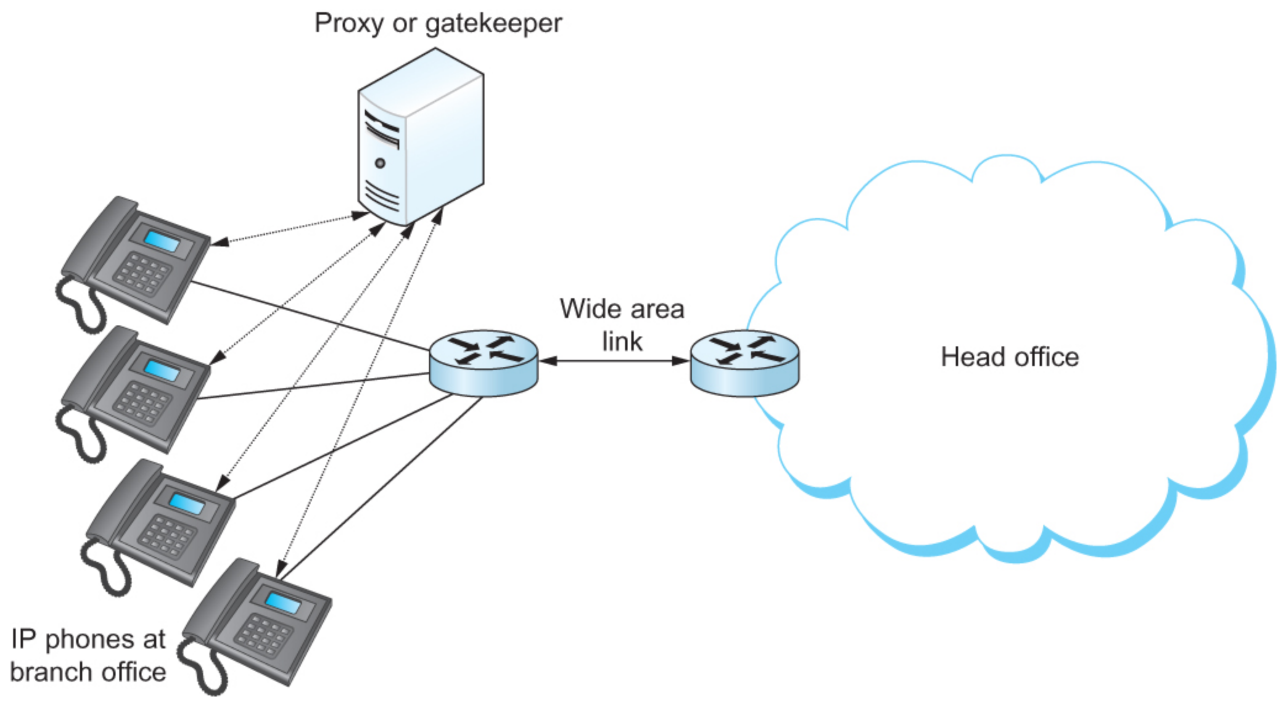
The (still?) missing piece:
Resource Allocation for Multimedia Applications



I can 'differentiate' VoIP from data but…
I can only control data going into the Internet

Multimedia Applications

- Resource Allocation for Multimedia Applications



Admission control using session control protocol.

