

# Computer Networking

Michaelmas/Lent Term

M/W/F 11:00-12:00

LT1 in Gates Building

## Slide Set 3

Andrew W. Moore

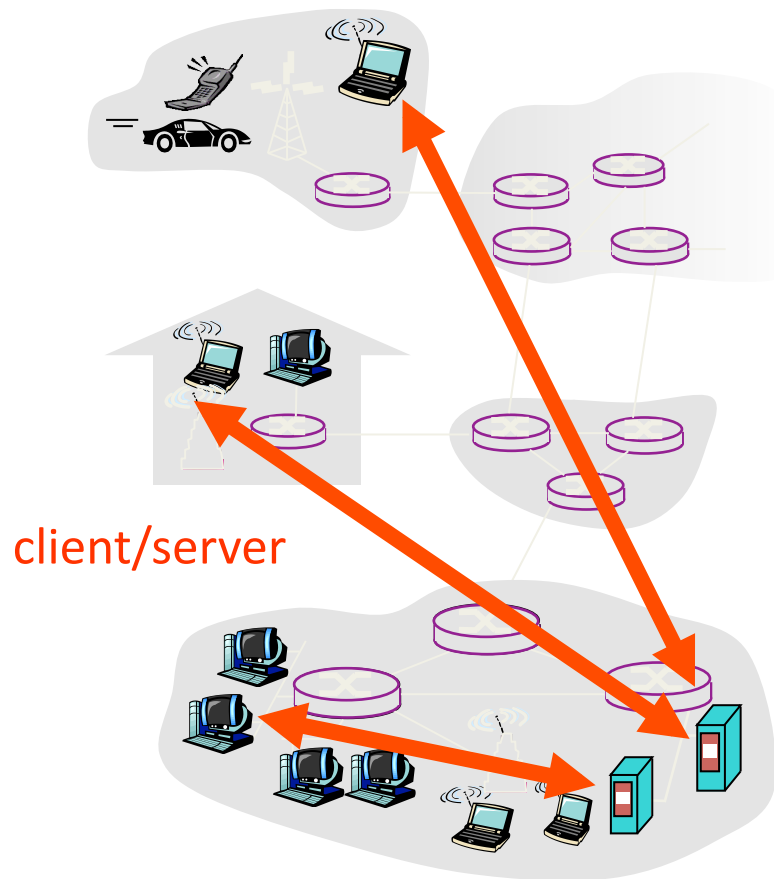
[andrew.moore@cl.cam.ac.uk](mailto:andrew.moore@cl.cam.ac.uk)

2014-2015

# Topic 6 – Applications

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

# Client-server architecture



## server:

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

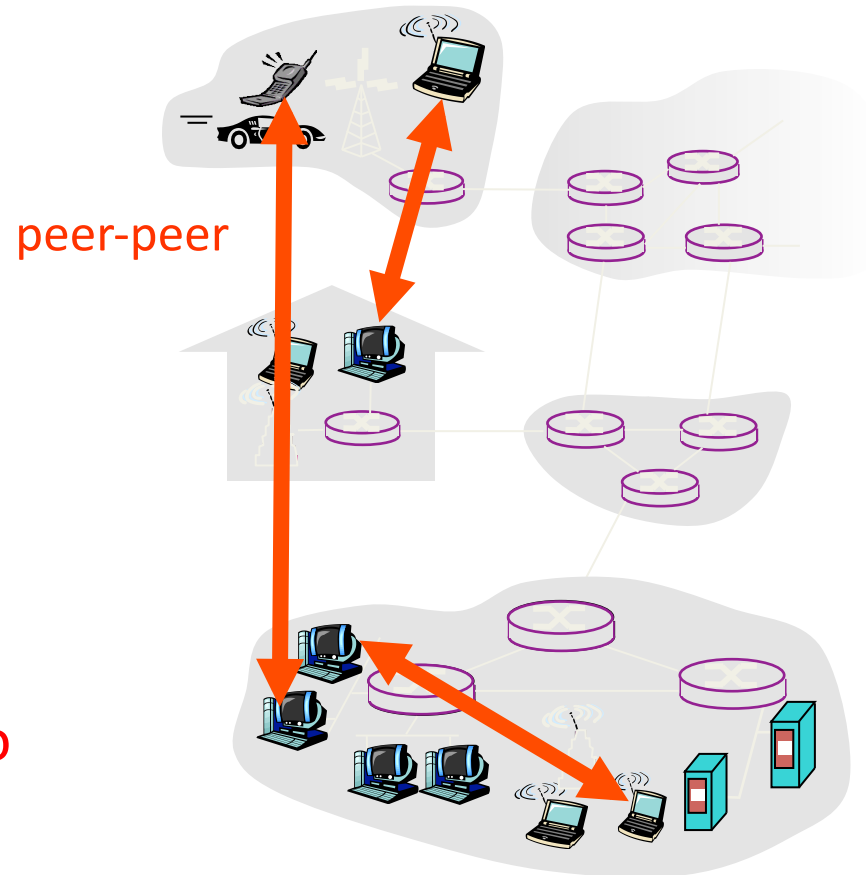
## clients:

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

# Pure P2P architecture

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

Highly scalable but difficult to manage



# Hybrid of client-server and P2P

## Skype

- voice-over-IP P2P application
- centralized server: finding address of remote party:
- client-client connection: direct (not through server)

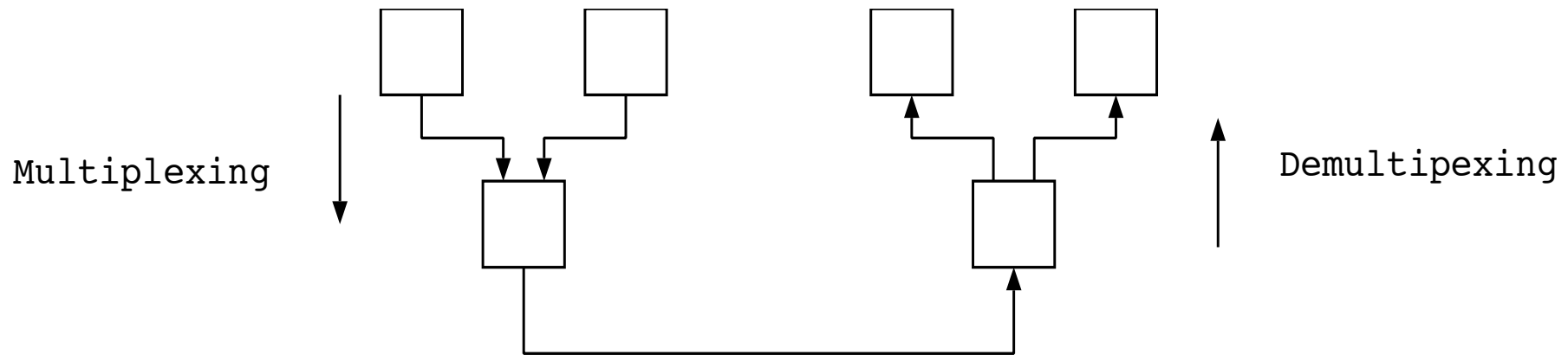
## Instant messaging

- chatting between two users is P2P
- centralized service: client presence detection/location
  - user registers its IP address with central server when it comes online
  - user contacts central server to find IP addresses of buddies

# Addressing processes

- to receive messages, process must have *identifier*
- host device has unique 32-bit IP address
- Q: does IP address of host on which process runs suffice for identifying the process?
  - A: No, *many* processes can be running on same host
- *identifier* includes both **IP address** and **port numbers** associated with process on host.
- Example port numbers:
  - HTTP server: 80
  - Mail server: 25
- to send HTTP message to yuba.stanford.edu web server:
  - **IP address**: 171.64.74.58
  - **Port number**: 80
- more shortly...

# Recall: Multiplexing is a service provided by (each) layer too!



Application: one web-server multiple sets of content

Host: one machine multiple services

Network: one physical box multiple addresses (like vns.cl.cam.ac.uk)

....

UNIX: /etc/protocols = examples of different transport-protocols on top of IP

UNIX: /etc/services = examples of different (TCP/UDP) services – by port

(These files are an example of a (static) approach to name services<sup>7</sup>)

# 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

## Public-domain protocols:

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

## Proprietary protocols:

- e.g., Skype



# What transport service does an app need?

## Data loss

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

## 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, ...

## Mysterious secret of *Transport*

- There is more than sort of *transport* layer

Shocked?

I seriously doubt it...

Recall the two most common TCP and UDP

# Naming

- Internet has one global system of addressing: IP
  - By explicit design
- And one global system of naming: DNS
  - Almost by accident
- At the time, only items worth naming were hosts
  - A mistake that causes many painful workarounds
- Everything is now named relative to a host
  - Content is most notable example (URL structure)

# Logical Steps in Using Internet

- Human has name of entity she wants to access
  - Content, host, etc.
- Invokes an application to perform relevant task
  - Using that name
- App invokes DNS to translate name to address
- App invokes transport protocol to contact host
  - Using address as destination

# Addresses vs Names

- Scope of relevance:
  - App/user is primarily concerned with names
  - Network is primarily concerned with addresses
- Timescales:
  - Name lookup once (or get from cache)
  - Address lookup on each packet
- When moving a host to a different subnet:
  - The address changes
  - The name does not change
- When moving content to a differently named host
  - Name and address both change!

