Application Layer

Dr. A Krishna Chaitanya,
Indian Institute of Information Technology Sri City

Network Applications

- Applications use the services of network (Transport layer)
- For an application developer, architecture and services of network are fixed
- Architectures of applications:
  - Client-Server architecture
  - Peer-to-Peer (P2P) architecture
- Application developer decides on the architecture and services of transport layer to be used.

Client-Server Architecture

- Server: An end system that serves the requests from various hosts.
- A server is always ON.
- Client: An end system that requests a server for content.
- A client can be either ON-OFF or always ON.
- Example applications using this architecture: web, e-mail, file transfer, etc.

Peer-to-Peer Architecture

- End systems communicate by a direct connection.
- The end systems are called peers.
- Example applications: skype, internet telephony, torrents, etc
- Advantages:
  - File distribution
  - Self-scalable: can handle growth in traffic
  - Cost effective: no server infrastructure and server bandwidth.
- Challenges in P2P Architecture:
  - ISP friendly: asymmetric data traffic.
  - Security
  - Incentives: Peers should share bandwidth.

Processes Communicating

- A process is a program that is running within an end system.
- A client process is a process running on a client and a server process is process running on a server.
- It is the client process and server processes that are actually communicating.
- A process sends and receives messages to and from transport layer through a software interface known as socket.
- A socket is also known as Application Programming Interface (API).

Services of Transport Layer

- Reliable data transfer: Guaranteed data delivery service.
- Throughput
- Timing: for example, it is guaranteed that a packet will be delivered no more than 100 msec later.
- security: end-point authentication, encryption and decryption.

Transport protocols

- Transmission Control Protocol (TCP)
  - Connection oriented service: handshaking, full-duplex connection
  - Reliable data transfer service: packets get delivered without error and in proper order.
  - Congestion control
- User Datagram Protocol (UDP)
  - Connectionless
  - Unreliable data transfer service.
  - No congestion control

Applications

Application	Application-Layer Protocol	Underlying Transport Protocol
Electronic mail	SMTP [RFC 5321]	TCP
Remote terminal access	Telnet [RFC 854]	TCP
Web	HTTP [RFC 2616]	TCP
File transfer	FTP [RFC 959]	TCP
Streaming multimedia	HTTP (e.g., YouTube)	TCP
Internet telephony	SIP [RFC 3261], RTP [RFC 3550], or proprietary (e.g., Skype)	UDP or TCP

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- We identify host by IP address.
- We identify processes by port numbers!
- For example, web server is identified by port number 80, mail server is identified by port number 25.

Web and HTTP

- A web page is a document and consists of objects
- An object is nothing but a file such as HyperText Markup Language (HTML) file, an image file, applet or video clip.
- If a web page contains a basic html file and ten images, we say the web page contains 11 objects.
- HyperText Transfer Protocol (HTTP) is the web's application layer protocol
- HTTP uses client-server architecture with TCP.
- The client program and server program talk to each other by exchanging HTTP messages.

Uniform Resource Locater

- An object should be addressable by a URL.
- Each URL consists of hostname and objects path name
- For example, http://www.iiits.ac.in/wp-content/uploads/2017/05/Untitled-design-15.png is url for an image.
- www.iiits.ac.in is host name
- wp-content/uploads/2017/05/Untitled-design-15.png is path name.
- Client side of HTTP is implemented in Web browser and server side is implemented in Web server.
- Examples: Apache and Microsoft Internet Information server.

HTTP

- HTTP client initiates a connection with HTTP server (handshaking).
- Once the connection is established, client and server exchange messages through socket interface.
- Client sends an HTTP request and receives HTTP messages through its socket
- Server receives HTTP requests and sends HTTP responses through its socket interface.
- Client/server need not worry about packets (does not have any control) after sending through their socket.
- Server sends requested files without storing state information of client. Thus HTTP is a stateless protocol.

HTTP Connection

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- How does client retrieve the web page?

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- Nonpersistent and Persistent

HTTP Connection

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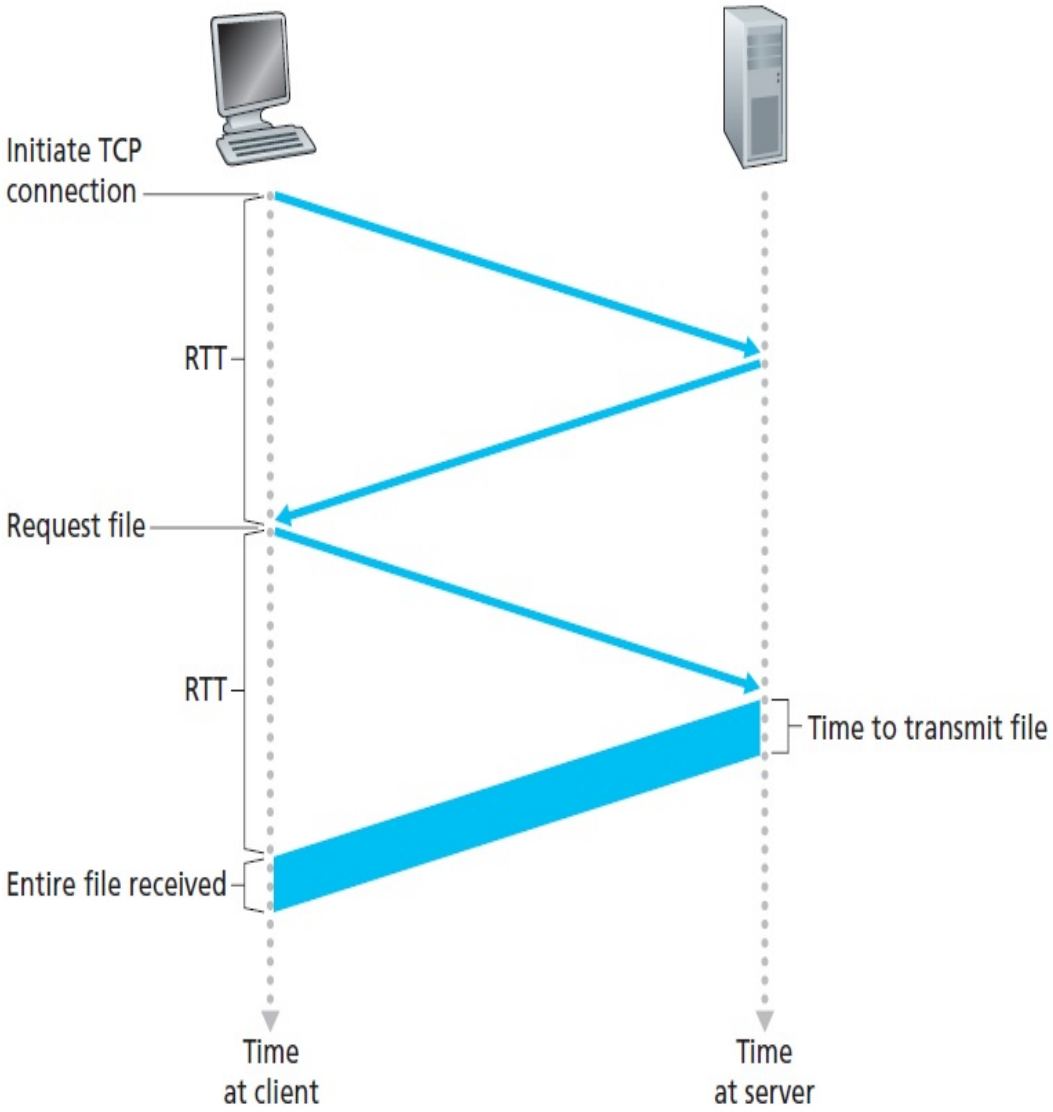
- How does client retrieve the web page?
- Nonpersistent and Persistent
- Nonpersistent: one TCP connection for each file
- Persistent: one TCP connection for all files

Nonpersistent Connection

- For each file:
  - HTTP client initiates a TCP connection to the server on port number 80
  - Client sends its HTTP request and it includes the path name to the file
  - HTTP server receives the request and retrieves the file and sends the HTTP response to the client
  - HTTP server tells TCP to close the connection.
- TCP connections can be serial or parallel depending on browser's configuration

Round-Trip Time



Persistent Connection

- Server leaves the connection after sending the HTTP response
- Pipelining: A browser can request for files without waiting for the reception of pending requests.
- TCP closes after some idle period
- Default mode HTTP: Persistent connection with pipelining.