Resource Allocation for Multimedia Applications

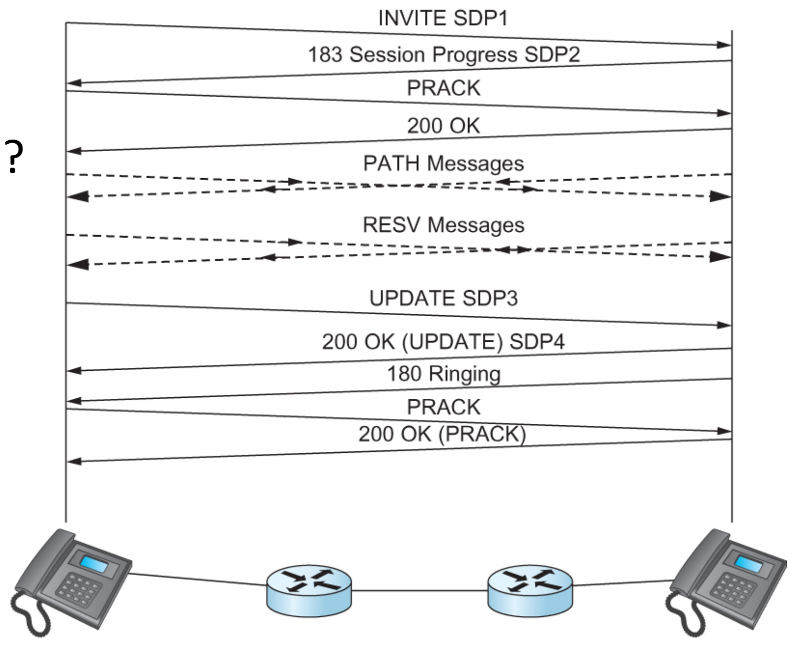
Coming soon… ~~1995~~

~~2000~~

~~2010~~

who are we kidding??

Co-ordination of SIP signaling and resource reservation.



So where does it happen?

Inside single institutions or *domains of control…..*

(Universities, Hospitals, big corp…)

What about my aDSL/CABLE/etc it combines voice and data?

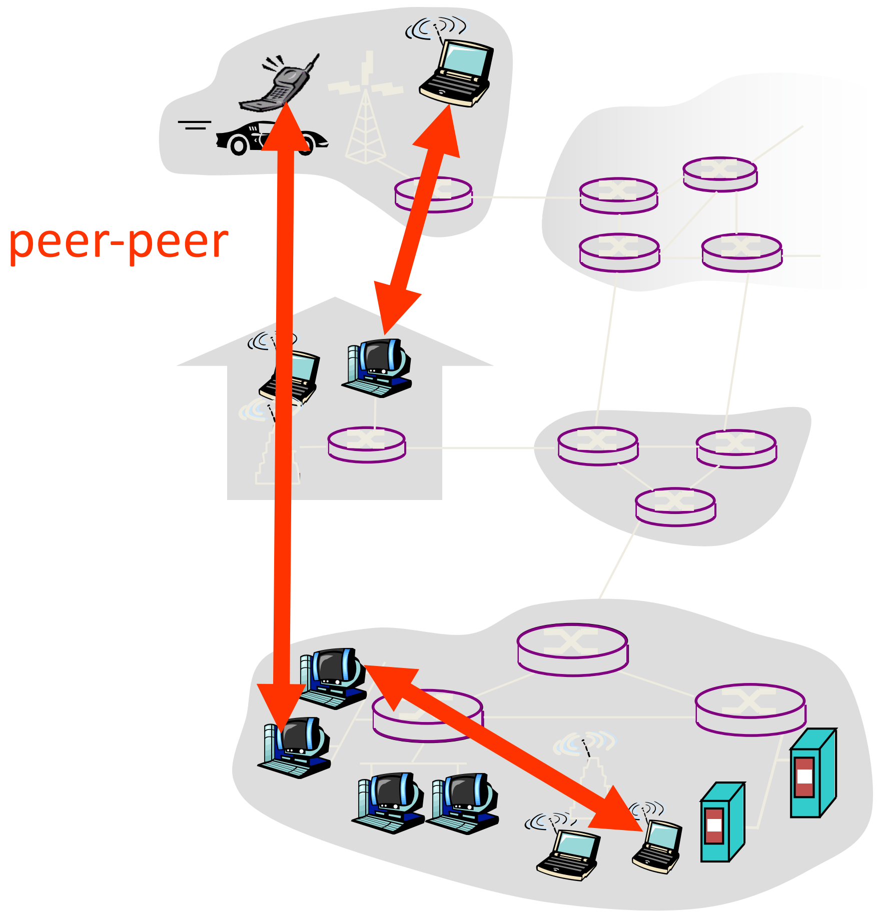
Phone company **controls** the multiplexing on the line and throughout their own network too……