# 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

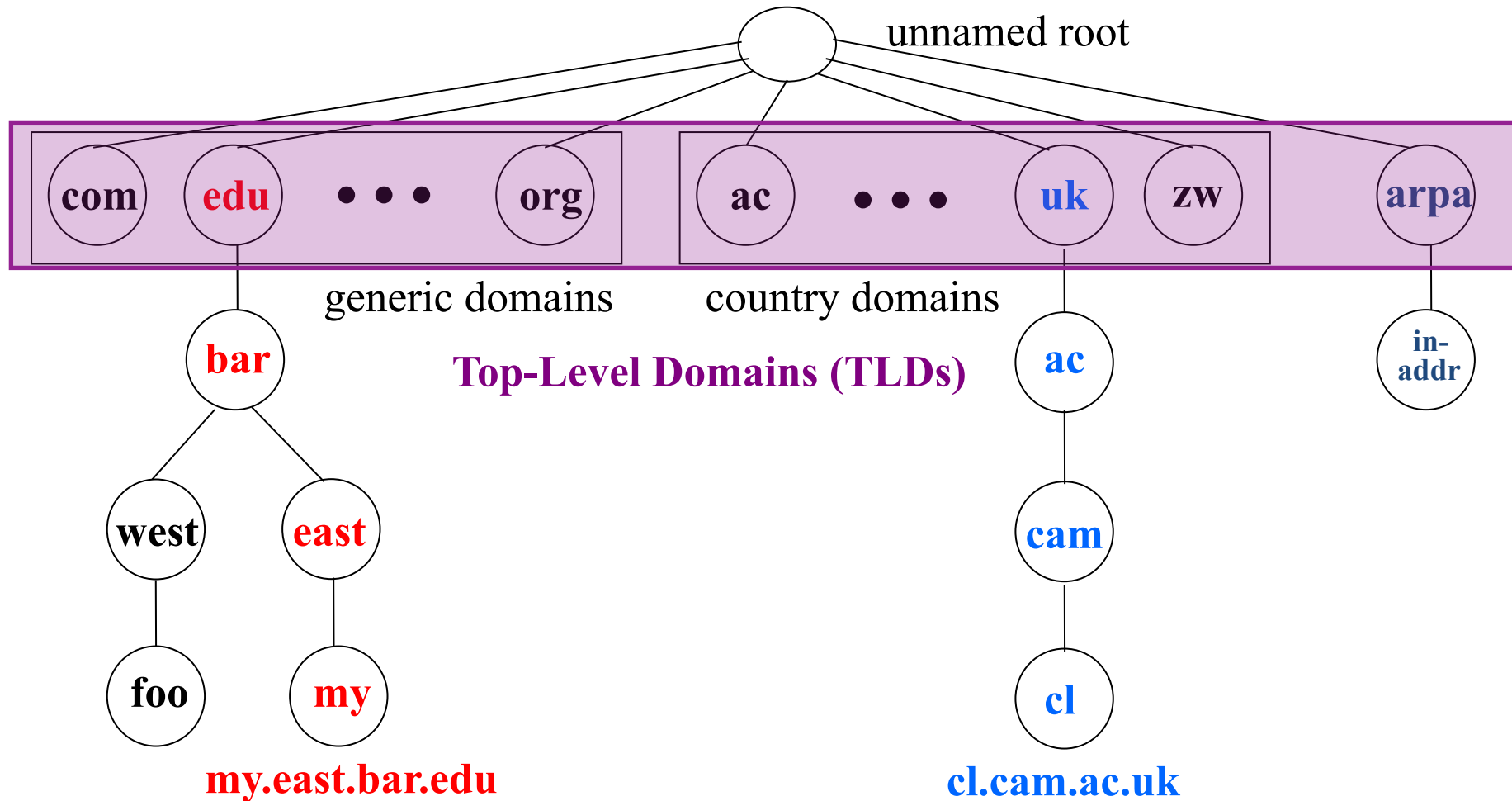
# Mapping from Names to Addresses

- 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

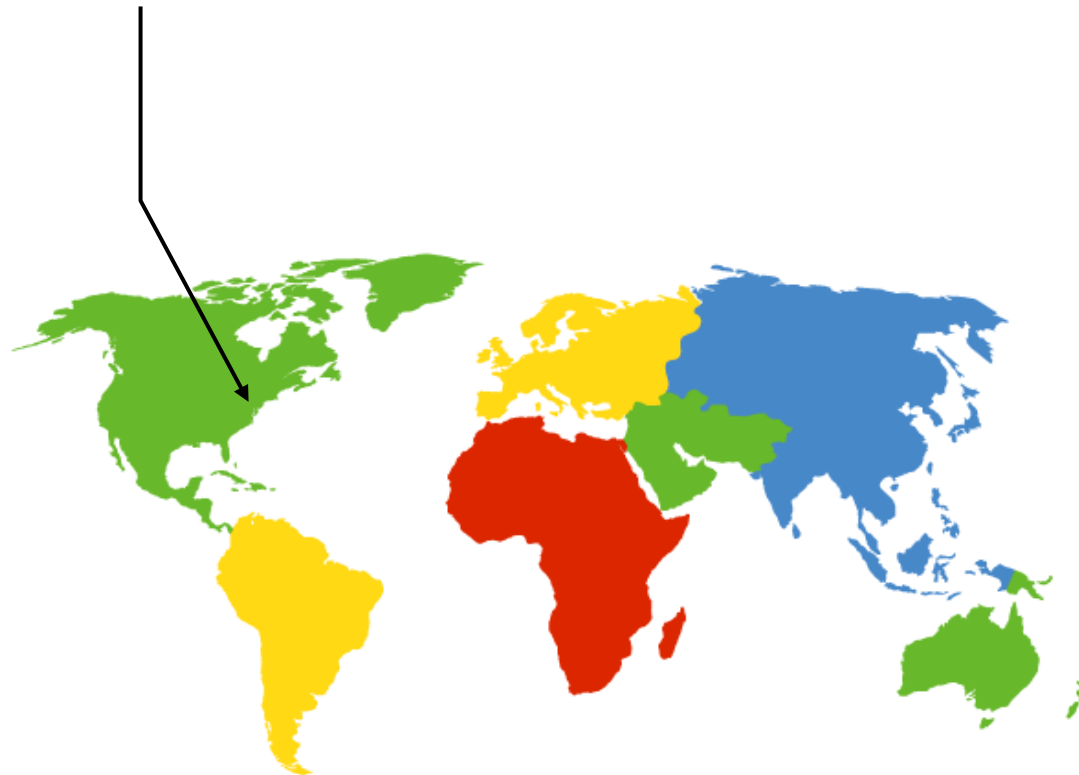




# DNS Root

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

Verisign, Dulles, VA



# 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)



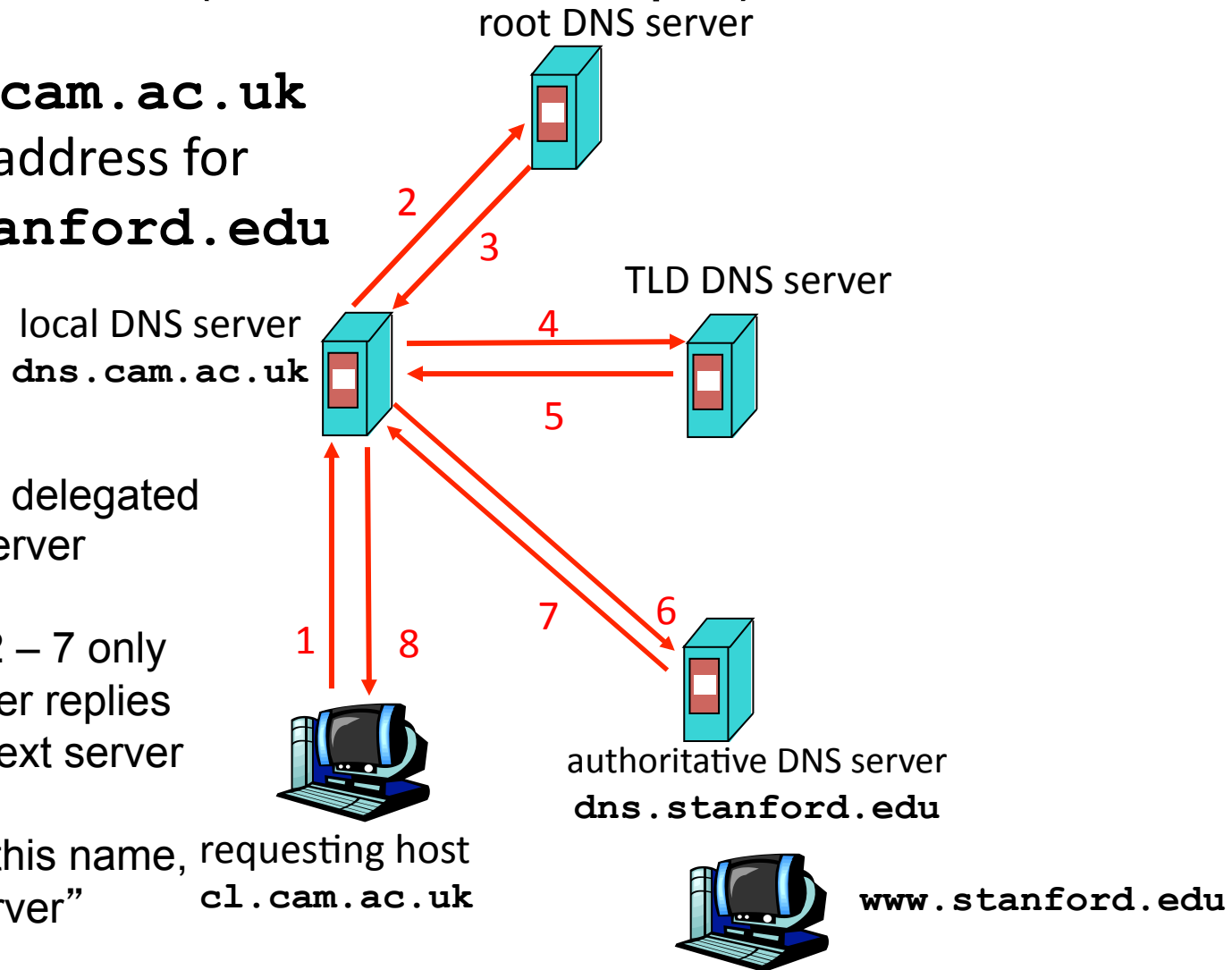
# Using DNS

- 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**



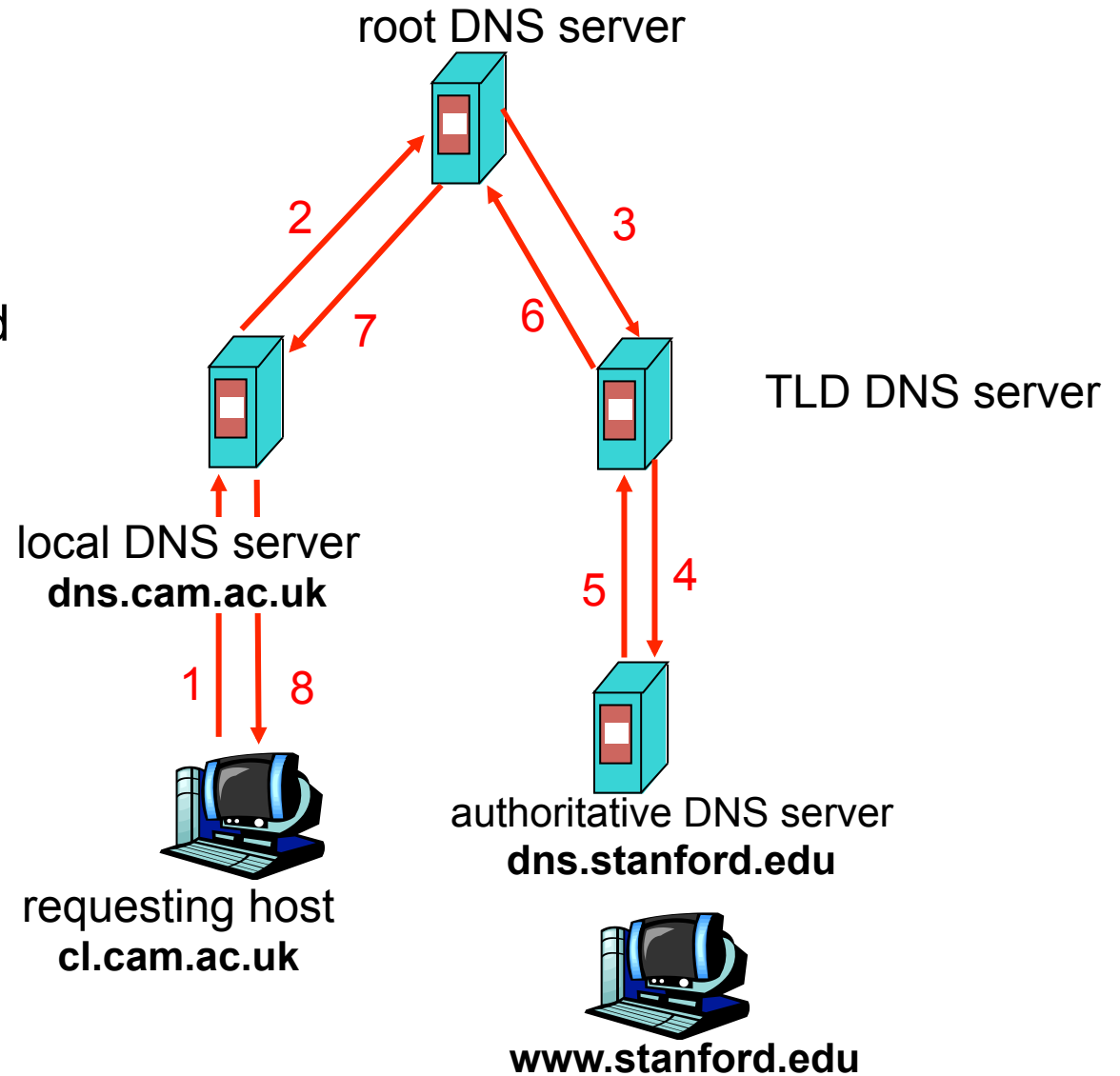
### iterated query:

- 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, requesting host but ask this server”

# DNS name resolution **recursive** example

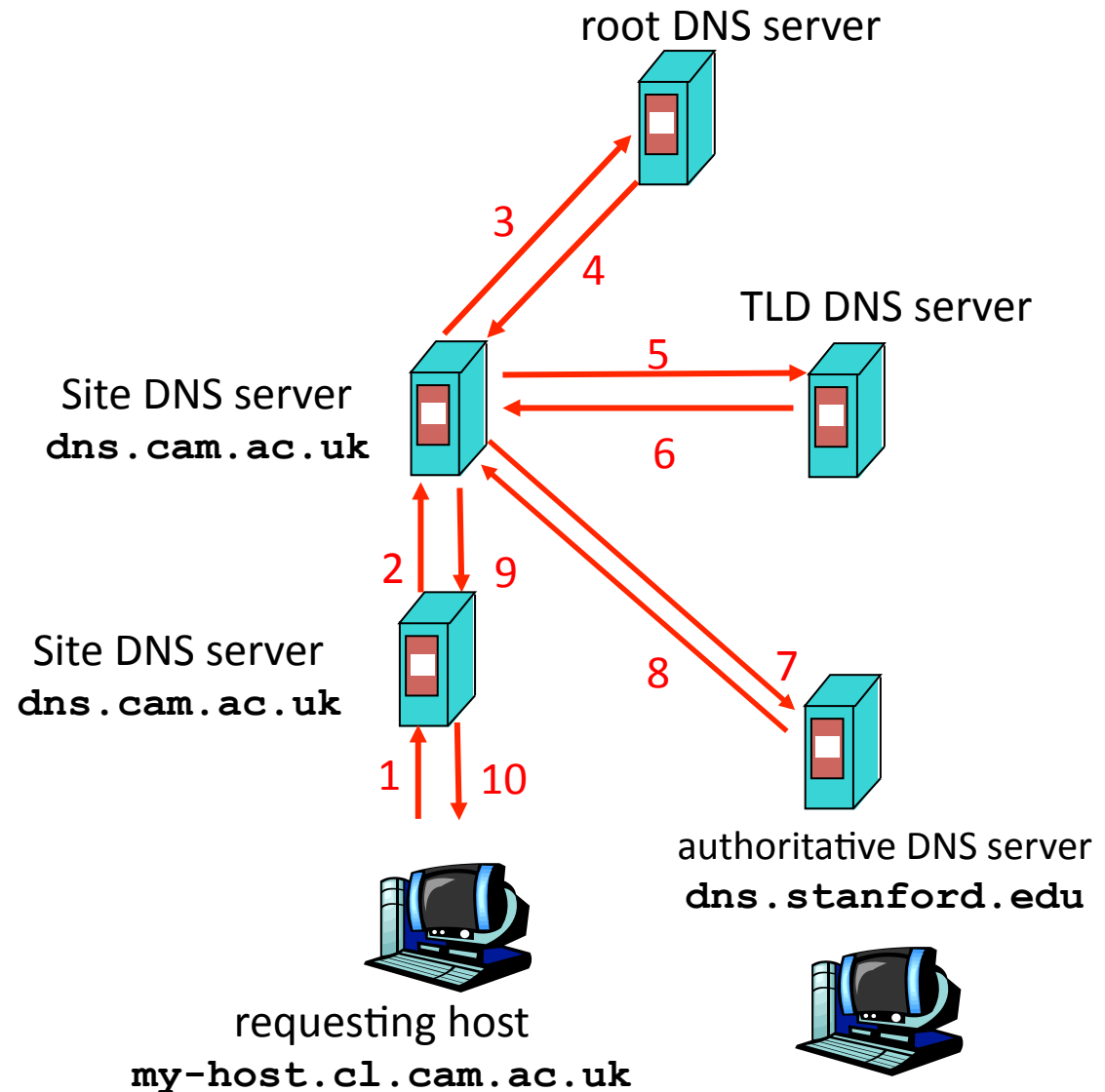
recursive query:

- ❑ 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](http://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 Measurements (MIT data from 2000)

- What is being looked up?
  - ~60% requests for A records
  - ~25% for PTR records
  - ~5% for MX records
  - ~6% for ANY records
- How long does it take?
  - Median ~100msec (but 90<sup>th</sup> percentile ~500msec)
  - 80% have no referrals; 99.9% have fewer than four
- Query packets per lookup: ~2.4
  - But this is misleading....