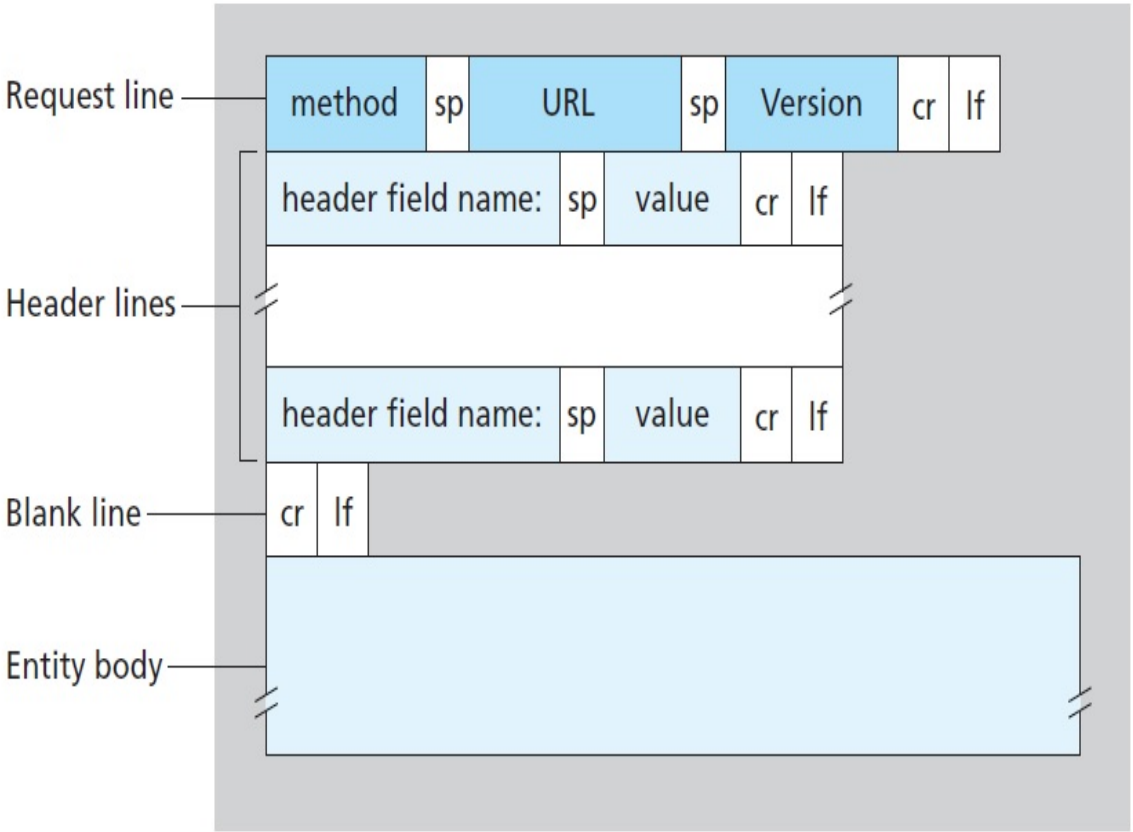
HTTP Request Format

- HTTP request message:

  GET /somedir/page.html HTTP/1.1
  Host: www.iitm.ac.in
  Connection: close
  User-agent: Mozilla/4.0
  Accept-language: En

- Methods: GET, PUT, POST, HEAD, DELETE

HTTP Request

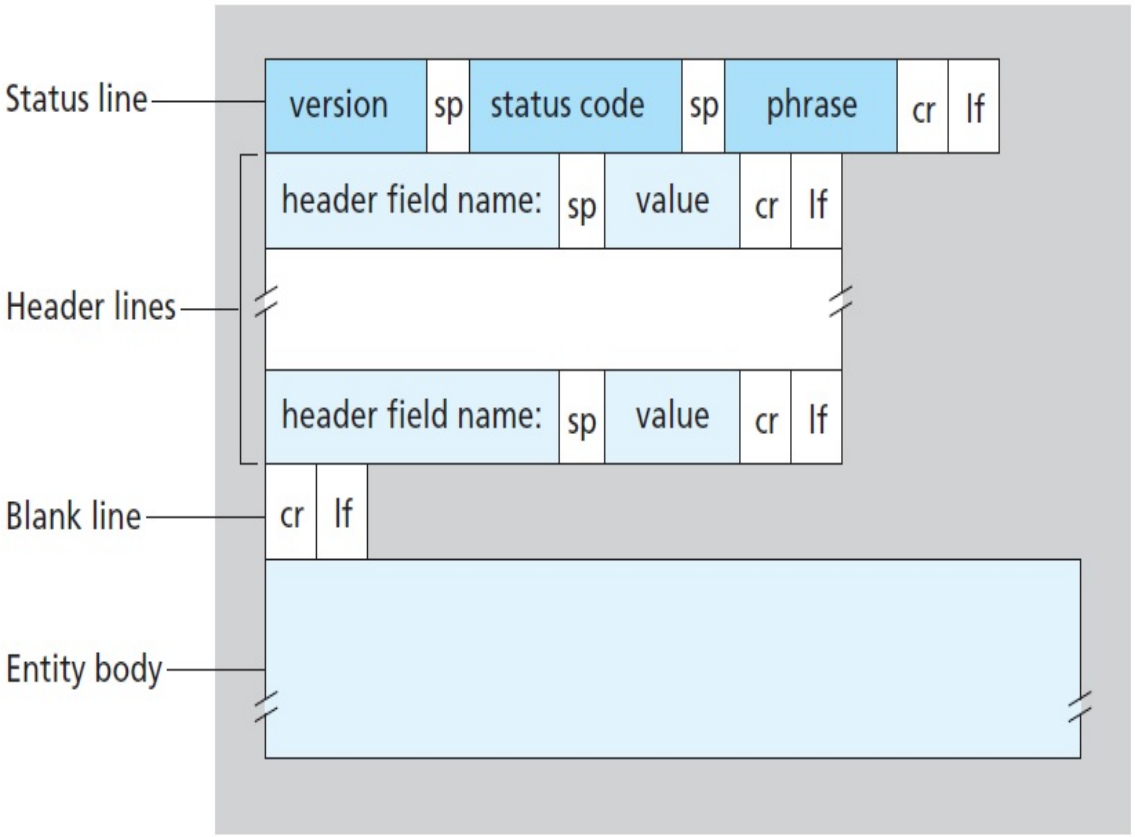


HTTP Response

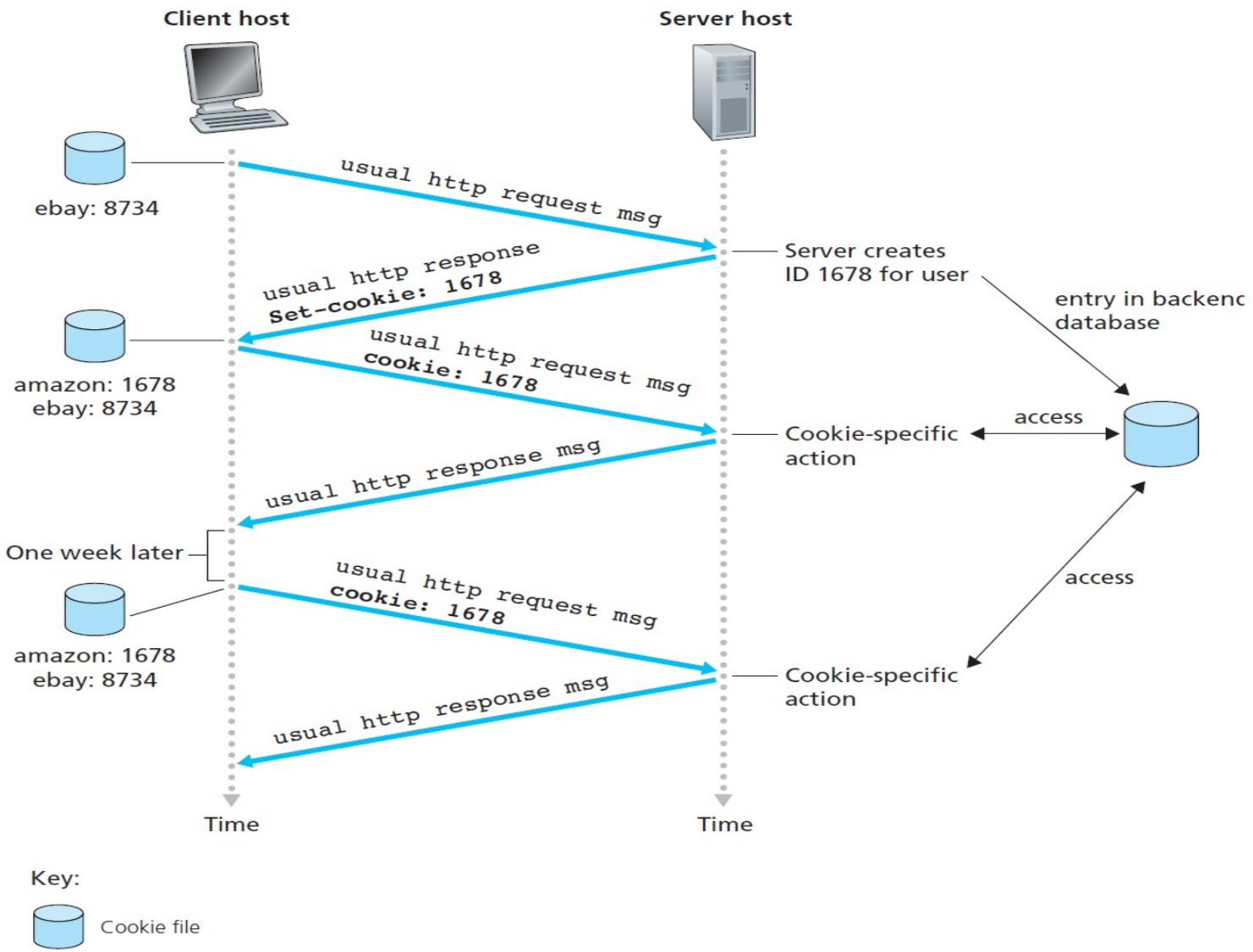
- HTTP response message:

  HTTP/1.1 200 OK
  Connection: close
  Date: Sat, 07 Jul 2007 12:00:15 GMT
  Server: Apache/1.3.0 (Unix)
  Last-Modified: Sun, 6 May 2007 09:23:24 GMT
  Content-length: 6821
  Content-Type: text/html
  (data data ... data)
- 200 OK
- 301 Moved Permanently
- 404 Not Found

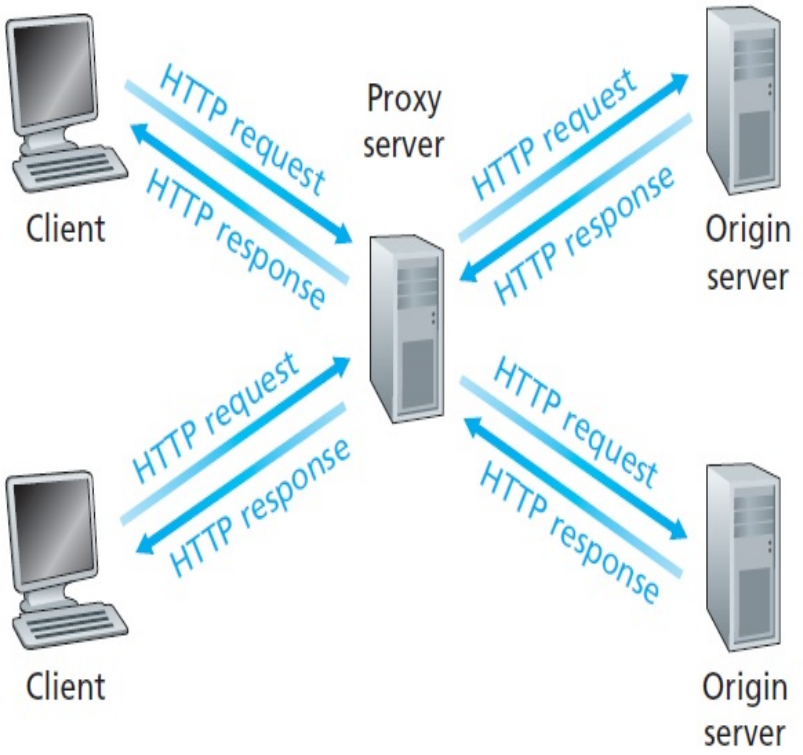
HTTP Response



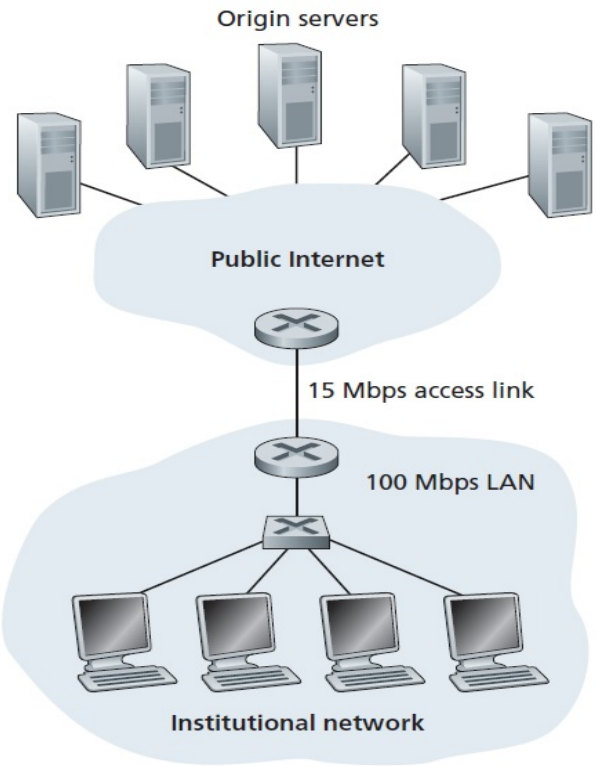
Cookies


Client host
Server host
ebay: 8734
usual http request msg
usual http response
Set-cookie: 1678
Server creates
ID 1678 for user
entry in backend
database
amazon: 1678
ebay: 8734
usual http request msg
cookie: 1678
access
Cookie-specific
action
usual http response msg
One week later
usual http request msg
cookie: 1678
access
amazon: 1678
ebay: 8734
Cookie-specific
action
usual http response msg
Time
Time
Key:
Cookie file

Web Caching


Client
HTTP request
HTTP response
Proxy server
HTTP request
HTTP response
Origin server
Client
HTTP request
HTTP response
HTTP request
HTTP response
Origin server

Problem



- Average object size is 1Mbits
- Average request rate 15 objects per sec.
- Average response time from internet is 2 sec.

Toatal Resposne Time

- Traffic intensity on the LAN

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- 0.15

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- Suppose the access link is upgraded to 100Mbps, find traffic intensity on the access link
- Find the average resposne time

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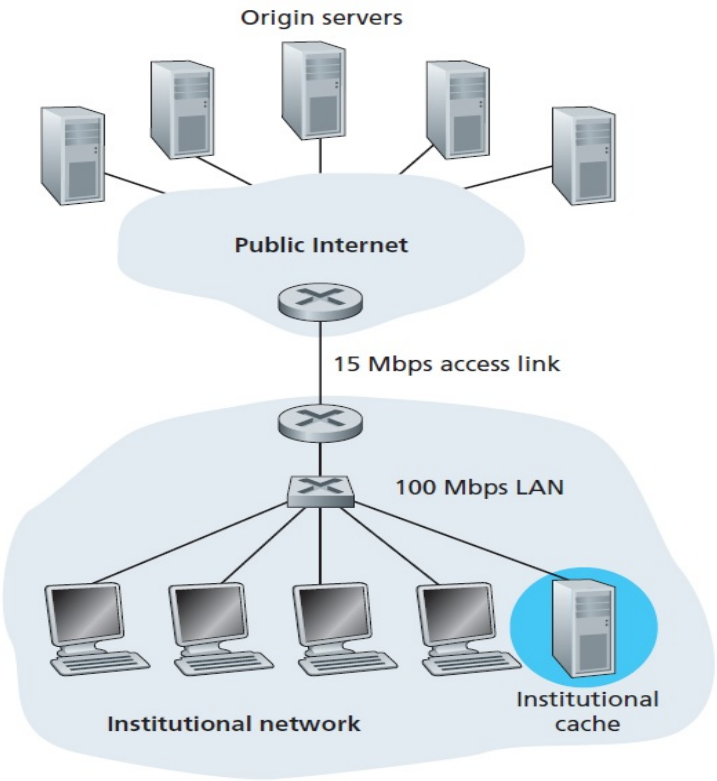
- Suppose the access link is upgraded to 100Mbps, find traffic intensity on the access link
- Find the average resposne time
- Expensive solution