P2P – efficient network use that annoys the ISP

Pure P2P architecture

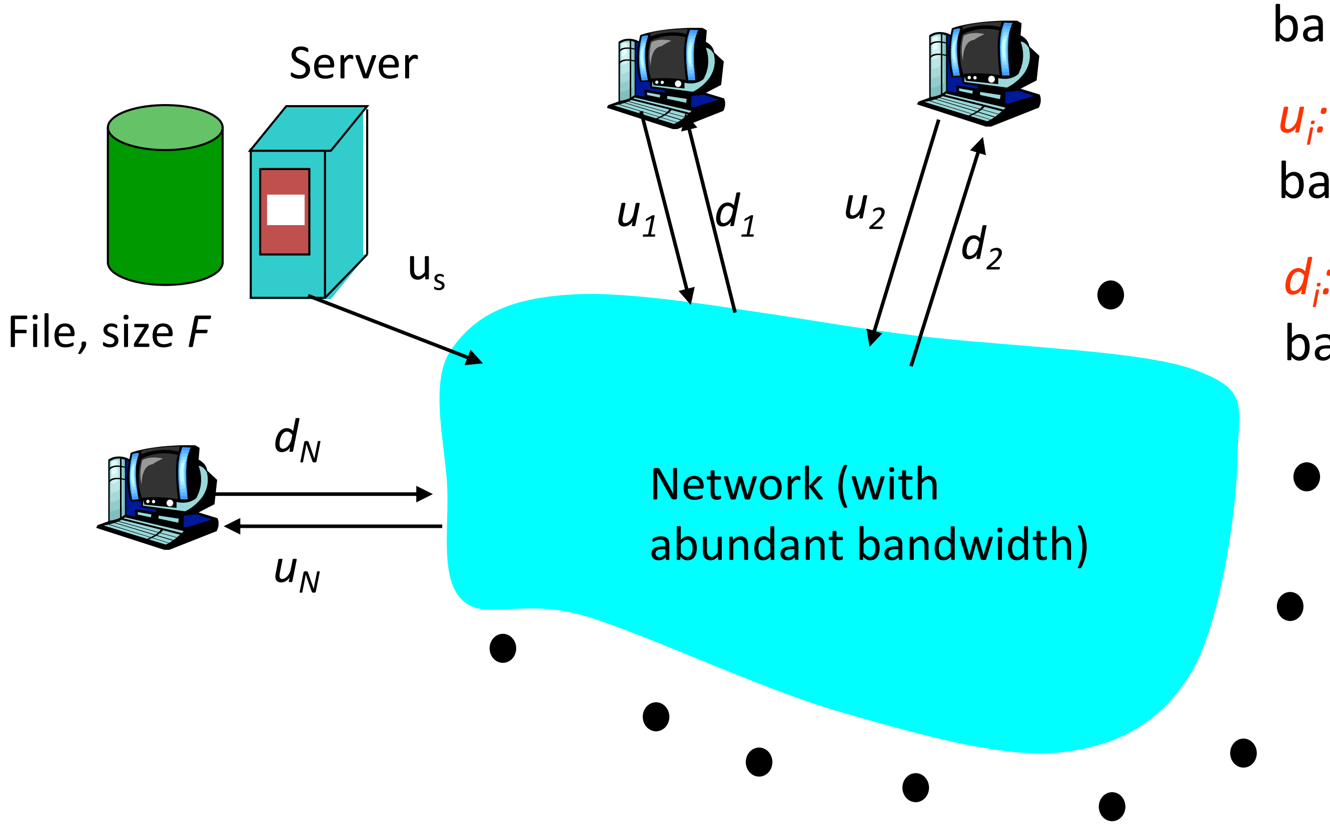
- *no* always-on server
- arbitrary end systems directly communicate
- peers are intermittently connected and change IP addresses

- <u>Three topics:</u>
  - File distribution
  - Searching for information
  - Case Study: Skype



File Distribution: Server-Client vs P2P

Question : How much time to distribute file from one server to *N peers*?