# DNS Measurements (MIT data from 2000)

- Does DNS give answers?
  - ~23% of lookups fail to elicit an answer!
  - ~13% of lookups result in NXDOMAIN (or similar)
    - Mostly reverse lookups
  - Only ~64% of queries are successful!
    - *How come the web seems to work so well?*
- ~ 63% of DNS packets in unanswered queries!
  - Failing queries are frequently retransmitted
  - 99.9% successful queries have  $\leq 2$  retransmissions

# DNS Measurements (MIT data from 2000)

- Top 10% of names accounted for ~70% of lookups
  - Caching should really help!
- 9% of lookups are unique
  - Cache hit rate can never exceed 91%
- Cache hit rates ~ 75%
  - But caching for more than 10 hosts doesn't add much

# A Common Pattern.....

- Distributions of various metrics (file lengths, access patterns, etc.) often have two properties:
  - Large fraction of total metric in the top 10%
  - Sizable fraction (~10%) of total fraction in low values
- Not an exponential distribution
  - Large fraction is in top 10%
  - But low values have very little of overall total
- Lesson: have to pay attention to both ends of dist.
- Here: caching helps, but not a panacea

# Moral of the Story

- If you design a highly resilient system, many things can be going wrong without you noticing it!

and this is a **good** thing

# Cache Poisoning, a *badness* story

- Suppose you are a Bad Guy and you control the name server for foobar.com. You receive a request to resolve www.foobar.com and reply:

```
;; QUESTION SECTION:
;www.foobar.com.      IN      A

;; ANSWER SECTION:
www.foobar.com.      300    IN      A      212.44.9.144

;; AUTHORITY SECTION:
foobar.com.          600    IN      NS      dns1.foobar.com.
foobar.com.          600    IN      NS      google.com.

;; ADDITIONAL SECTION:
google.com.          5      IN      A      212.44.9.155
```

**Evidence of the attack disappears 5 seconds later!**

**A foobar.com machine, *not* google.com**



# 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!

# Why is the web so successful?

- What do the web, youtube, fb 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=do
wn&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

```
$ telnet www.cl.cam.ac.uk 80  
GET /~awm22/win HTTP/1.0  
<blank line, i.e., CRLF>
```

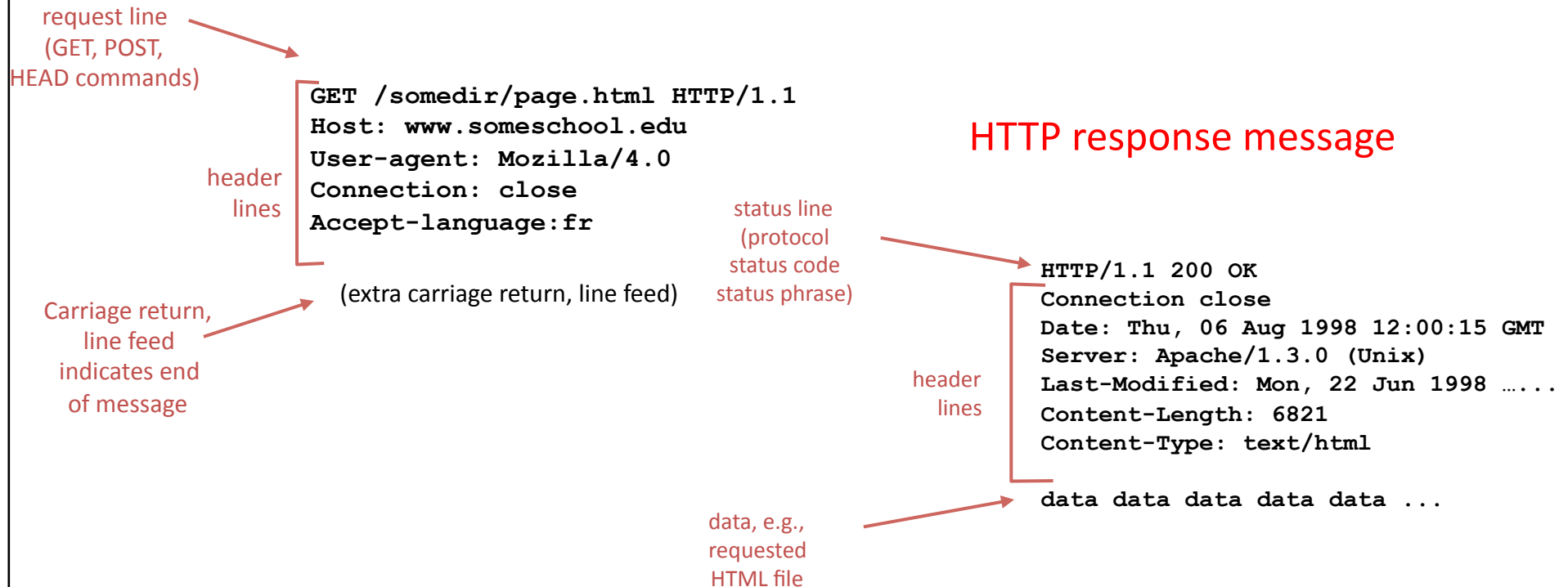
# Steps in HTTP Request

- 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 ....)





# 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

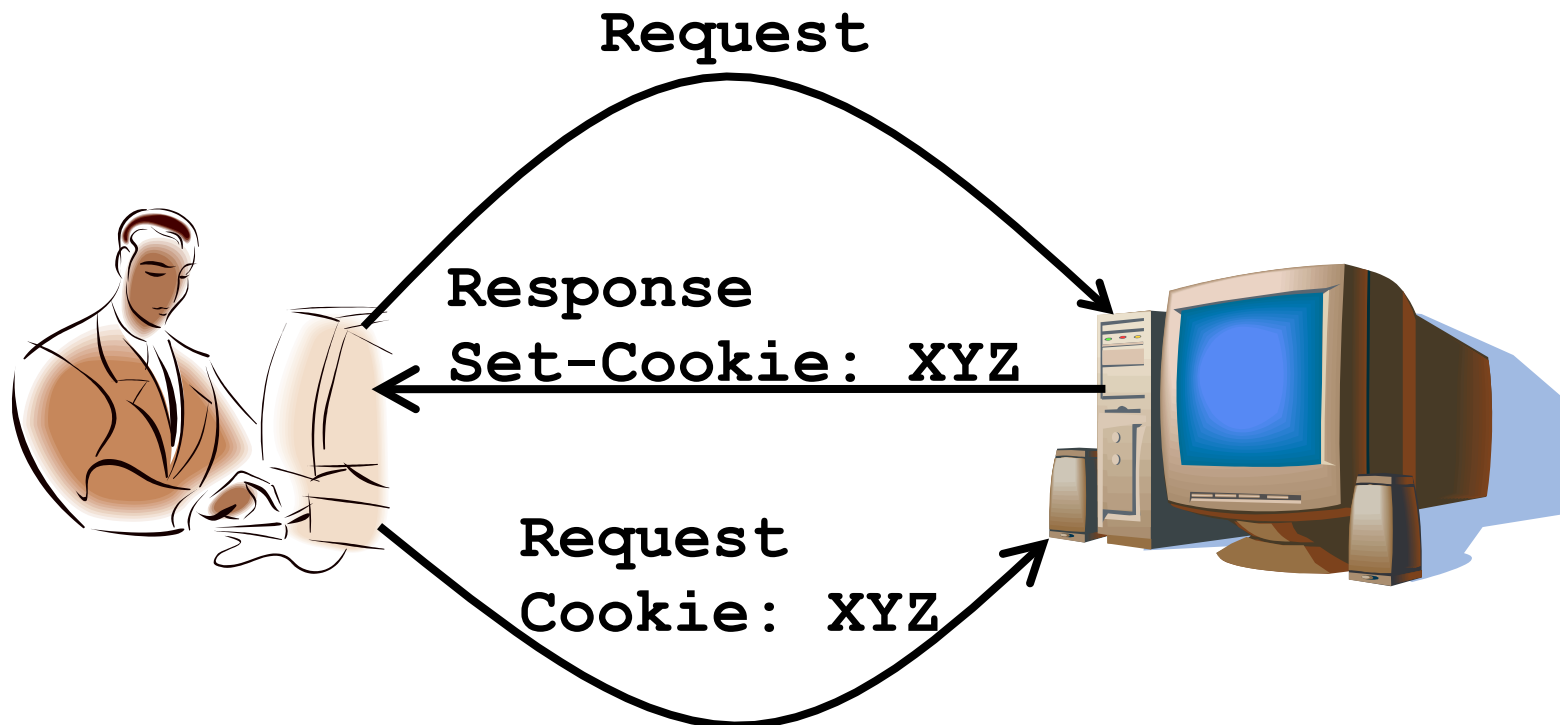
- Meta-data
  - Info *about* a resource, stored as a separate entity
- Examples:
  - Size of resource, last modification time, type of content
- Usage example: Conditional GET Request
  - Client requests object “**If-modified-since**”
  - If unchanged, “**HTTP/1.1 304 Not Modified**”
  - No body in the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

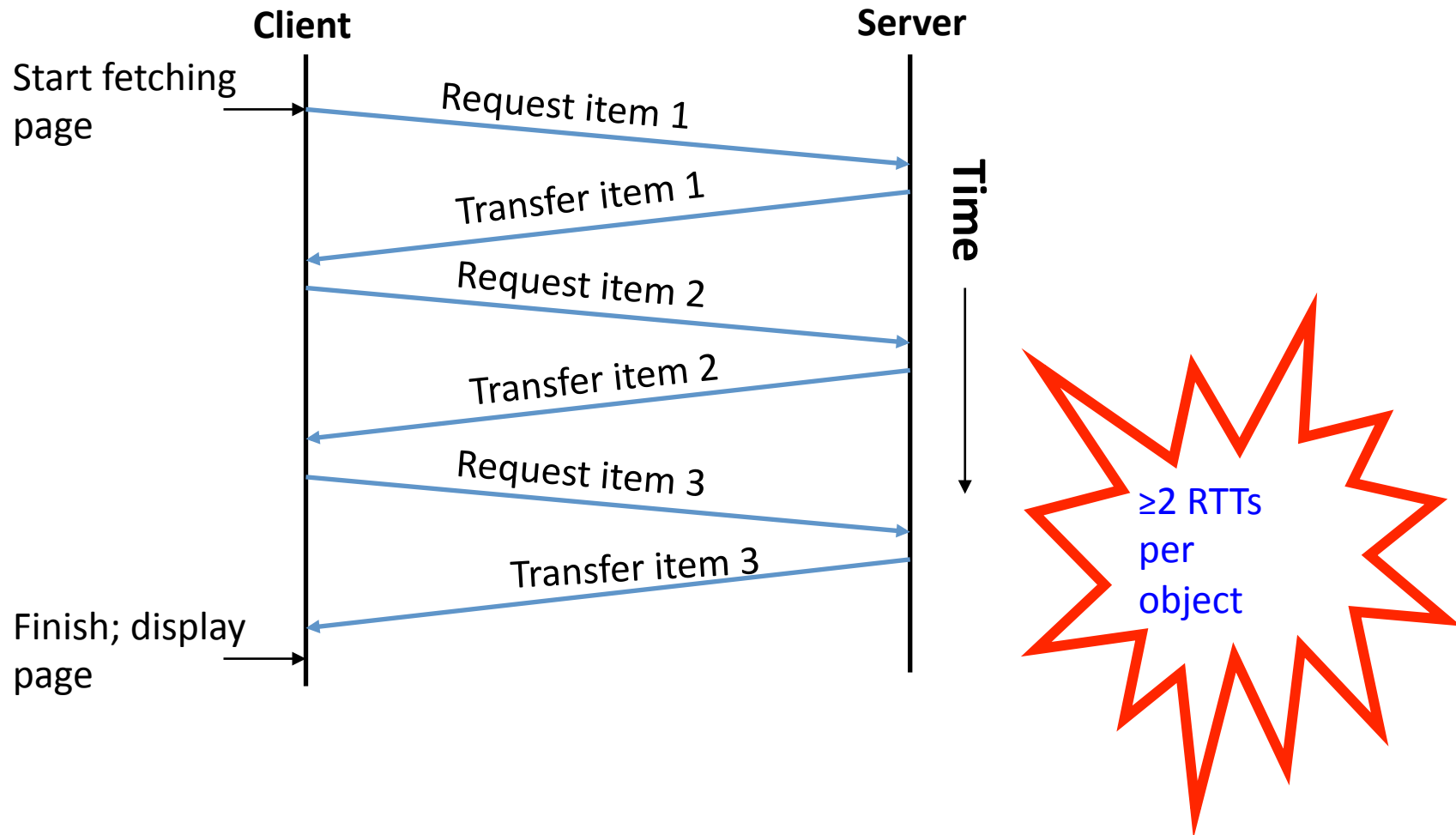
- *Client-side* state maintenance
  - Client stores small(?) state on behalf of server
  - Client sends state in future requests to the server
- Can provide authentication



# 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***

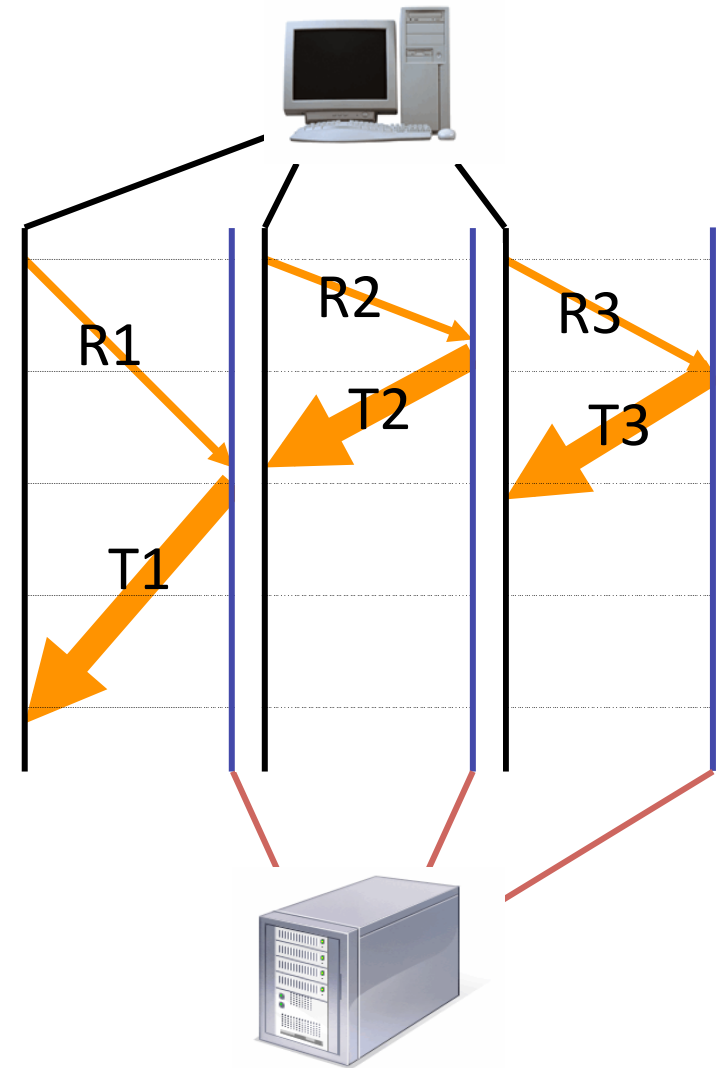
# Fetch HTTP Items: Stop & Wait



## Improving HTTP Performance: Concurrent Requests & Responses

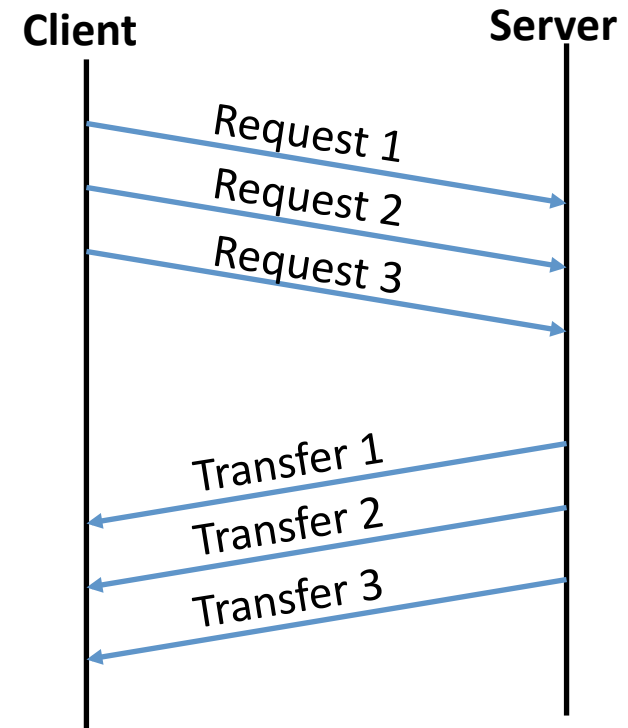
- Use multiple connections *in parallel*
- Does not necessarily maintain order of responses