Problem


Origin servers
Public Internet
15 Mbps access link
100 Mbps LAN
Institutional network
Institutional cache

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- Typical delay in the order of 10 milliseconds

Toatal Resposne Time

- Traffic intensity on the LAN
- 0.15
- Traffic intensity on the access link, assuming a hit ratio of 0.4 on the proxy server
- 0.6
- Typical delay in the order of 10 milliseconds
- Average response time: 0.4*0.01 + 0.6*2.01 seconds

Conditional GET

- Cache request message:

  GET /somedir/student.jpg HTTP/1.1
  Host: www.iiits.ac.in
  If-modified-since: Wed, 23 Aug 2017 17:30:00

Conditional GET

- Cache request message:

  GET /somedir/student.jpg HTTP/1.1
  Host: www.iiits.ac.in
  If-modified-since: Wed, 23 Aug 2017 17:30:00

- Response: HTTP/1.1 304 Not Modified

  Date: Tue, 29 Aug 2017 13:00:00
  Server: Apache/1.3.0 (Unix)
  (empty empty empty)

File Transfer Protocol

- Similar to HTTP: client-server architecture, transmission control protocol
- Two parallel TCP connections to transfer a file: TCP control connection and TCP data connection
- Control information:
  - User identification
  - Change remote directory
  - Commands to put and get files
- FTP is said to control information out-of-band where as HTTP is said to control information in-band.

FTP

- Commands:
  - USER username
  - PASS password
  - LIST
  - RETR filename
  - STOR filename
- Replies:
  - 331 username OK, password required
  - 125 data connection already open; transfer starting
  - 425 can not open data connection
  - 452 error writing file

Electronic Mail

- Asynchronous communication medium
- Major components of e-mail system:
  - User agent: allows users to read, forward, save and compose messages
  - Mail server
  - SMTP
- Examples of user agents: Microsoft Outlook, Mozilla Thunderbird, Apple Mail

SMTP

- User agent sends message to user's mail server.
- SMTP transfers message from user's mail server to recipient's mail server.
- Client side of SMTP is running on sender's mail server and server side of SMTP is running on recipient's mail server.
- Recipient's mail server delivers the message in recipient's mail box.

SMTP Sequence of Operations

- Alice composes message using her user agent. Provides Bob's mail address and instructs to send the message.
- User agent sends the message to her mail server and message waits in the queue of the server.
- SMTP client sees the message in the mail server and it opens a TCP connection to an SMTP server running on Bob's mail server.
- SMTP transfers the message from client to server.
- SMTP server receives the message. Bob's mail server places the message in Bob's mail box.
- Bob invokes his user agent to read the message.

SMTP Sequence of Operations

- If recipient's mail server is down, SMTP client reattempts to send the message (say for every 30 minutes)
- If the delivery is not successful after some duration, it will be notified to the sender and message will be dropped.

Client-Server Conversation

```
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
```

Message Formats

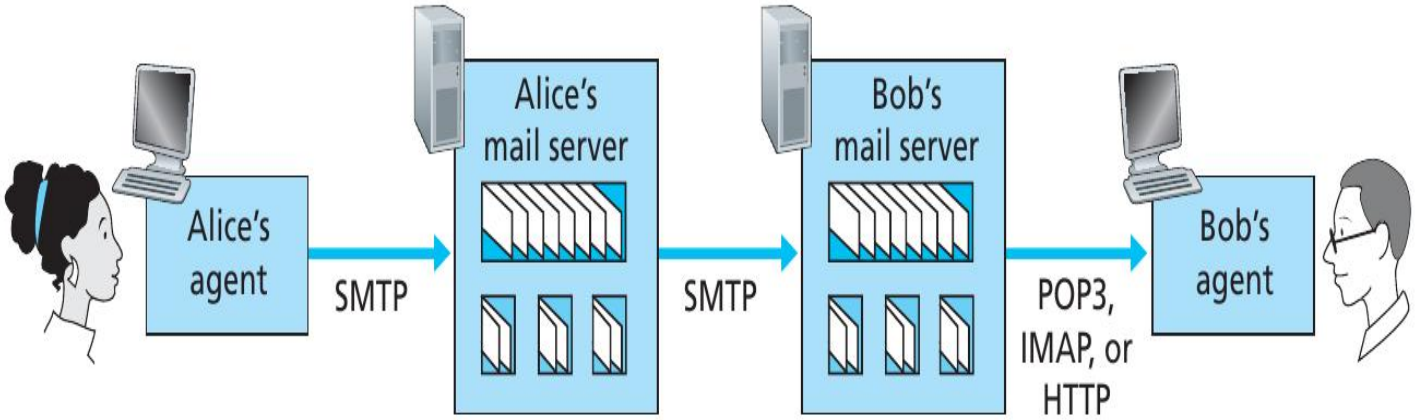
- Header lines similar to those in HTTP messages
- Header must have From:, To:
- Optional header lines include Subject:

Comparison with HTTP

- HTTP is a pull protocol
- SMTP is push protocol
- SMTP requires each message to be 7-bit ASCII format. HTTP does not have this restriction
- HTTP encapsulates each object in its own HTTP response message. Internet mail places all of its objects into one message.

Extensions of SMTP

- SMTP can transfer only text messages
- Multipurpose Internet Mail Extensions (MIME): Defines encoding rules to convert non-ASCII to 7-bit ASCII format.
- Extended SMTP (ESMTP): Authentication and added secutiy features.



Mail Access Protocols

- In early days of internet, Bob reads mail by logging onto mail server and executing a mail reader on that host
- Client-server architecture
- Reads e-mail by running a client on the user's end system
- Mail access protocol transfers message from Bob's mail server to his local PC.
- Popular mail access protocols: Post Office Protocol - version 3 (POP3), Internet Mail Access Protocol (IMAP) and HTTP

POP3

- Begins when a user agent opens a TCP connection with mail server on port 110.
- POP3 progresses in three phases:
  - Authorization
  - Transaction
  - Update
- Authorization: user <username> and pass <password>
- Transaction: user agent sends commands and server responds with +OK and -ERR

POP3 Transaction

- Two modes:
  - download and delete
  - download and keep
- Download and delete:

```
C: list
S: 1 498
S: 2 912
S: .
C: retr 1
S: (blah blah ...
S: ..................
S: ..........blah)
S: .
C: dele 1
C: retr 2
S: (blah blah ...
S: ..................
S: ..........blah)
S: .
C: dele 2
C: quit
S: +OK POP3 server signing off
```

IMAP and HTTP

- IMAP associates each message with a folder
- Provides commands to allow users to create folder and move messages across folders
- Provides commands to search for a message
- Maintains user state information across IMAP sessions
- Components of messages can be retrieved
- HTTP:
  - e-mail access through web browser
  - web browser communicates to the mail server via HTTP