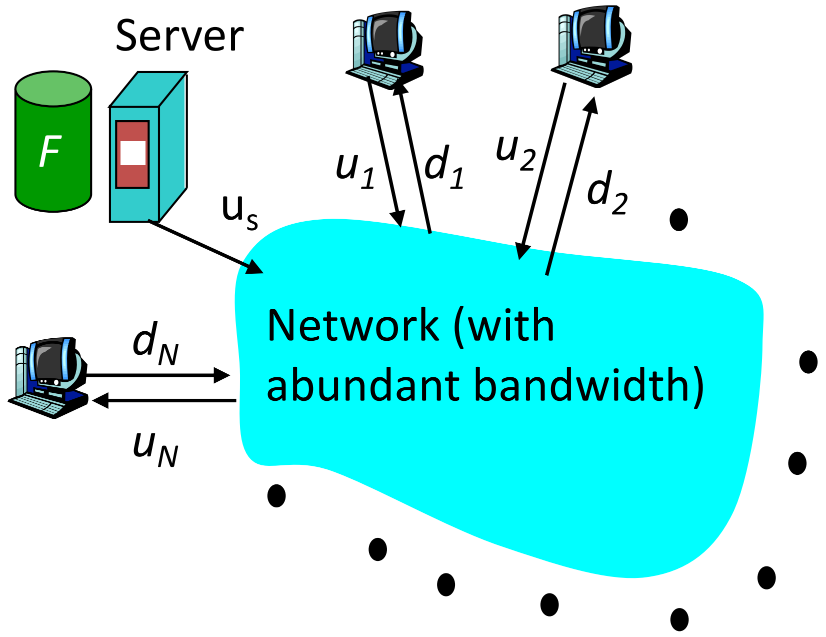
u_s: server upload bandwidth

u_i: peer i upload bandwidth

d_i: peer i download bandwidth

File distribution time: server-client

- server sequentially sends N copies:
  - NF/u_s time
- client i takes F/d_i time to download

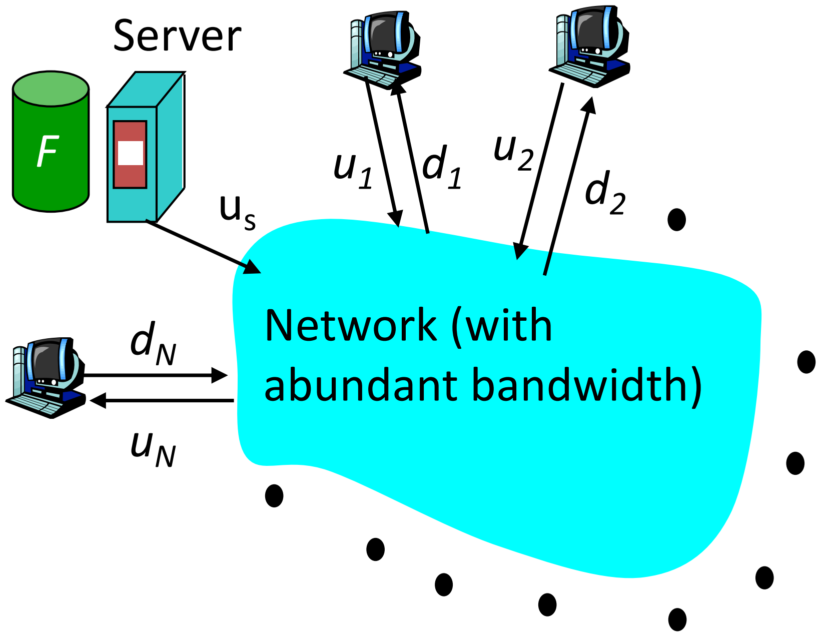


Time to distribute *F* to *N* clients using client/server approach $= d_{cs} = \max \left\{ NF/u_s, F/\min_i(d_i) \right\}$

increases linearly in N (for large N)