- 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:  $\sim 2n$  RTT
- Persistent:  $\sim (n+1)$ RTT
- M concurrent:  $\sim 2[n/m]$  RTT
- Pipelined:  $\sim 2$  RTT
- Pipelined/Persistent:  $\sim 2$  RTT first time, RTT later

# Scorecard: Getting n Large Objects

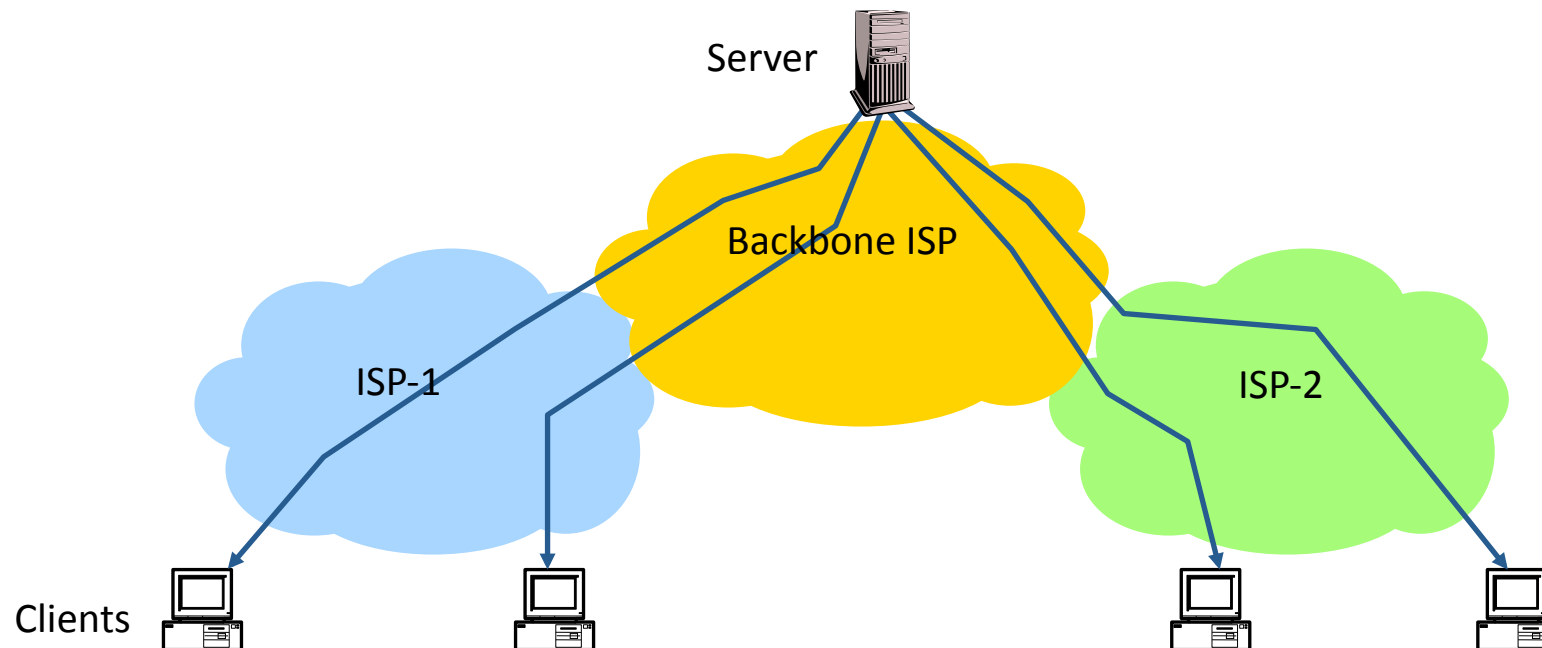
*Time dominated by bandwidth*

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

Improving HTTP Performance:

# Caching

- Many clients transfer **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



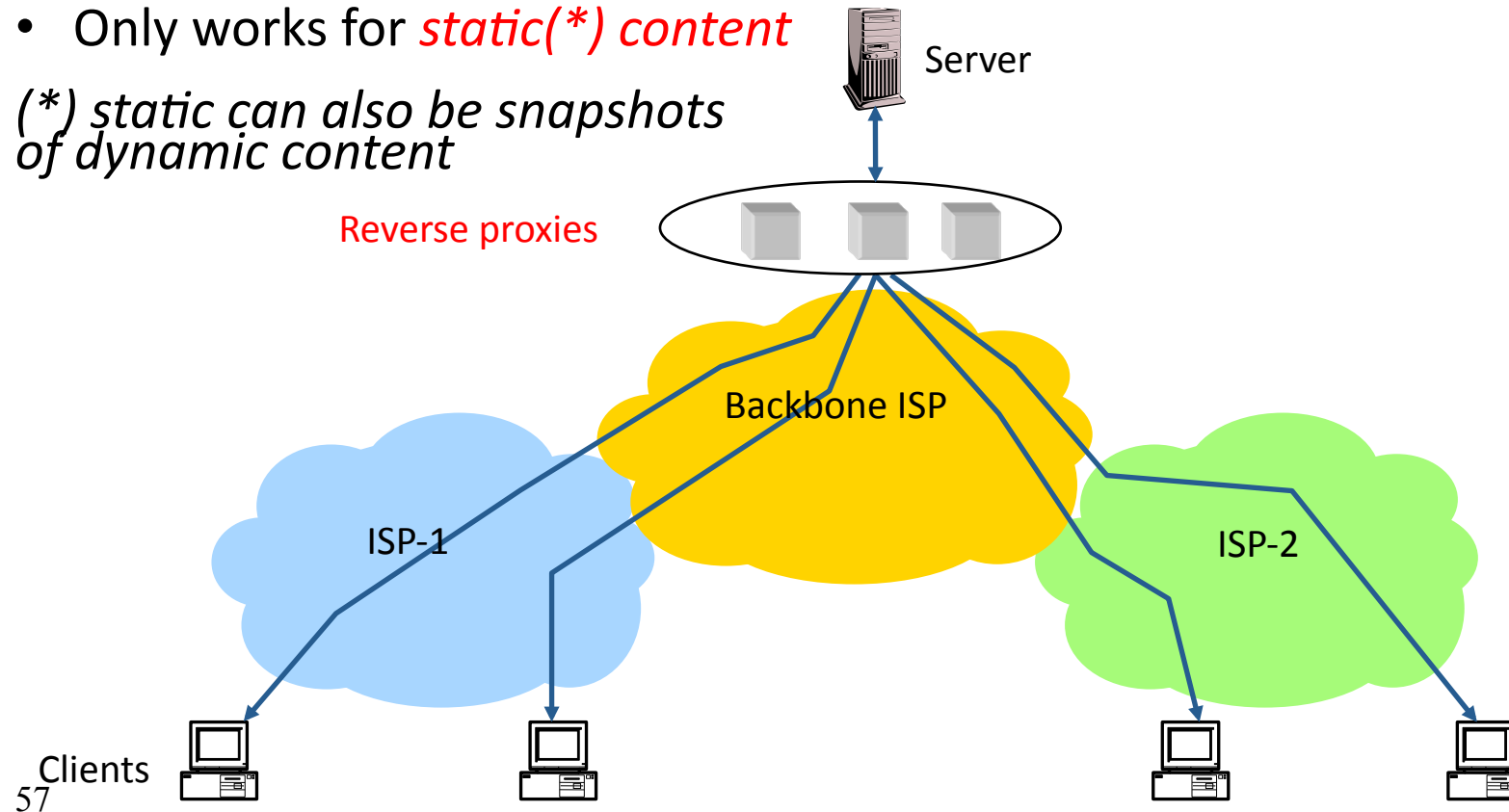
# Improving HTTP Performance: Caching with Reverse Proxies

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*

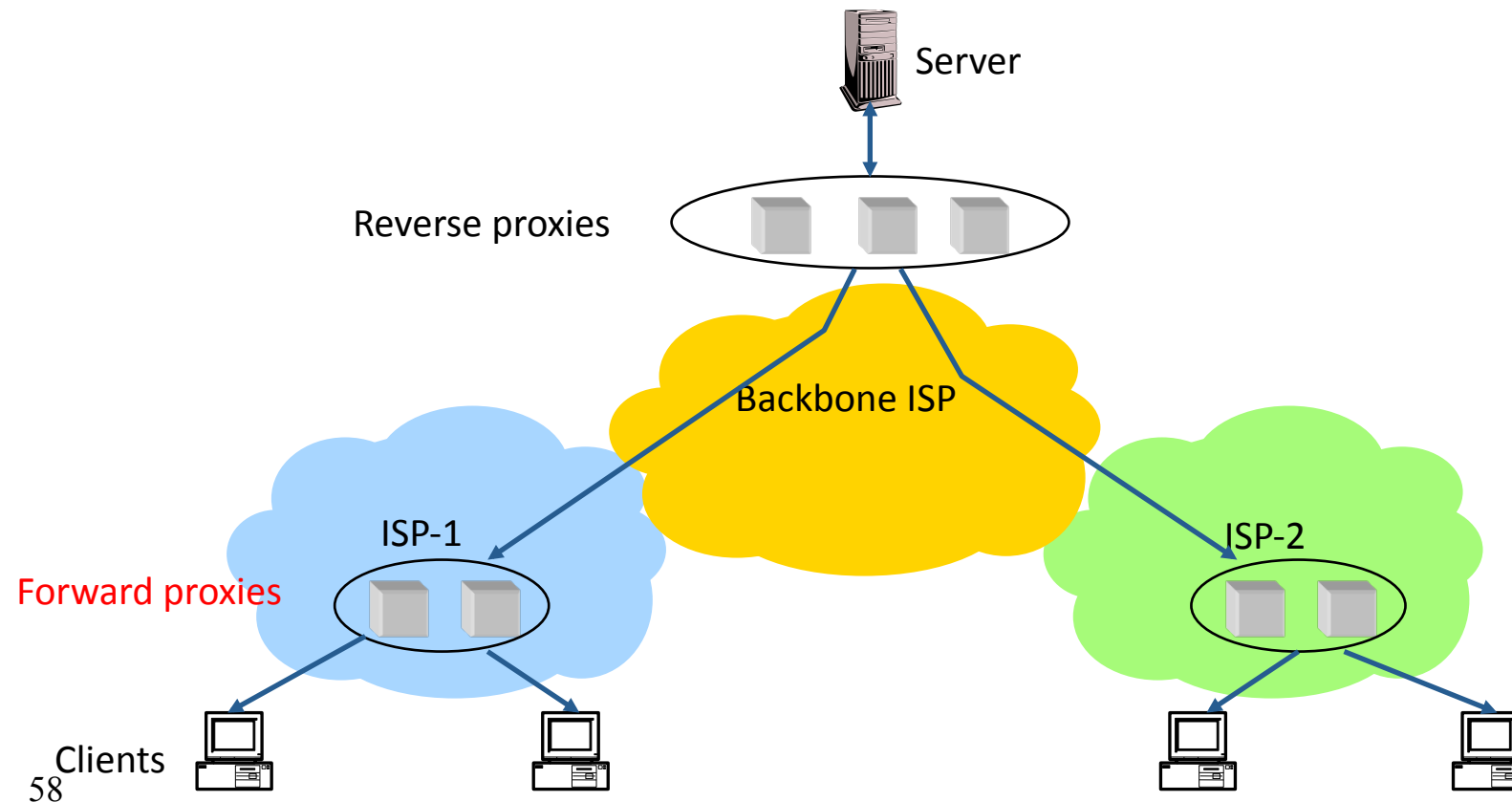


# Improving HTTP Performance: Caching with Forward Proxies

Cache documents close to **clients**

→ reduce network traffic and decrease latency

- Typically done by ISPs or corporate LANs

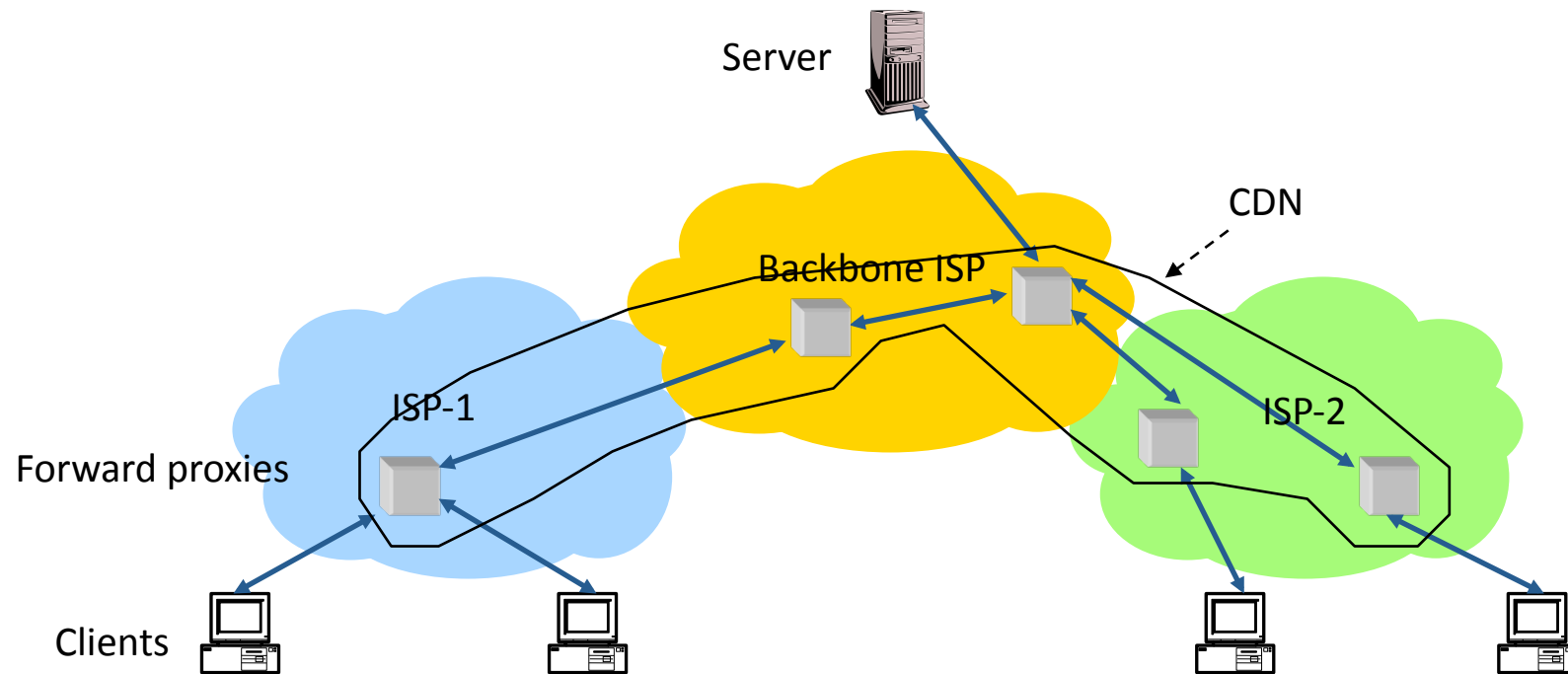


Improving HTTP Performance:

## 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](http://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

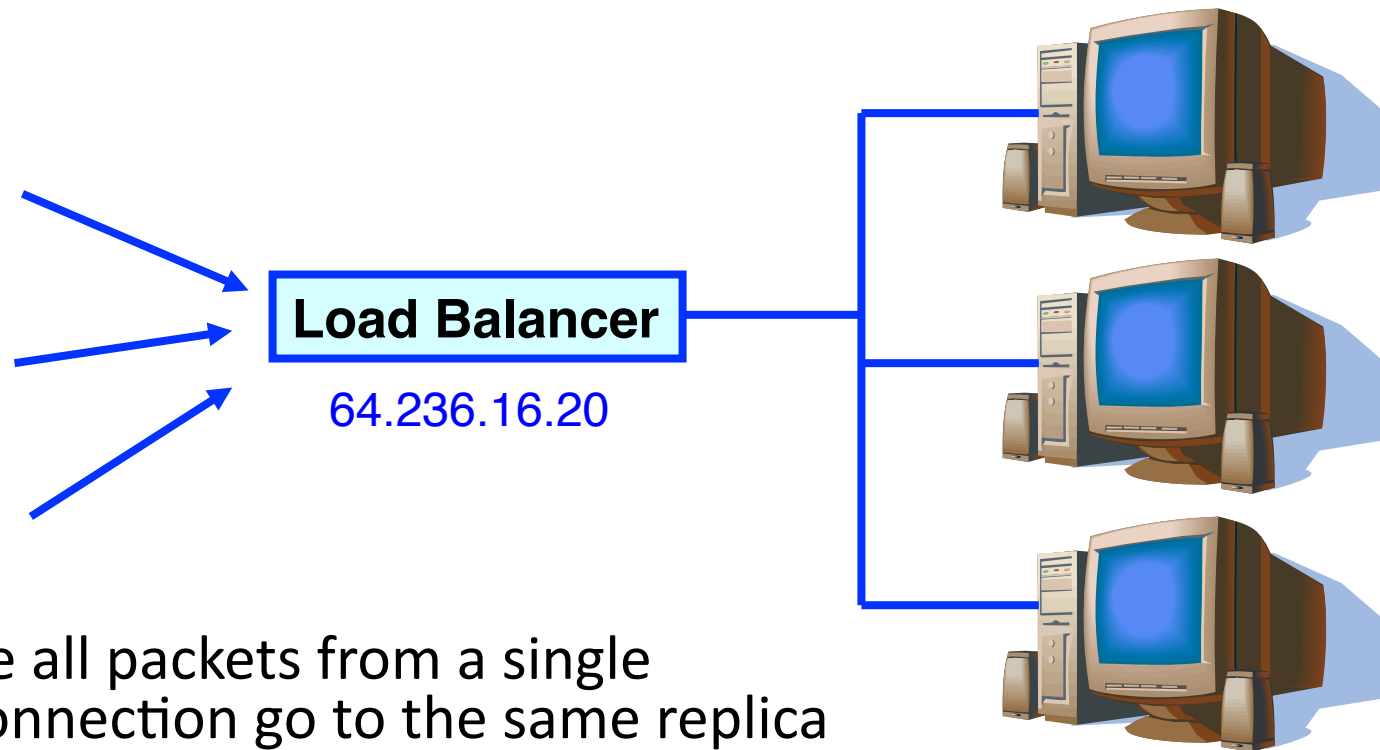
- Multiple Web sites on a single machine
  - Hosting company runs the Web server on behalf of multiple sites (*e.g.*, `www.foo.com` and `www.bar.com`)
- Problem: `GET /index.html`
  - `www.foo.com/index.html` Or `www.bar.com/index.html`?
- Solutions:
  - Multiple server processes on the same machine
    - 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

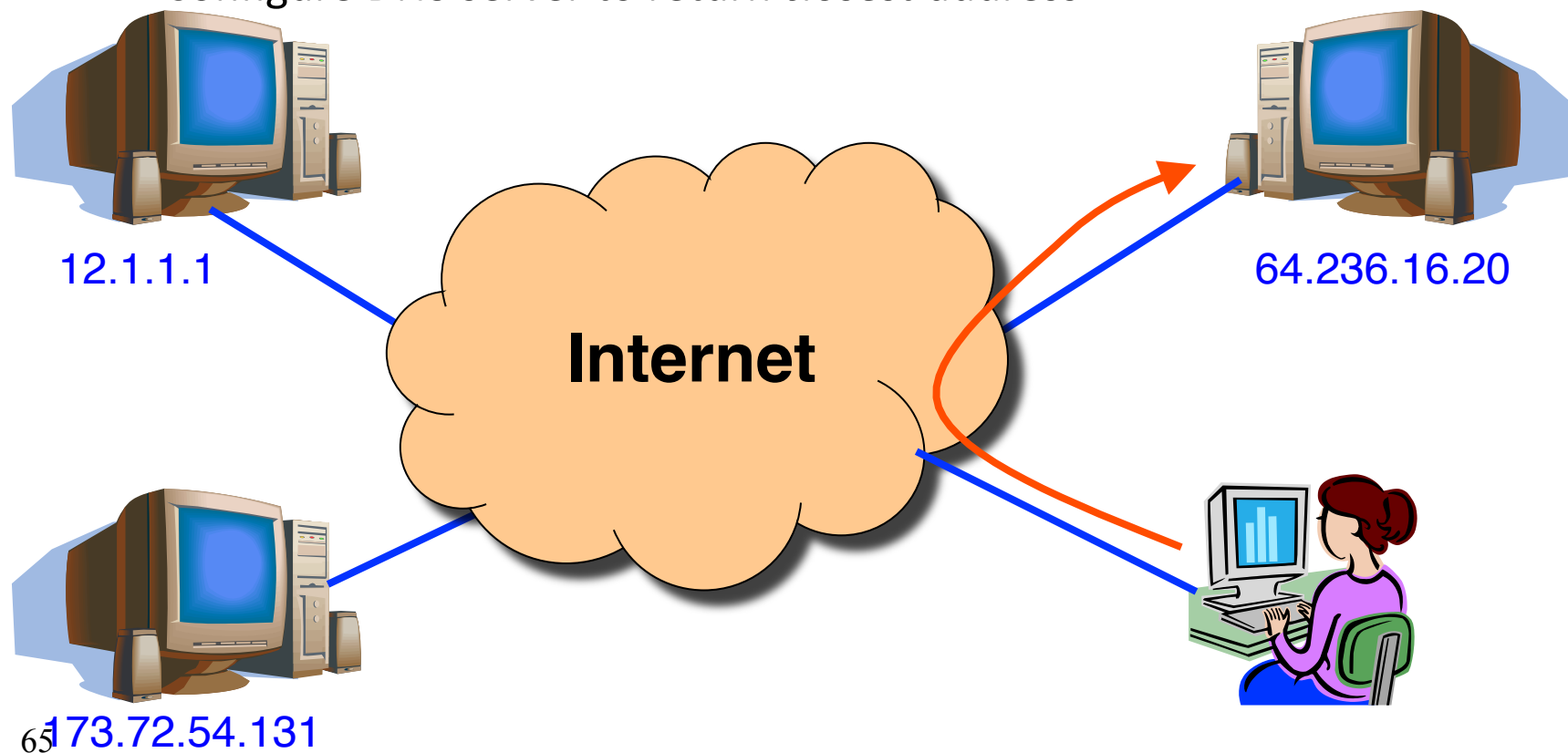


- Ensure all packets from a single TCP connection go to the same replica



# 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

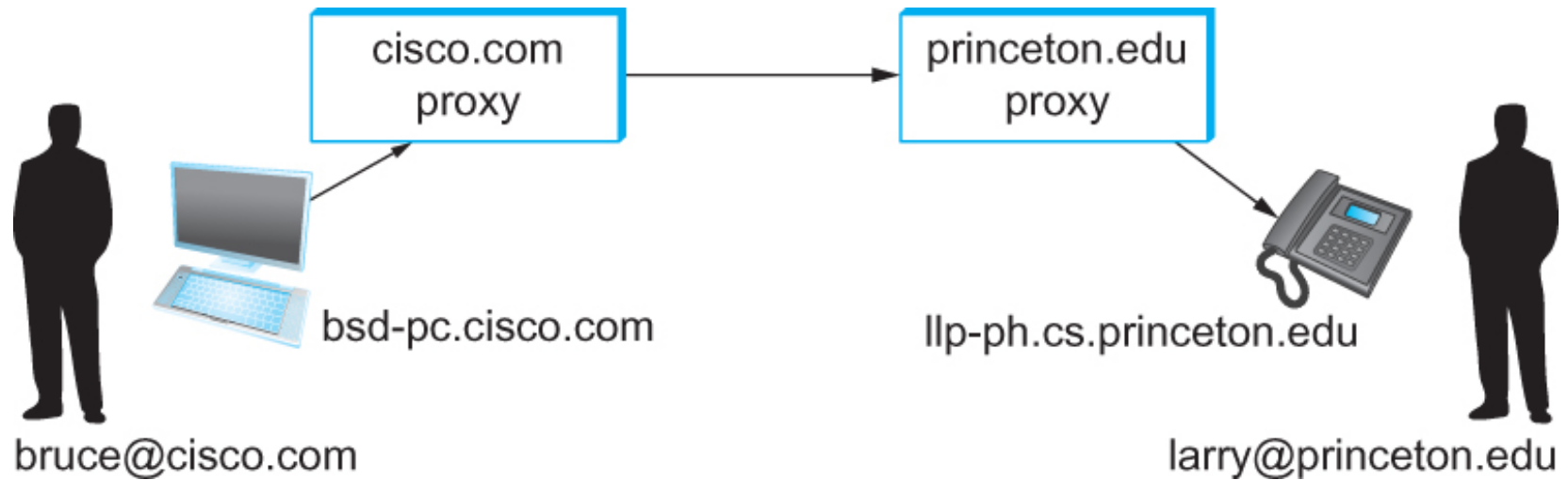
- **CDN using DNS**  
DNS has information on loading/distribution/location
- **CDN using anycast**  
same address from DNS name but local routes
- **CDN based on rewriting HTML URLs**  
(akami example just covered – akami uses DNS too)

# SIP – Session Initiation Protocol

Session?

Anyone smell an OSI / ISO standards document burning?

# SIP - VoIP



Establishing communication through SIP proxies.



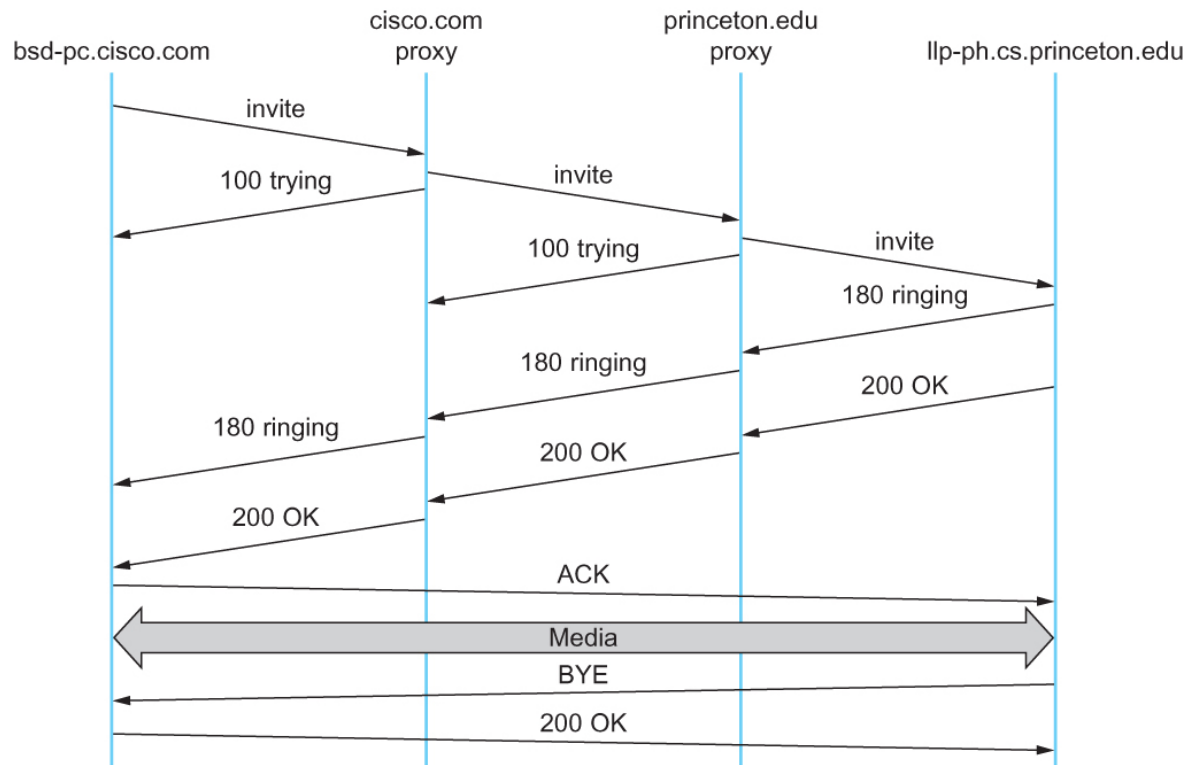
# SIP?