What is a Domain Name

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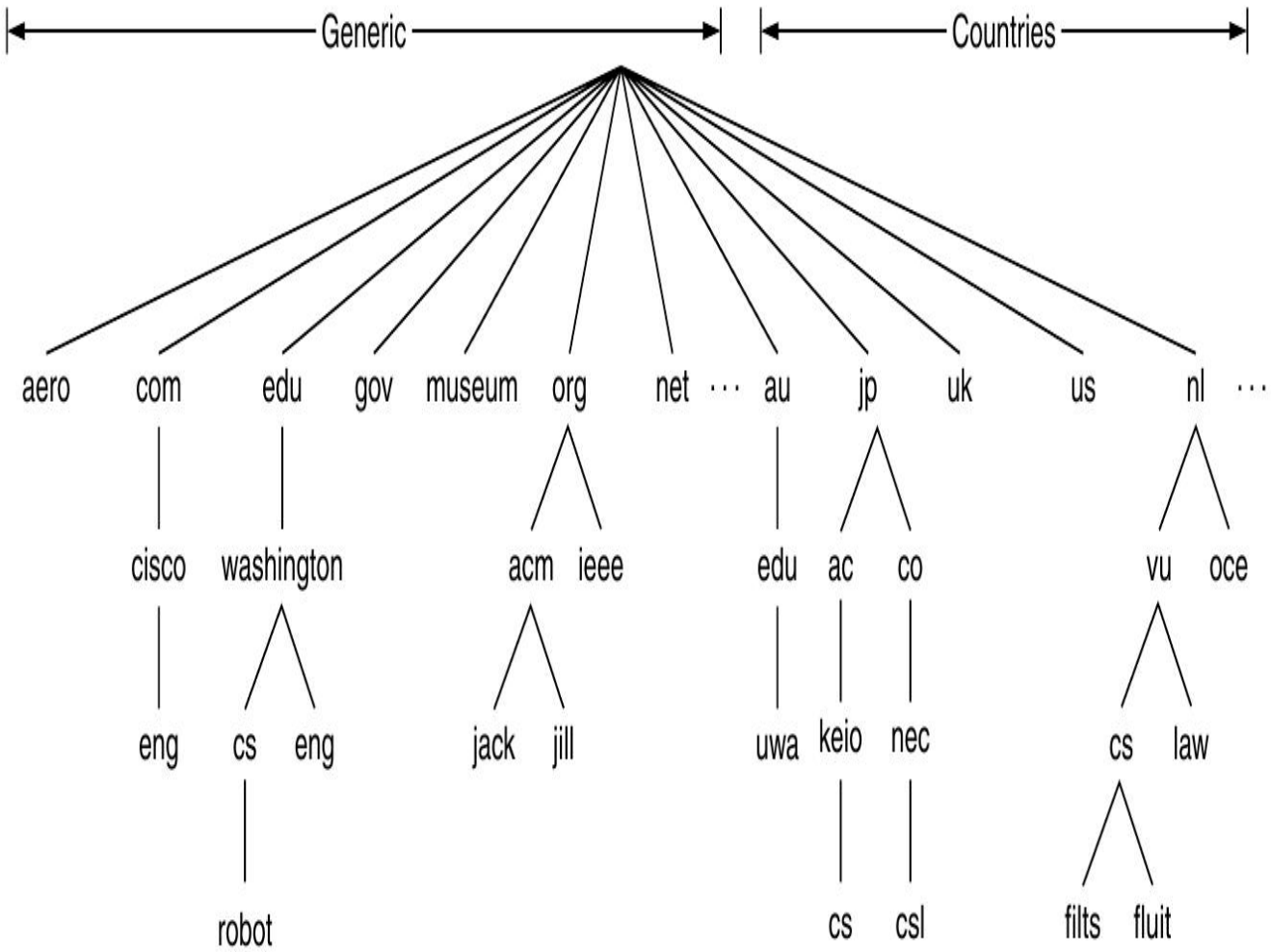
- **250** top-level domains; examples: com, org, edu.

Domain Name Space



Examples of Domains

Domain	Intended use	Start date	Restricted?
com	Commercial	1985	No
edu	Educational institutions	1985	Yes
gov	Government	1985	Yes
int	International organizations	1988	Yes
mil	Military	1985	Yes
net	Network providers	1985	No
org	Non-profit organizations	1985	No

Who Manages Domains

- ICANN: Internet Corporation for Assigned Names and Numbers
- Registrars of ICANN check for uniqueness
- Domain names can be **absolute** or **relative**
- Absolute domain names end with **.**
- Relative domain names have to be interpreted based on the context

Domain Name Server: The Directory

- We identify hosts by hostnames. For example, www.amazon.in

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- For a network, there is a very little information about the host. Network needs IP address for processing
- Domain name servers (DNS) provides the necessary mapping from hostname to IP address
- DNS is an application layer protocol used by other applications
- Client-Server architecture; uses UDP at its transport layer

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- The canonical hostnames are not mnemonic. Canonical: *according to the rules*
- Example: *www.timesofindia.com* is the alias but the actual host name or canonical name is *timesofindia.indiatims.com*
- Different canonical names might have the same alias
- Many hosts can be installed within a domain or subdomain. Example: *www.ee.iitm.ac.in*, *www.cse.iitm.ac.in*, *smail.iitm.ac.in*

Services of DNS

- The Internet's directory service

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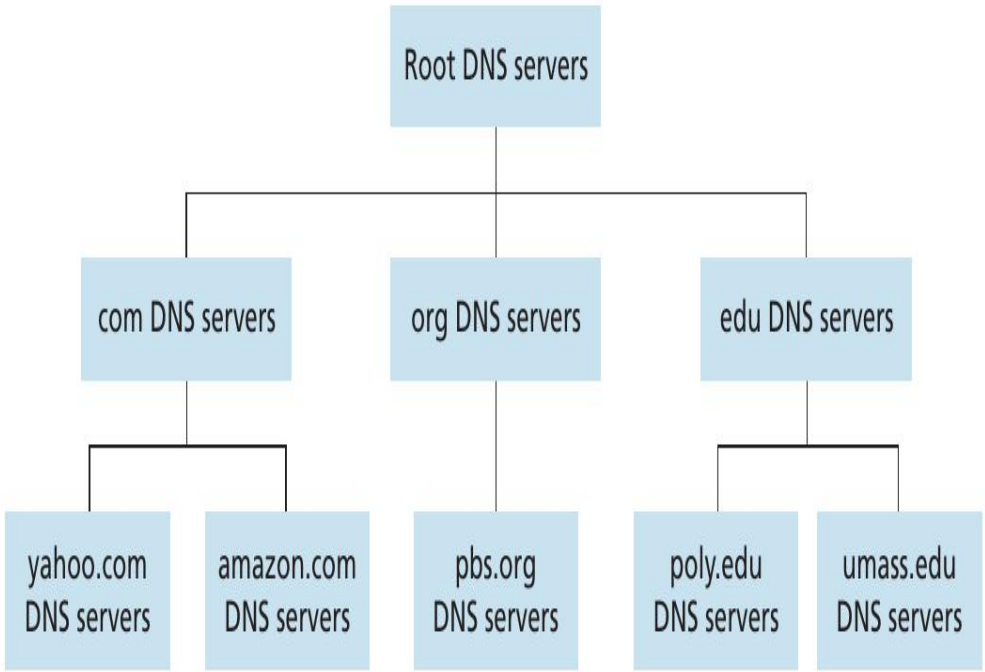
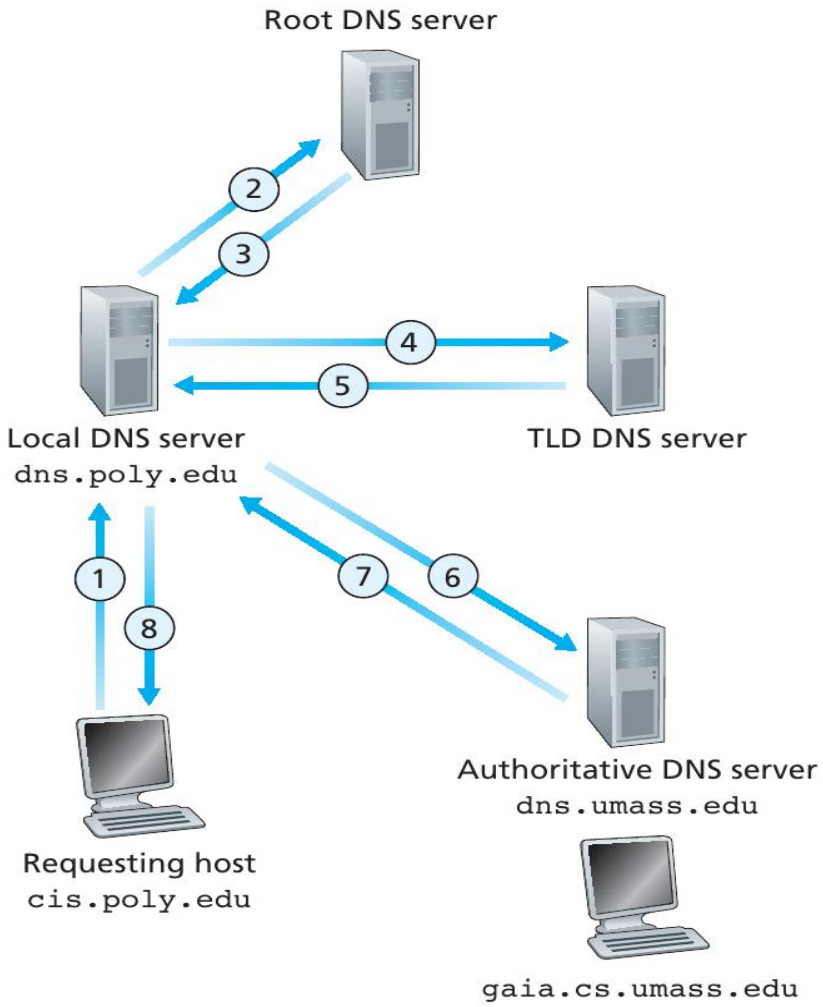
- Load distribution, example: *IRCTC*