File distribution time: P2P

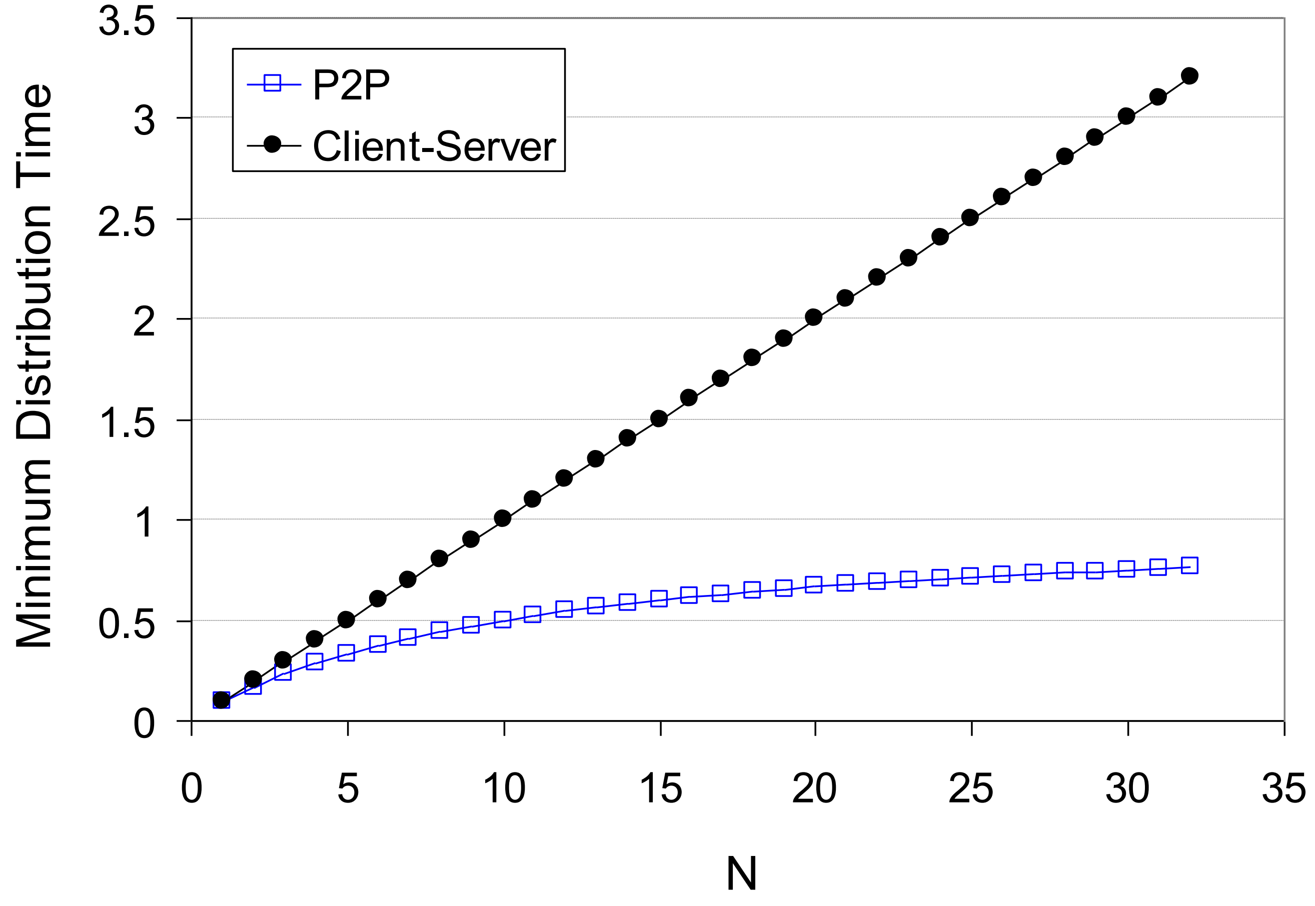
- server must send one copy: F/u_s time
- client i takes F/d_i time to download
- NF bits must be downloaded (aggregate)
  - r fastest possible upload rate: $u_s + \sum u_i$



$$d_{P2P} = \max \{ F/u_s, F/\min_i(d_i) , NF/(u_s + \sum u_i) \}$$

Server-client vs. P2P: example

Client upload rate = u, F/u = 1 hour, u_s = 10u, $d_{min} \geq u_s$



Distributed Hash Table (DHT)

- DHT = distributed P2P database
- Database has (key, value) pairs;
  - key: ss number; value: human name
  - key: content type; value: IP address
- Peers query DB with key
  - DB returns values that match the key
- Peers can also insert (key, value) peers