- 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

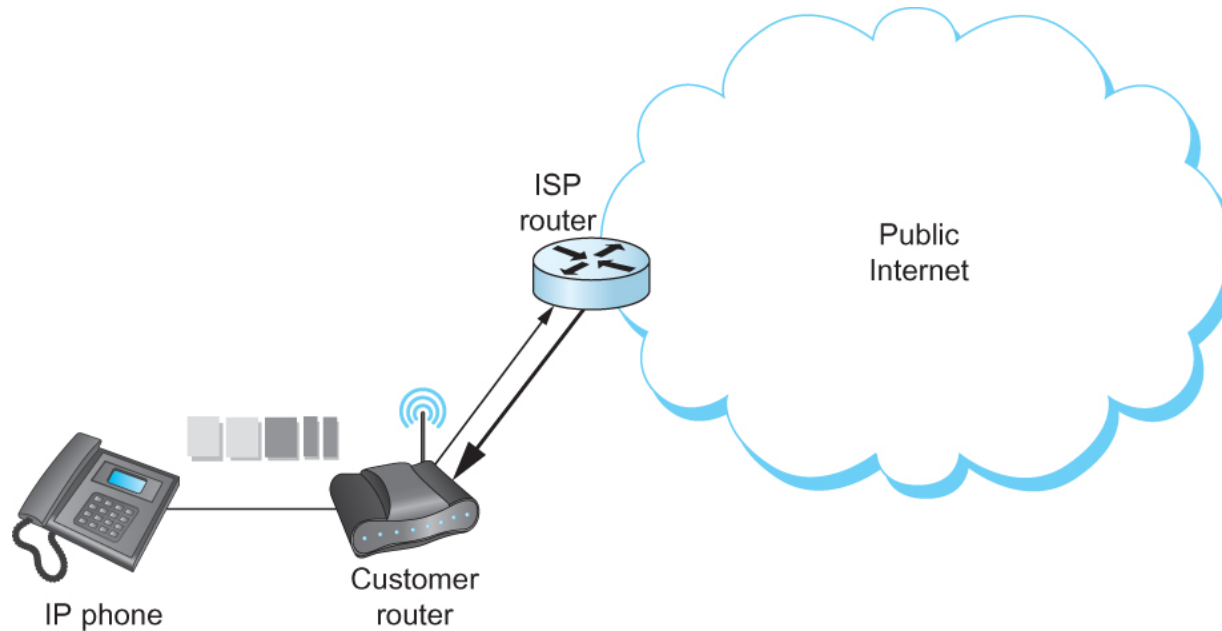
- Why have one standard when there are at least two....
- The full H.323 is hundreds of pages
  - The protocol is known for its complexity – an ITU hallmark
- SIP is not much better
  - IETF grew up and became the ITU....

# Multimedia Applications



Message flow for a basic SIP session

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



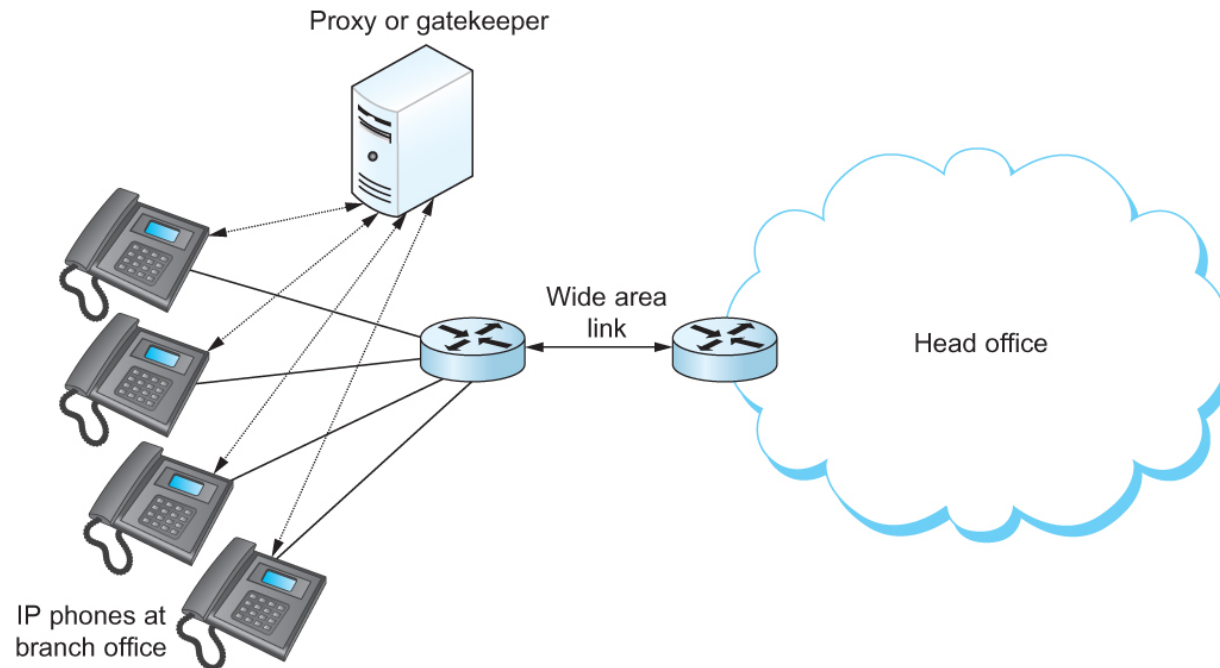
I can 'differentiate' VoIP from data but...

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

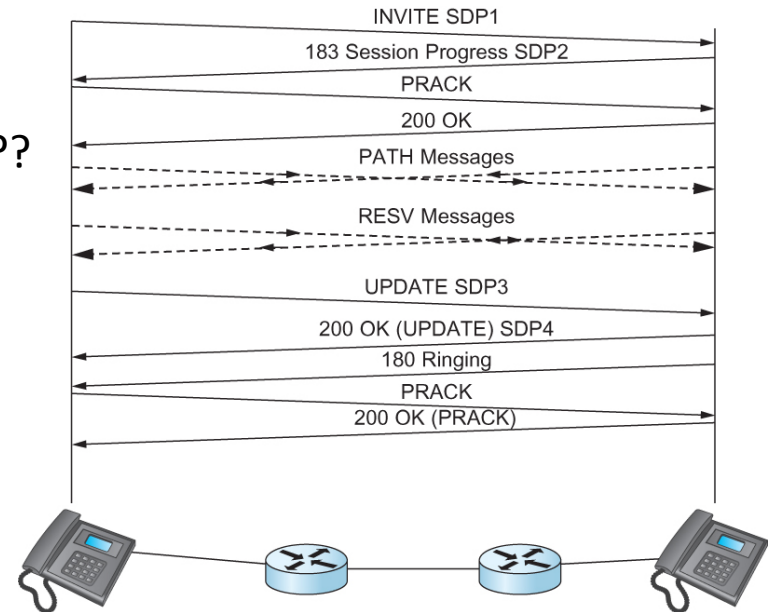
Coming soon... ~~1995~~

~~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...)

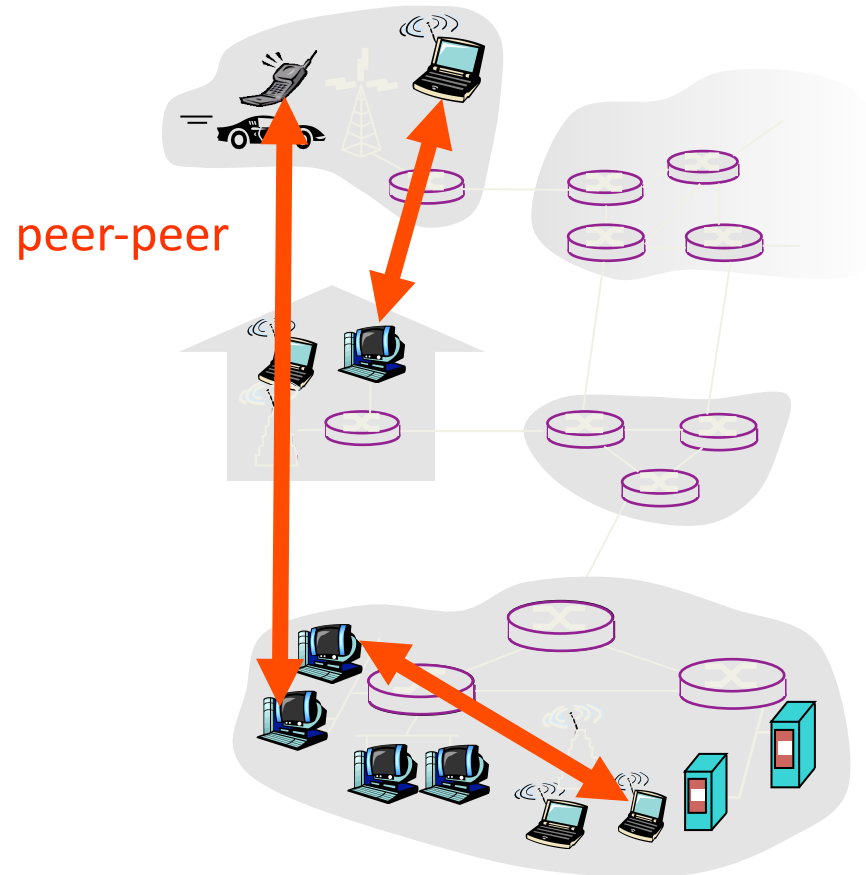
What about my aDSL/CABLE/etc it combines voice and data?

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

P2P – efficient network use that  
annoys the ISP

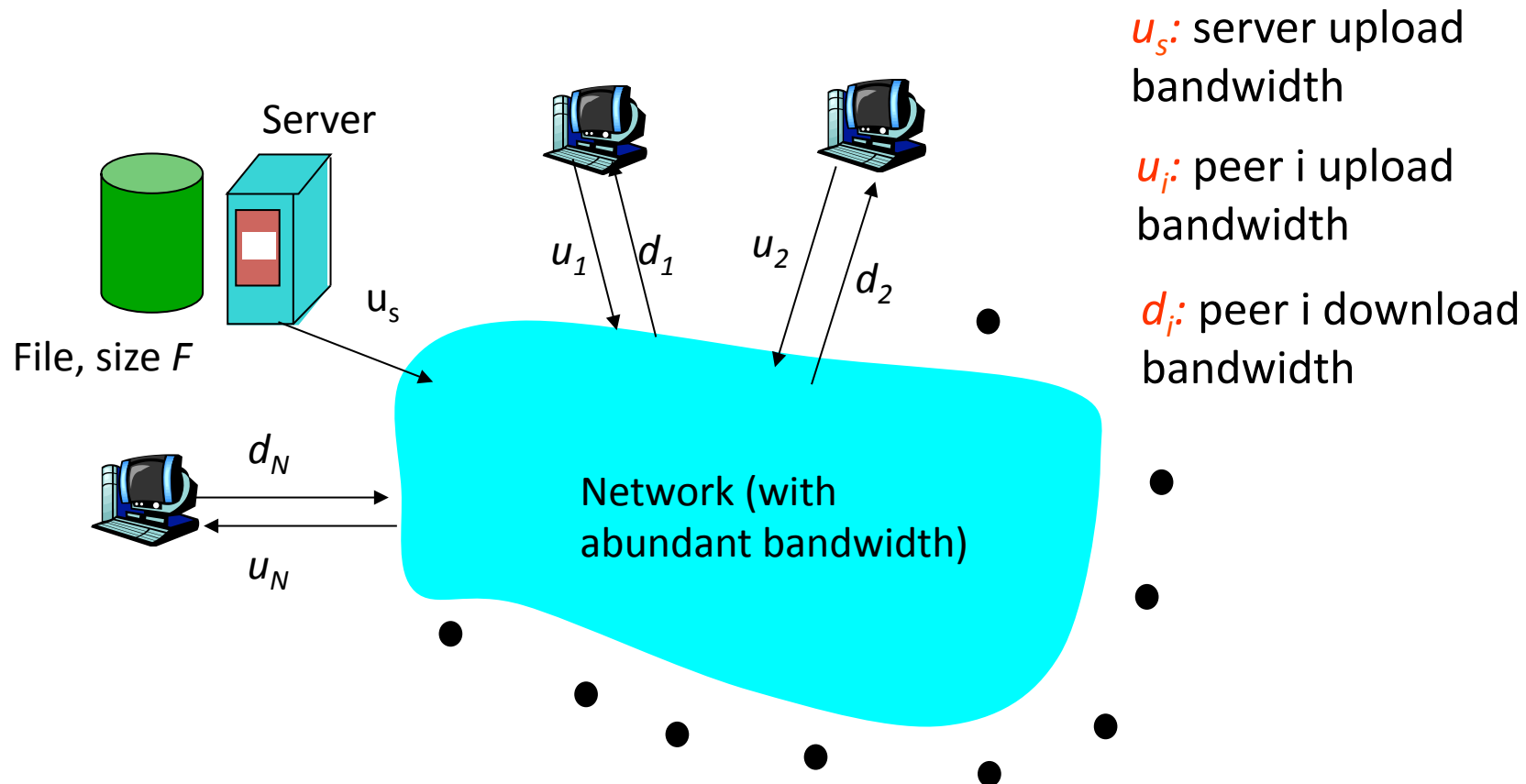
# Pure P2P architecture

- *no* always-on server
- arbitrary end systems directly communicate
- peers are intermittently connected and change IP addresses
- Three topics:
  - File distribution
  - Searching for information
  - Case Study: Skype



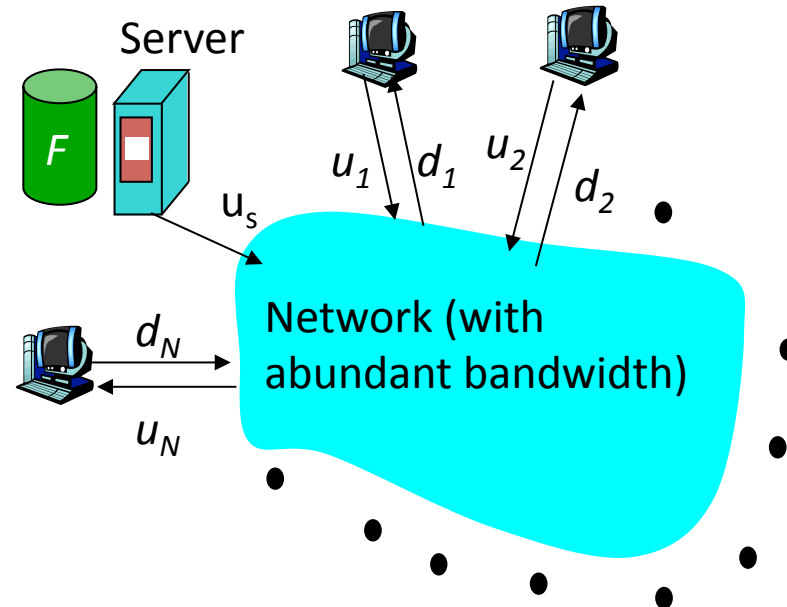
# File Distribution: Server-Client vs P2P