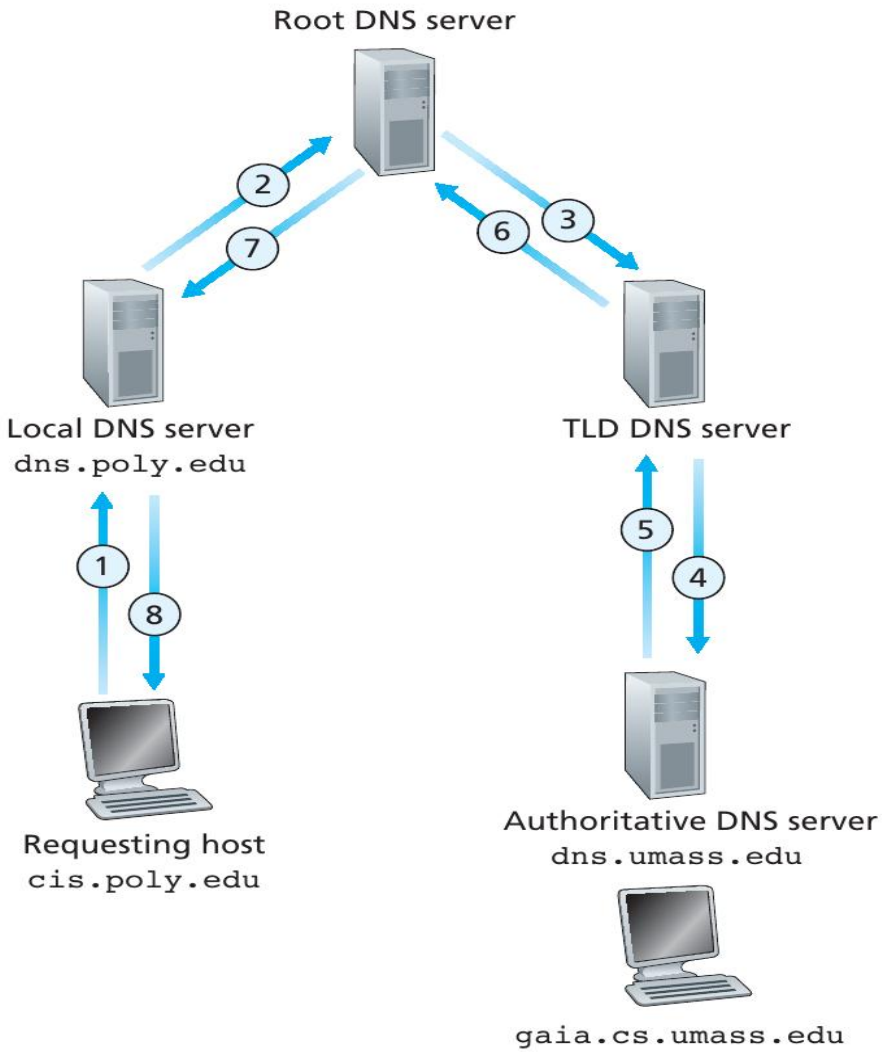
Hierarchy of DNS



How does DNS Work: Recursive and Iterative Query



How does DNS Work: Recursive Query



Local DNS

- An ISP can provide local DNS
- Host will query the local DNS and that takes it forward to the root DNS
- Cache DNS replies

DNS Resource Records

- DNS distributed database store resource records

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- TTL: Time-to-Live
- The interpretation of Name and Value files change based on Type

Types in RR

- Type = A: *Name* is a hostname and *Value* is the IP address of the host

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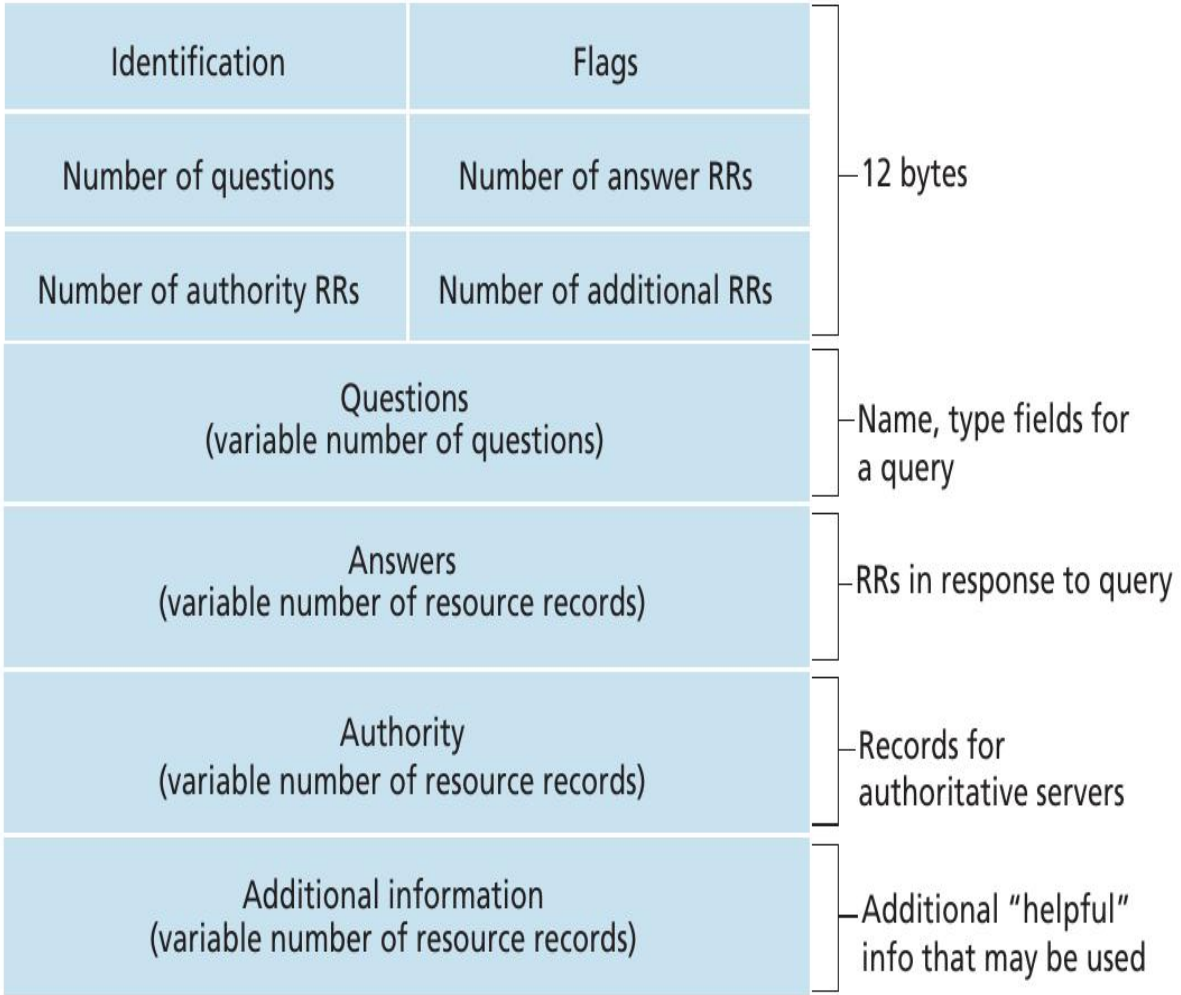
- Type = NS: *Name* is a domain and *Value* is the hostname of the authoritative DNS server
- Type = CNAME: *Name* is an alias and *Value* is the canonical hostname of the alias.
- Type = MX: *Name* is an alias hostname and *Value* is the canonical hostname of a mail server of the alias.