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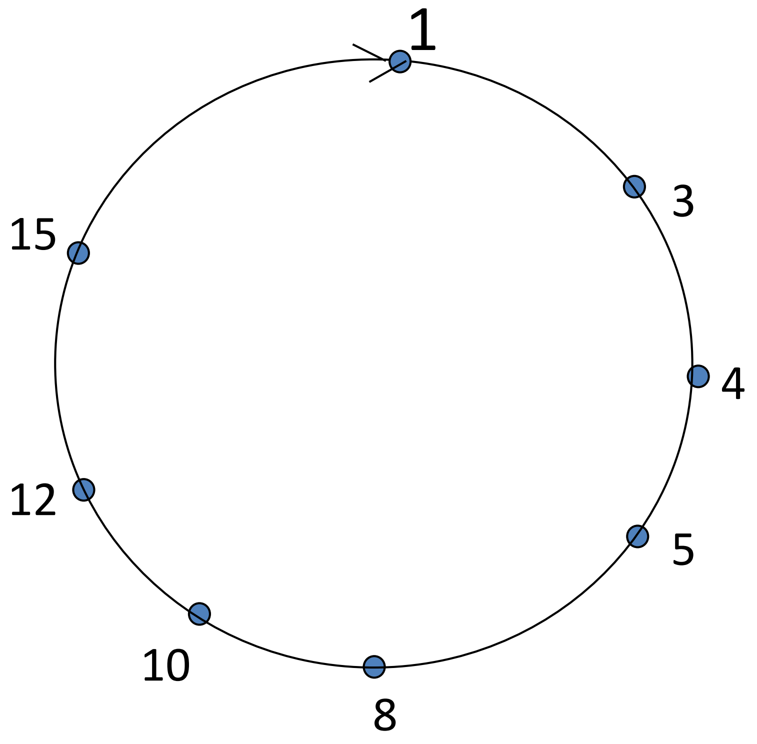
DHT Identifiers

- Assign integer identifier to each peer in range $[0,2^n-1]$.
  - Each identifier can be represented by n bits.
- Require each key to be an integer in same range.
- To get integer keys, hash original key.
  - eg, key = h("Game of Thrones season 29")
  - This is why they call it a distributed "hash" table

How to assign keys to peers?

- Central issue:
  - Assigning (key, value) pairs to peers.
- Rule: assign key to the peer that has the closest ID.
- Convention in lecture: closest is the immediate successor of the key.
- Ex: n=4; peers: 1,3,4,5,8,10,12,14;
  - key = 13, then successor peer = 14
  - key = 15, then successor peer = 1