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



## File distribution time: server-client

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

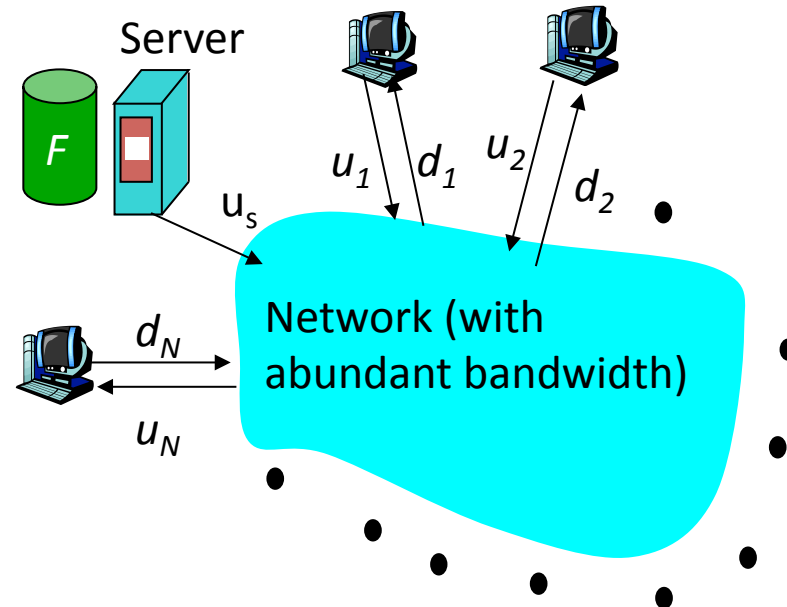


Time to distribute  $F$  to  $N$  clients using client/server approach =  $d_{cs} = \max \{ NF/u_s, F/\min(d_i) \}$

increases linearly in  $N$  (for large  $N$ )

## File distribution time: P2P

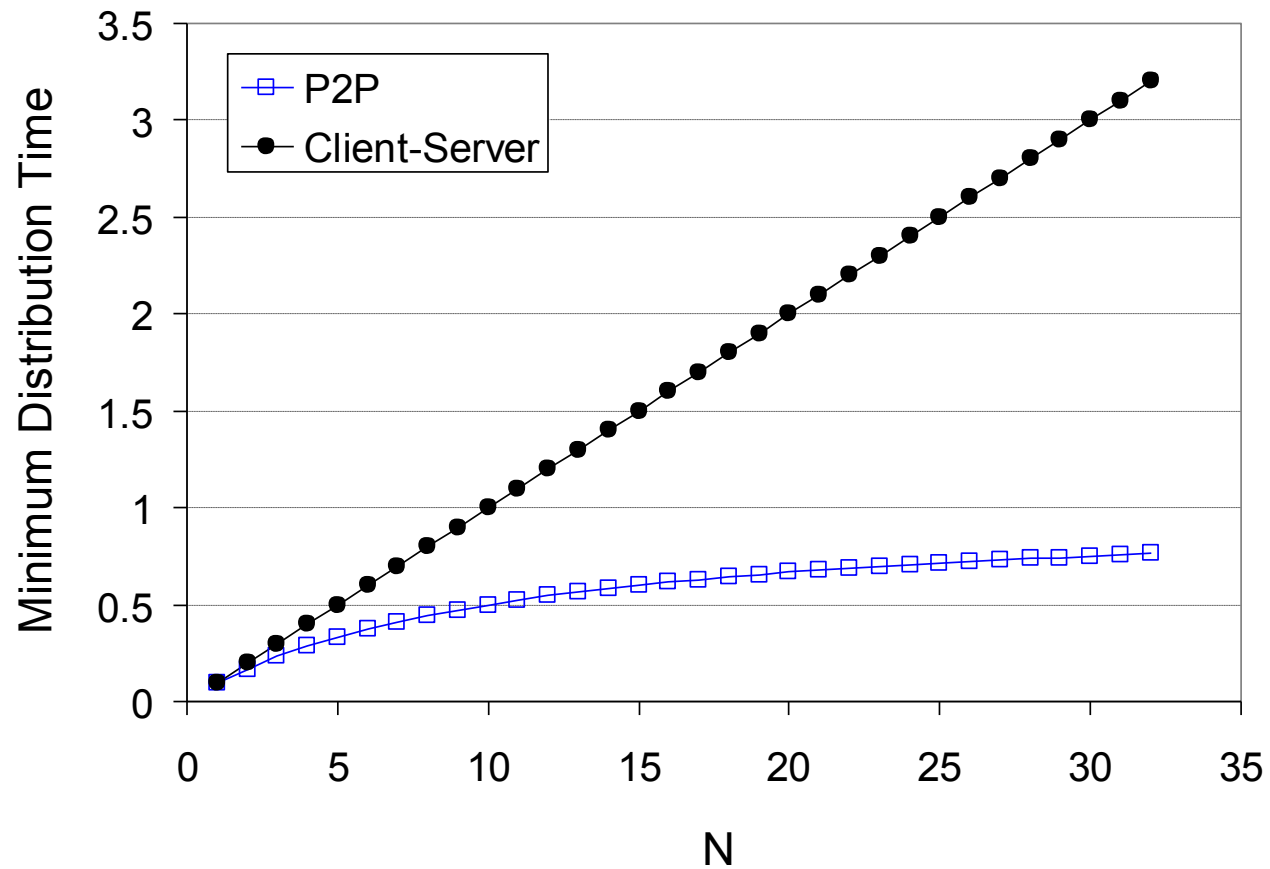
- server must send one copy:  
 $F/u_s$  time
- client  $i$  takes  $F/d_i$  time to download
- $NF$  bits must be downloaded (aggregate)
  - fastest possible upload rate:  $u_s + \sum u_i$



$$d_{\text{P2P}} = \max \left\{ F/u_s, F/\min(d_i), NF/\left(u_s + \sum u_i\right) \right\}$$

## Server-client vs. P2P: example

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





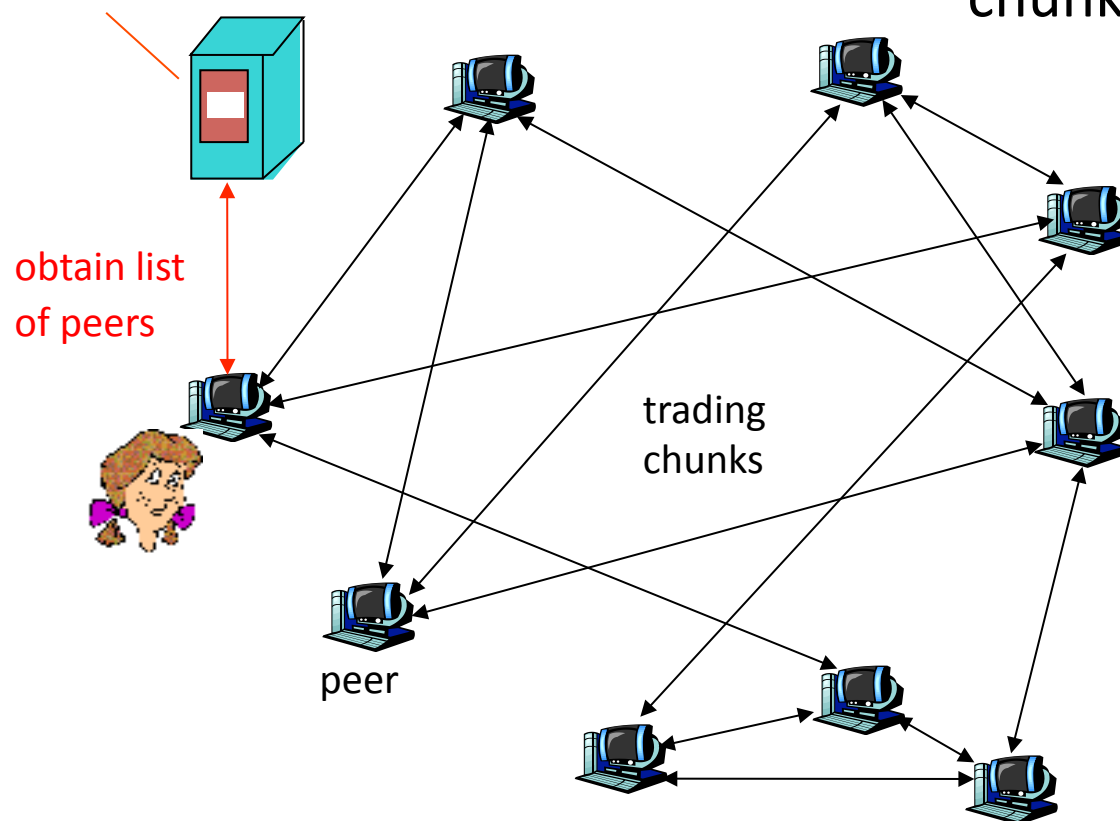
# File distribution: BitTorrent\*

\*rather old BitTorrent

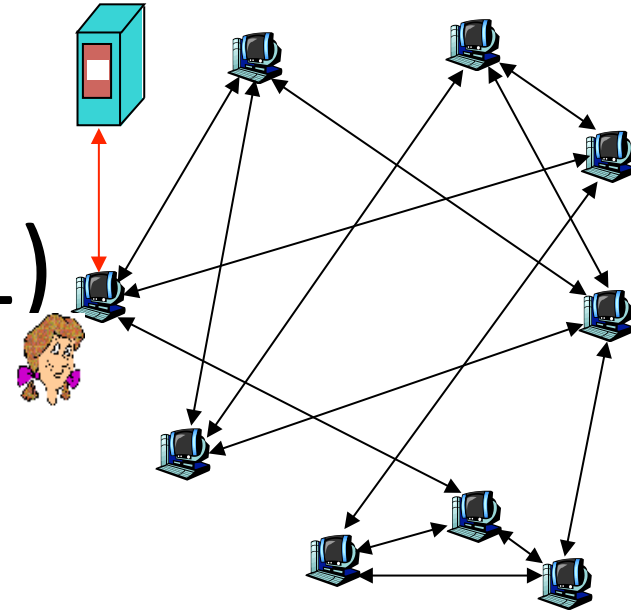
- ❑ P2P file distribution

tracker: tracks peers  
participating in torrent

torrent: group of  
peers exchanging  
chunks of a file



# BitTorrent (1)



- file divided into 256KB *chunks*.
- peer joining torrent:
  - has no chunks, but will accumulate them over time
  - registers with tracker to get list of peers, connects to subset of peers (“neighbors”)
- while downloading, peer uploads chunks to other peers.
- peers may come and go
- once peer has entire file, it may (selfishly) leave or (altruistically) remain

# BitTorrent (2)

## Pulling Chunks

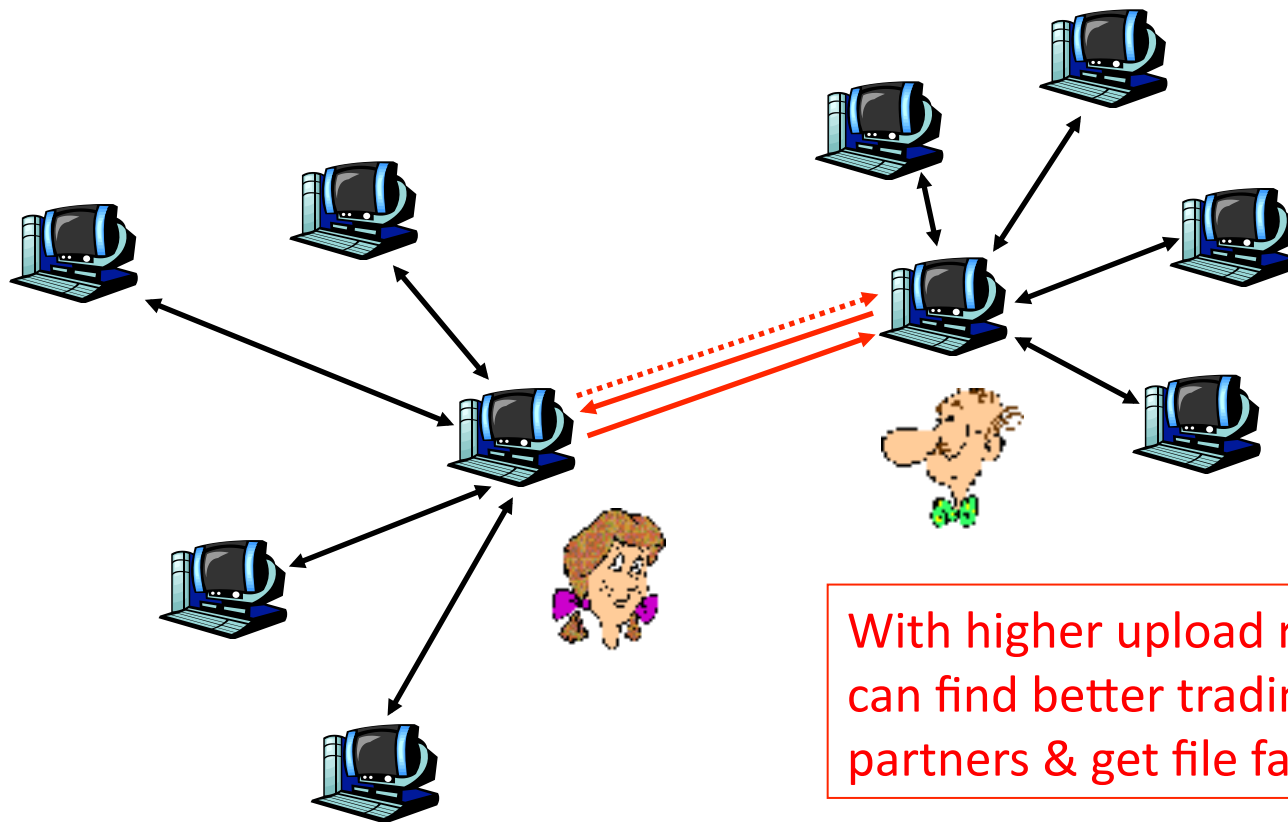
- at any given time, different peers have different subsets of file chunks
- periodically, a peer (Alice) asks each neighbor for list of chunks that they have.
- Alice sends requests for her missing chunks
  - rarest first

## Sending Chunks: tit-for-tat

- ☐ Alice sends chunks to four neighbors currently sending her chunks *at the highest rate*
  - ❖ re-evaluate top 4 every 10 secs
- ☐ every 30 secs: randomly select another peer, starts sending chunks
  - ❖ newly chosen peer may join top 4
  - ❖ “optimistically unchoke”