Types in RR

Type	Meaning	Value
SOA	Start of authority	Parameters for this zone
A	IPv4 address of a host	32-Bit integer
AAAA	IPv6 address of a host	128-Bit integer
MX	Mail exchange	Priority, domain willing to accept email
NS	Name server	Name of a server for this domain
CNAME	Canonical name	Domain name
PTR	Pointer	Alias for an IP address
SPF	Sender policy framework	Text encoding of mail sending policy
SRV	Service	Host that provides it
TXT	Text	Descriptive ASCII text

DNS Message Fromat



Flags

- 1-bit flag to indicate its a query/reply
- 1-bit recursion flag is set if the DNS supports recursion

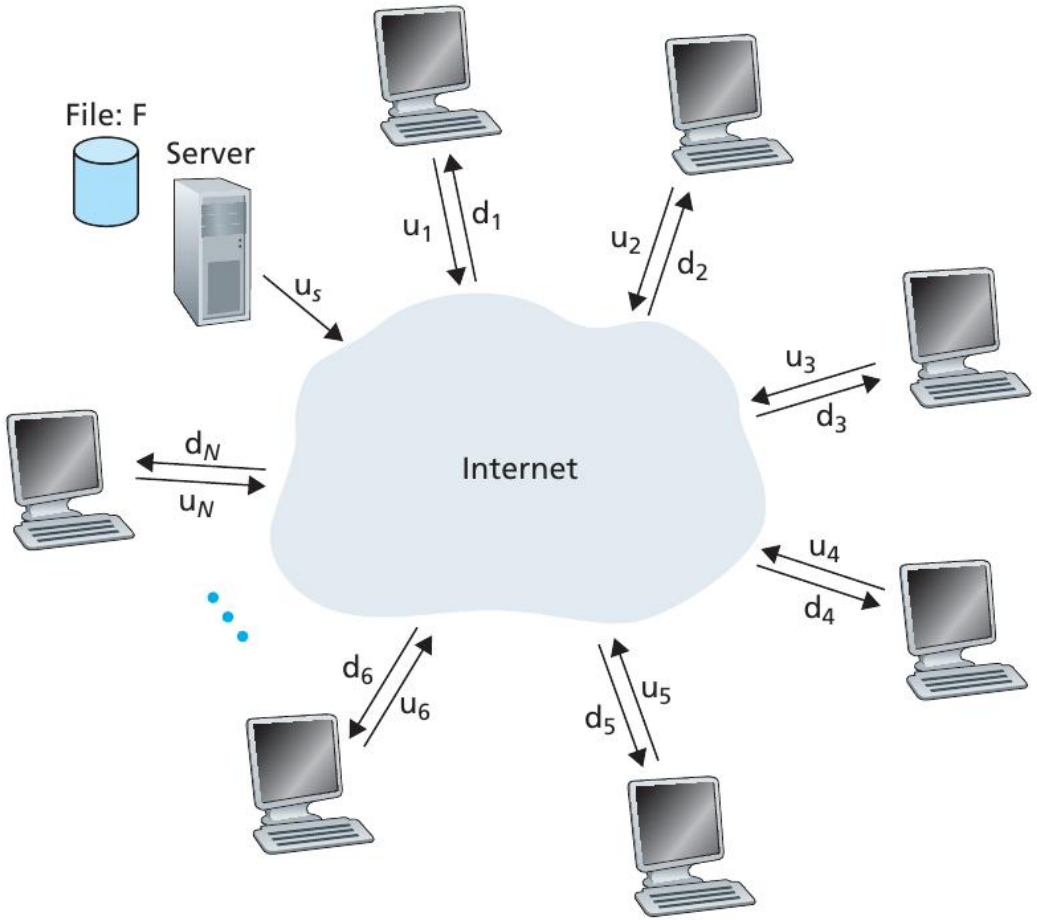
Applications of Peer-to-Peer Architecture

- File distribution: application that transfers a file from a single source to multiple peers.
- Database distributed over a large community of peers.
- Internet telephony : Skype.

File Distribution

- Each peer can redistribute any portion of the file to any other peer
- Popular file distribution protocol : BitTorrent,developed by Bram Cohen
- Scalability

Scalability



- N peers
- Distribution time: the time required to distribute a file to all peers.

Assumptions

- Internet has abundant bandwidth and all bottlenecks are in the network access
- All the server and client bandwidth is available for file distribution

Distribution Time for Client-Server Architecture

- Let D_{cs} denote the distribution time for client-server architecture for a file size of F bits
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- Let $d_{min} = \min\{d_1, \ldots, d_N\}$
- Minimum distribution time is $\frac{F}{d_{min}}$ seconds
- Thus,

$$D_{cs} \geq \max\left\{\frac{NF}{u_s}, \frac{F}{d_{min}}\right\}$$

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- Minimum time required for distribution is $\frac{NF}{u_s}$ seconds
- Let $d_{min} = \min\{d_1, \ldots, d_N\}$
- Minimum distribution time is $\frac{F}{d_{min}}$ seconds
- Thus,

$$D_{cs} \geq \max\left\{\frac{NF}{u_s}, \frac{F}{d_{min}}\right\}$$

- Show that

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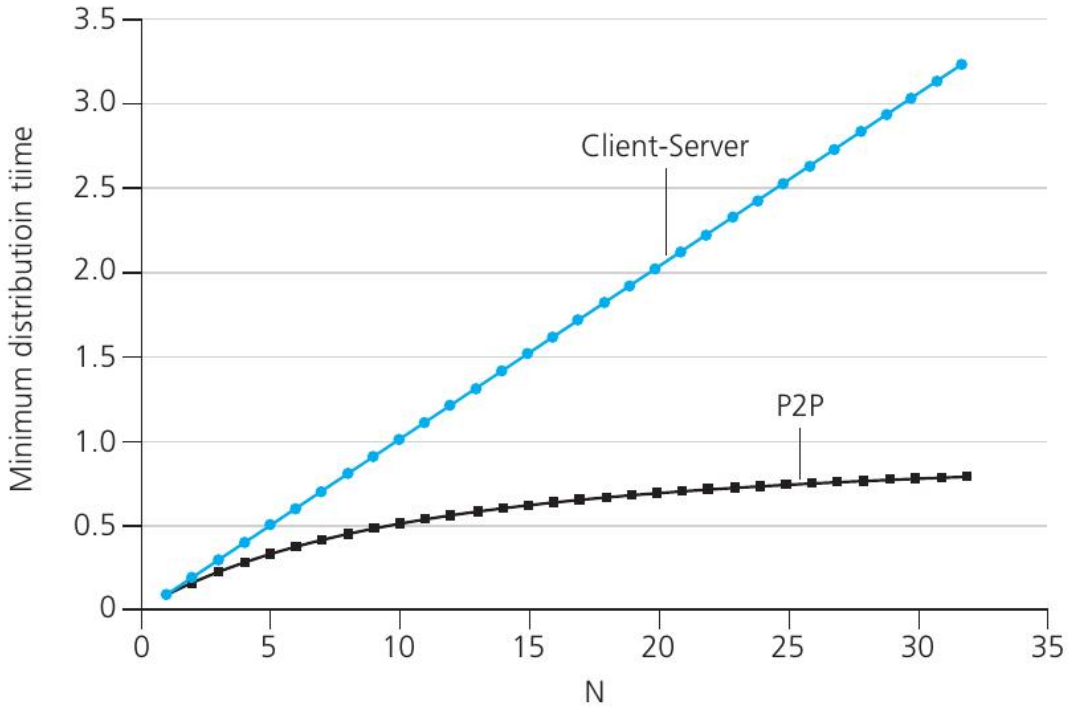
- Assumption: each peer can redistribute a bit as soon as it receives the bit.
- There is a scheme that actually achieves this lower bound.