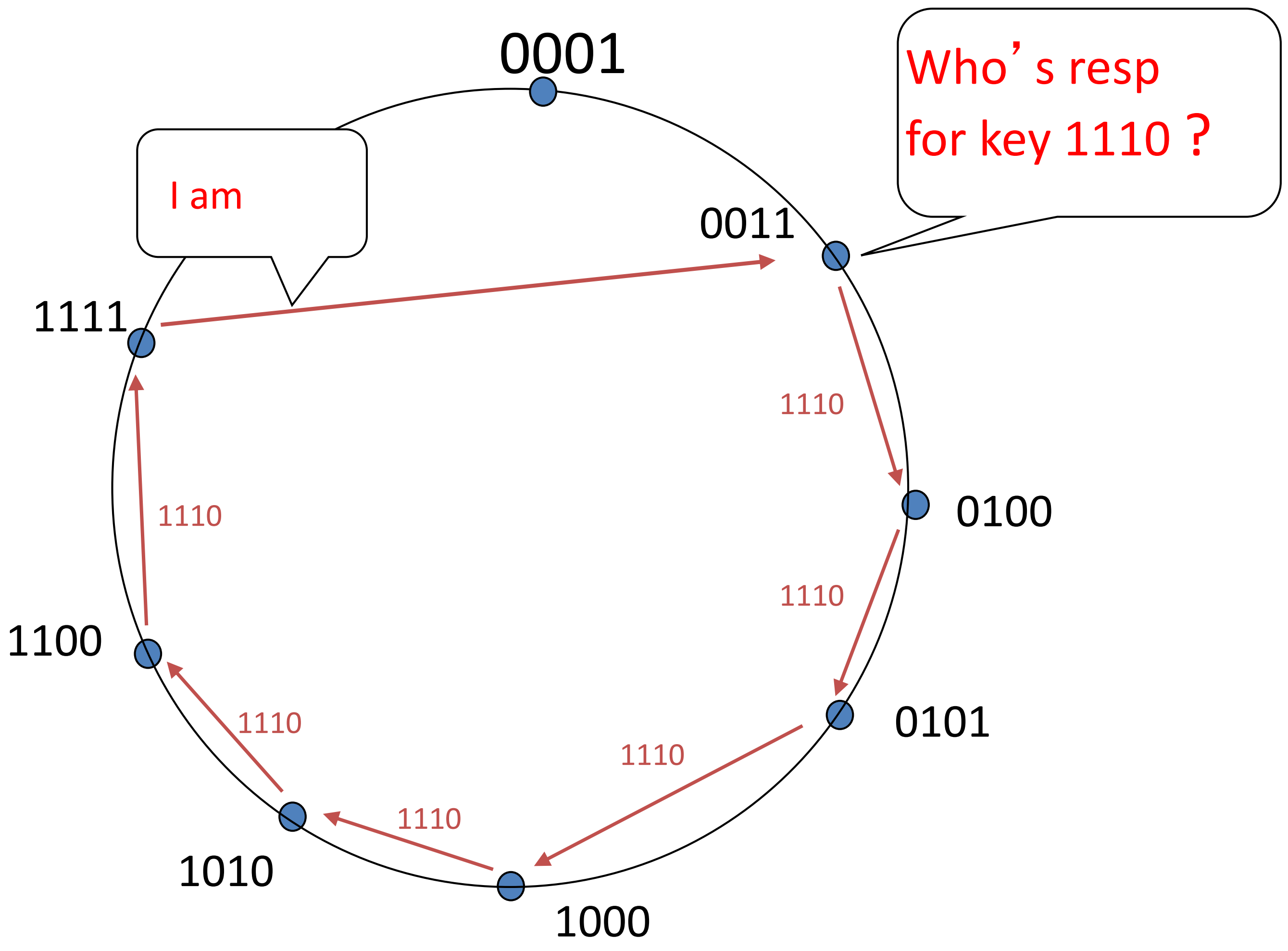
Circular DHT (1)



- Each peer *only* aware of immediate successor and predecessor.
- "Overlay network"

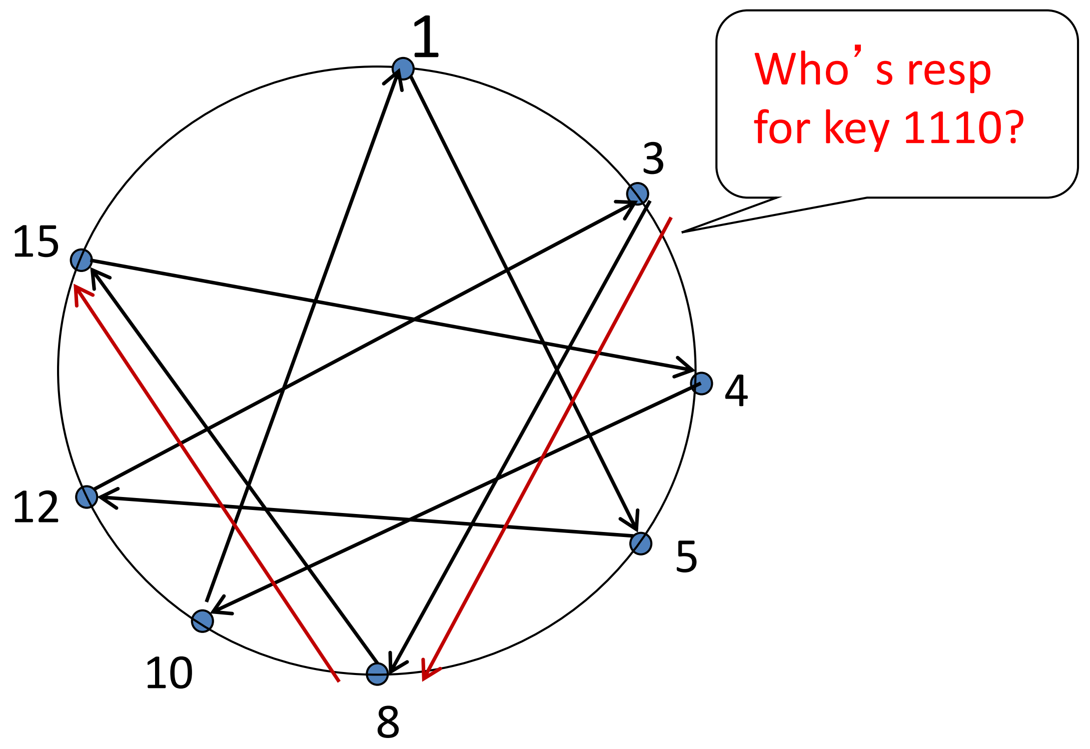
Circle DHT (2)