# 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



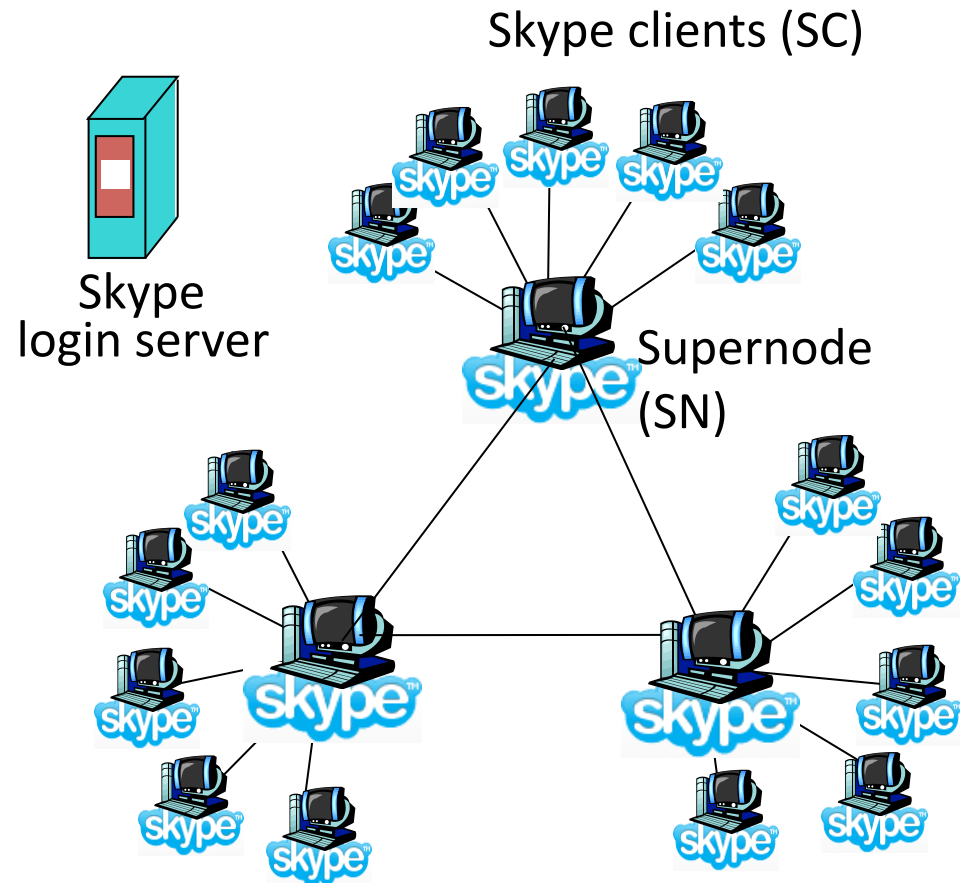
With higher upload rate,  
can find better trading  
partners & get file faster!

# 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

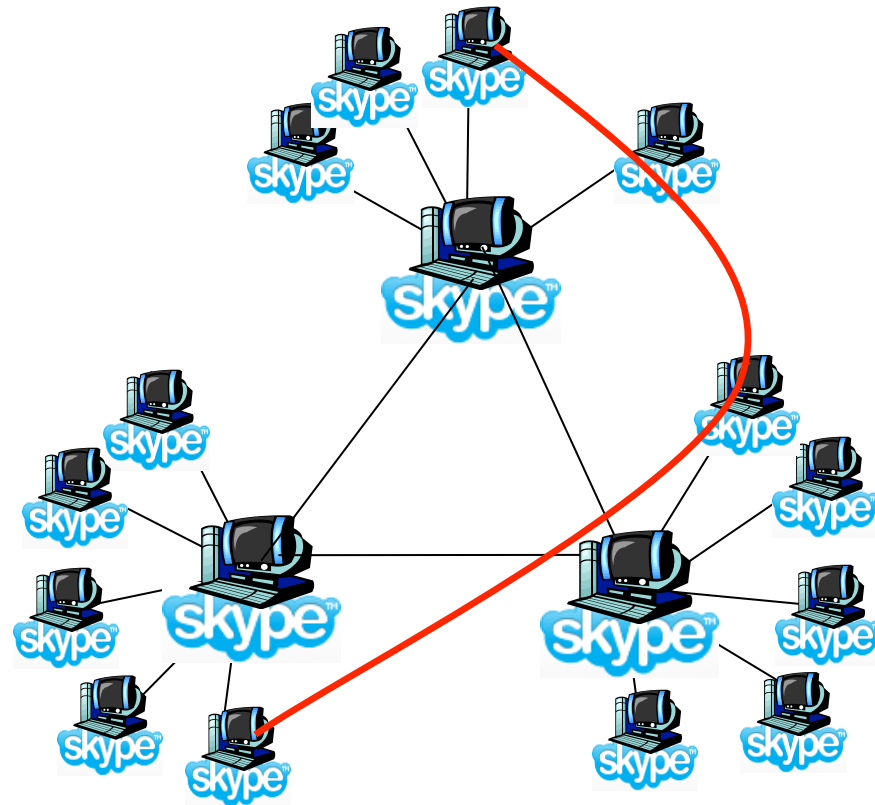
# P2P Case study: Skype

- inherently P2P: pairs of users communicate.
- proprietary application-layer protocol (inferred via reverse engineering)
- hierarchical overlay with SNs
- Index maps usernames to IP addresses; distributed over SNs



# Peers as relays

- Problem when both Alice and Bob are behind “NATs”.
  - NAT prevents an outside peer from initiating a call to insider peer
- Solution:
  - Using Alice’s and Bob’s SNs, Relay is chosen
  - Each peer initiates session with relay.
  - Peers can now communicate through NATs via relay



# 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



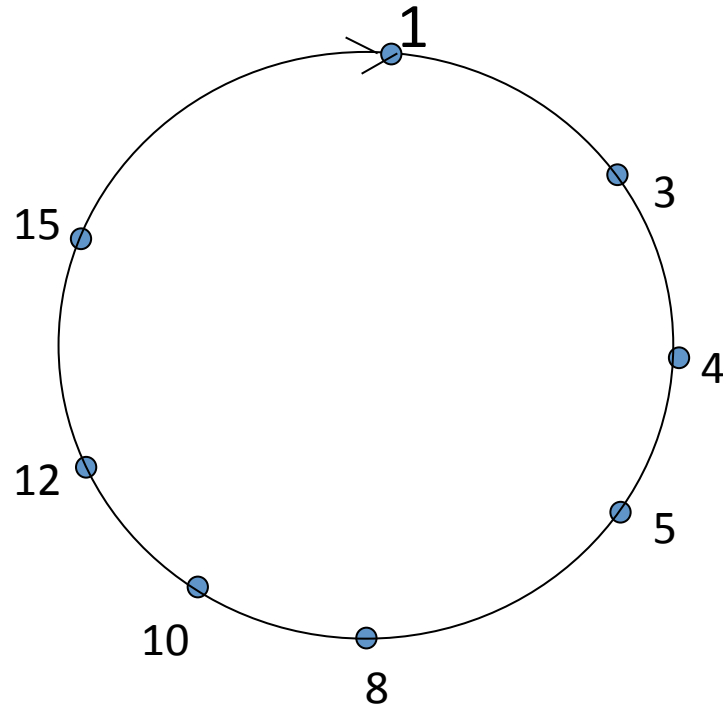
# DHT Identifiers

- 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 =  $h(\text{"Game of Thrones season 4"})$
  - 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

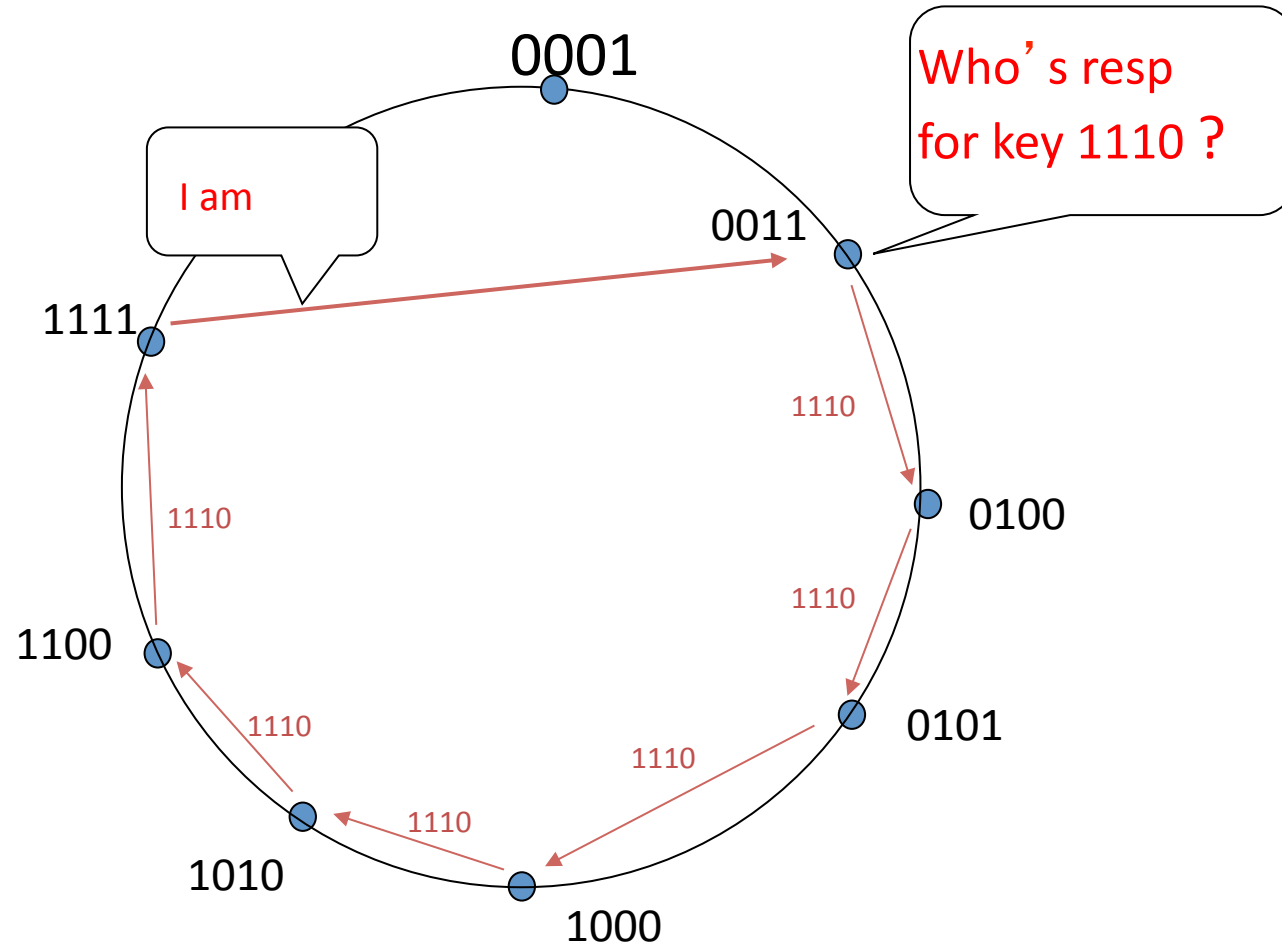
# Circular DHT (1)



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

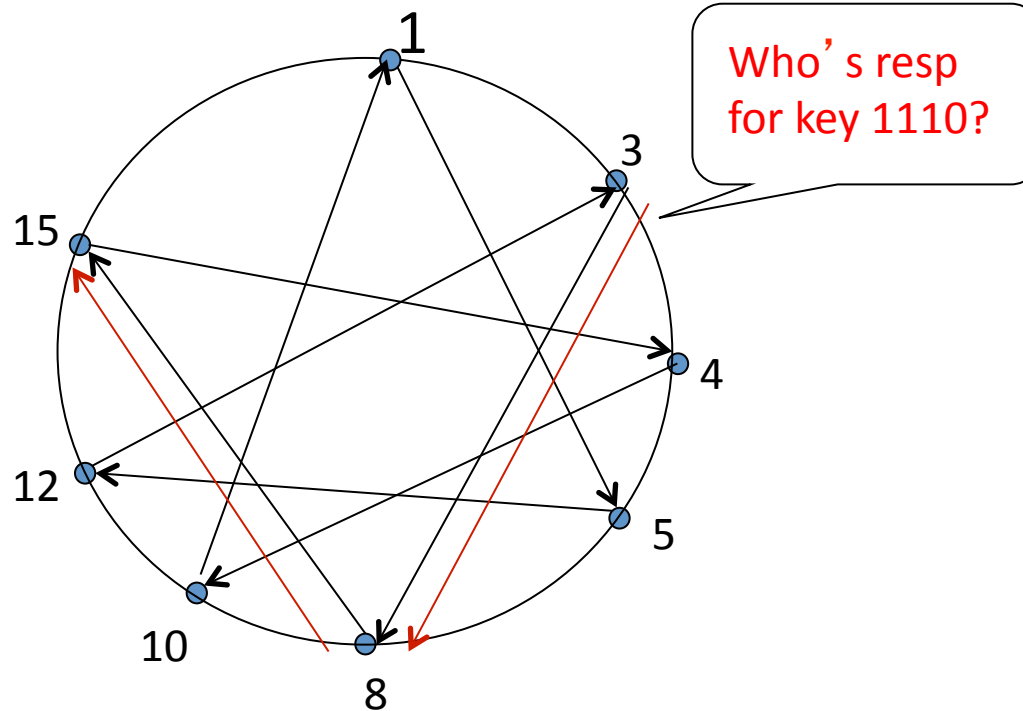
# Circle DHT (2)

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



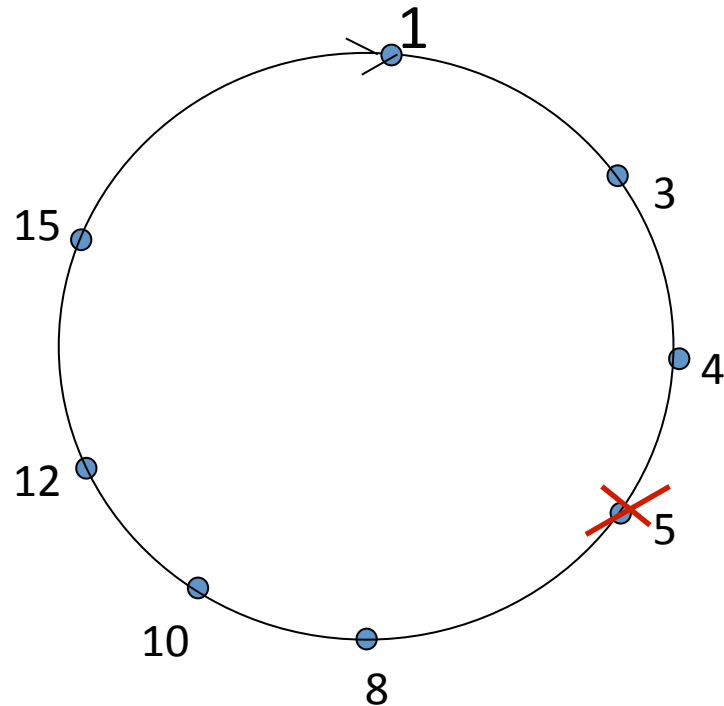
Define closest  
as closest  
successor

# 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