Distribution Time for P2P Architecture



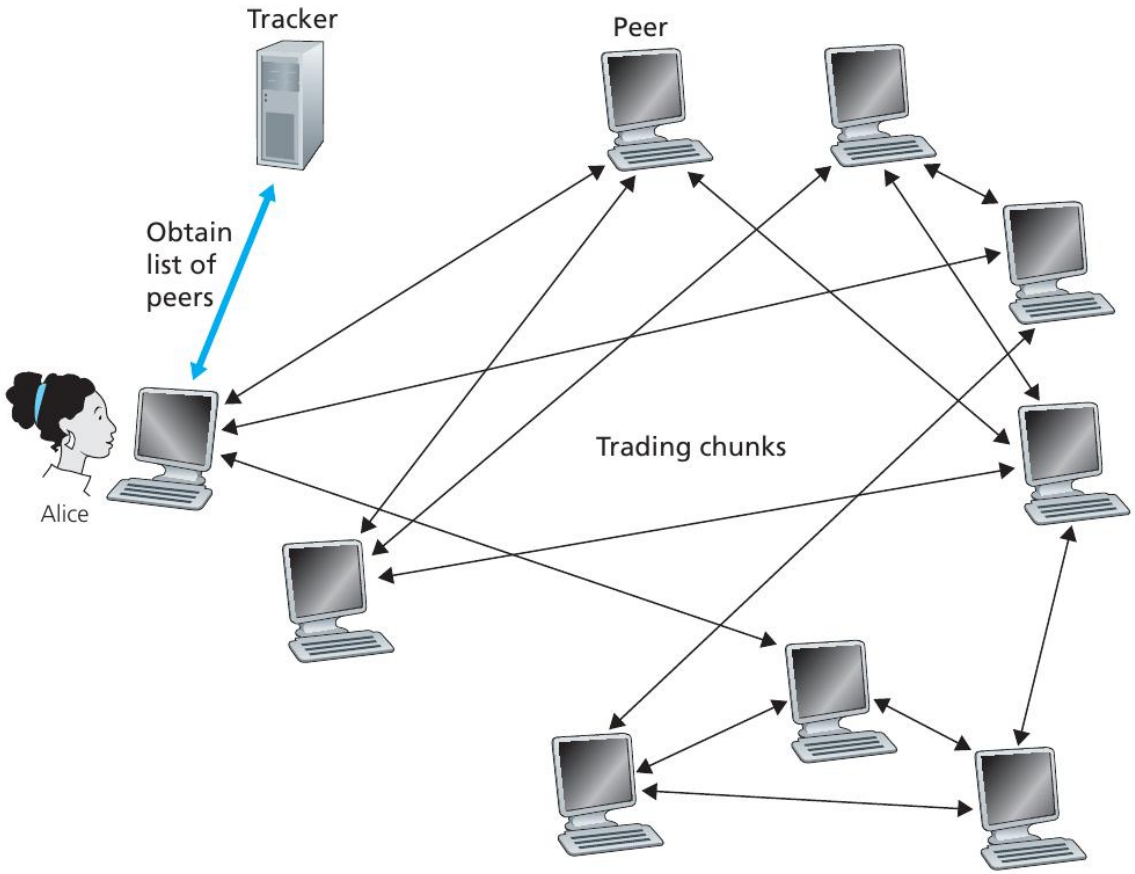
- All peers upload at a rate of u bps.
- $\frac{F}{u} = 1$ hour, $u_s = 10u$ and $d_{min} \geq u_s$.

Bit Torrent

- Collection of peers participating in the distribution of a file is called a torrent
- Peers in a torrent download equal-size chunks of the file (typically 256 KBytes)
- A peer accumulates more and more chunks over time
- Once a peer has acquired complete file, it may leave the torrent or continue to participate in the torrent
- Peers may leave torrents with subsets of chunks

Bit Torrent

- Each torrent has a node called tracker.
- When a peer joins the torrent, it registers with the tracker
- Each peer in the torrent periodically updates the tracker about its presence.



Bit Torrent

- Alice receives a subset of participating peers in the torrent
- She establishes TCP connection with some of the peers and we call them as neighboring peers of Alice
- Neighboring peers may vary over time
- Each peer will have some subset of chunks from the file, with different peers having different subsets
- Alice maintains a list of chunks that her neighbors have.

Bit Torrent

- Alice will issue requests for chunks she currently does not have
- Which chunks should be requested first?

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Bit Torrent

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- Rarest first: finds the chunks that are rarest among her neighbors

Bit Torrent

- Alice will issue requests for chunks she currently does not have
- To which of her neighbors should she send requested chunks?
- Tit-for-tat

Tit-for-tat

- Alice gives priority to the neighbors that are currently supplying her data at the highest rate
- Typically four neighbors are chosen. These peers are said to be unchoked
- Every 30 seconds, she also picks one additional neighbor at random and sends it chunks. Let it be Bob.
- Bob is said to be optimistically unchoked.
- In due course of time, Alice, may become one of the top uploaders in which case Bob could start sending data to Alice.

Distributed Hash Tables (DHT)

- Huge database to be stored among number of peers in a distributed way
- Database is consists of (key, value) pairs. For Example, (PAN No., Aadhar No.), (Content Name, IP), etc.
- Peers query the database by supplying the key and database replies the matching pairs to the querying peer
- How to store database among the peers

DHT

- Assign an identifier to each peer.
- An identifier is an integer in $[0, 2^n - 1]$ for some fixed n
- (key, value) pairs are also identified by integers using hash functions
- Hash function is available to all peers.

Storing in DHT

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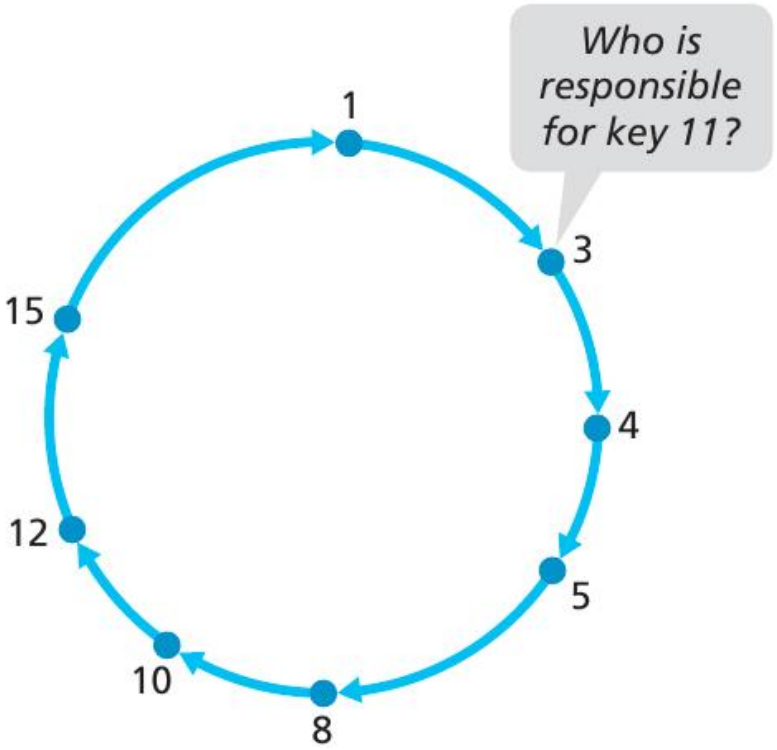
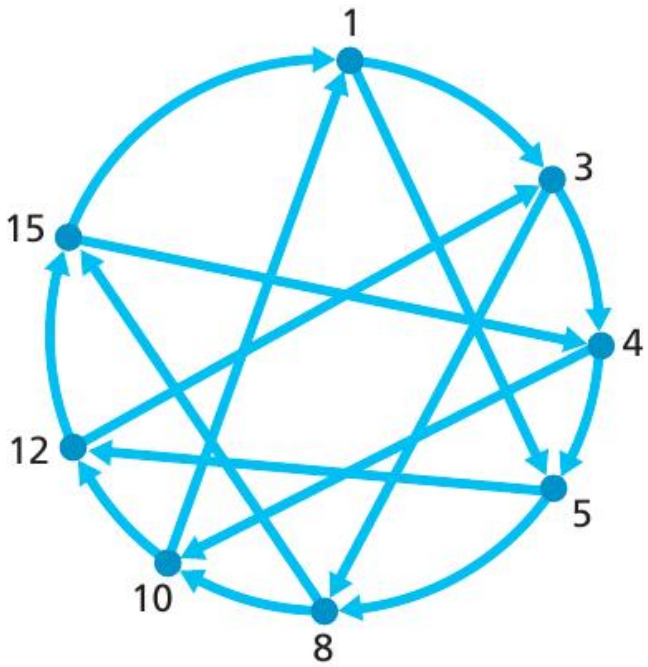
- Closest to the key:
- For example, $n = 4$, with eight peers: 1,3,4,5,8,10,12 and 15. Store (11, 0123-4567-8910) in one of the eight peers
- By closest convention, peer 12 is the immediate successor for key 11. Store in peer 12.
- If the key is larger than all the peer identifiers, we use modulo-2^n convention.

Circular DHT



- Each peer is aware of only its immediate predecessor and successor
- N messages at most

Shortcut



- Number of shortcuts are relatively small in number
- How many shortcut neighbors and which peers should be these shortcut neighbors? Research problem: $O(\log(N))$

Peer Churn

- Peers can come and go without warning
- Peers keep track to two immediate predecessor and successors.
- When a peer abruptly leaves, its predecessor and successor learn that a peer has left and updates the list of its predecessor and successor.