O(N) messages on avg to resolve query, when there are N peers



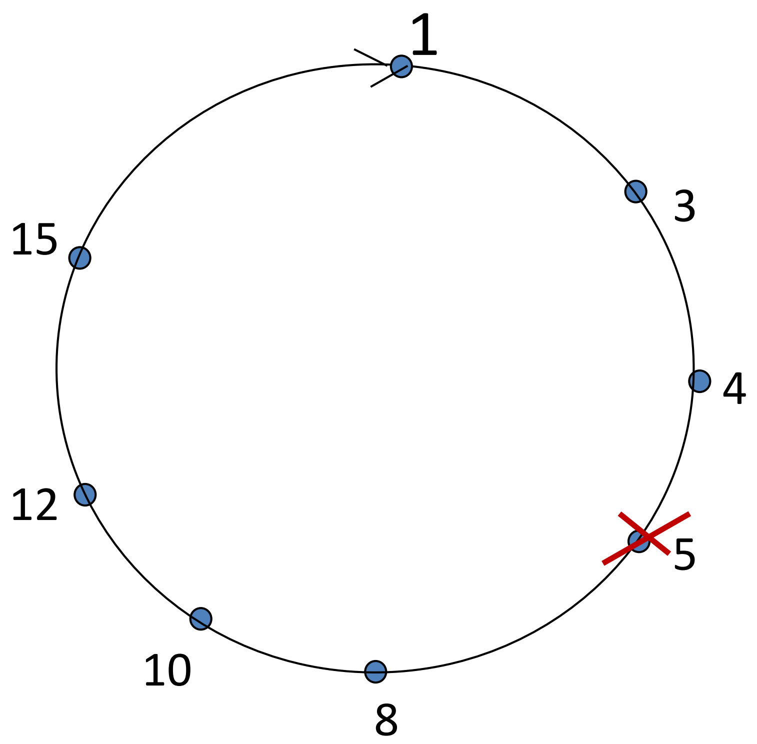
Define <u>closest</u> as closest successor

Circular DHT with Shortcuts



- Each peer keeps track of IP addresses of predecessor, successor, short cuts.
- Reduced from 6 to 2 messages.
- Possible to design shortcuts so O(log N) neighbors, O(log N) messages in query

Peer Churn



•To handle peer churn, require each peer to know the IP address of its two successors.
• Each peer periodically pings its two successors to see if they are still alive.

- Peer 5 abruptly leaves
- Peer 4 detects; makes 8 its immediate successor; asks 8 who its immediate successor is; makes 8's immediate successor its second successor.
- What if peer 13 wants to join?

Summary.

- Apps need protocols too
- We covered examples from
  - Traditional Applications (web)
  - Scaling and Speeding the web (CDN/Cache tricks)
- Infrastructure Services (DNS)
  - Cache and Hierarchy
- Multimedia Applications (SIP)
  - Extremely hard to do better than worst-effort
- P2P Network examples