Chapter 2: outline

2.1 principles of network applications
- app architectures
- app requirements

2.2 Web and HTTP

2.3 FTP

2.4 electronic mail
- SMTP, POP3, IMAP

2.5 DNS

2.6 P2P applications

2.7 socket programming with UDP and TCP

DNS: domain name system

people: many identifiers:
- SSN, name, passport #

Internet hosts, routers:
- IP address (32 bit) - used for addressing datagrams
- "name", e.g., www.yahoo.com - used by humans

Q: how to map between IP address and name, and vice versa ?

Domain Name System:
- *distributed database* implemented in hierarchy of many *name servers*
- *application-layer protocol:* hosts, name servers communicate to *resolve* names (address/name translation)
  - note: core Internet function, implemented as application-layer protocol
  - complexity at network's "edge"

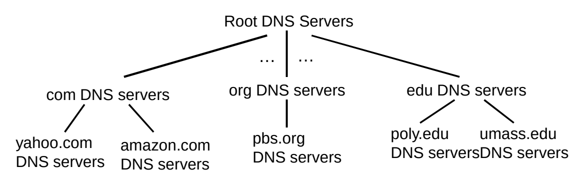
DNS: services, structure

DNS services
- hostname to IP address translation
- host aliasing
  - canonical, alias names
- mail server aliasing
- load distribution
  - replicated Web servers: many IP addresses correspond to one name

why not centralize DNS?
- single point of failure
- traffic volume
- distant centralized database
- maintenance

A: doesn't scale!

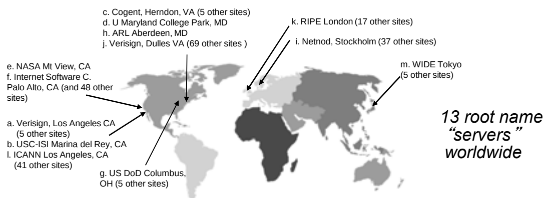
DNS: a distributed, hierarchical database



client wants IP for www.amazon.com; 1st approx:
- client queries root server to find com DNS server
- client queries .com DNS server to get amazon.com DNS server
- client queries amazon.com DNS server to get IP address for www.amazon.com

DNS: root name servers

- contacted by local name server that can not resolve name
- root name server:
  - contacts authoritative name server if name mapping not known
  - gets mapping
  - returns mapping to local name server



TLD, authoritative servers

top-level domain (TLD) servers:
- responsible for com, org, net, edu, aero, jobs, museums, and all top-level country domains, e.g.: uk, fr, ca, jp
- Network Solutions maintains servers for .com TLD
- Educause for .edu TLD

authoritative DNS servers:
- organization's own DNS server(s), providing authoritative hostname to IP mappings for organization's named hosts
- can be maintained by organization or service provider

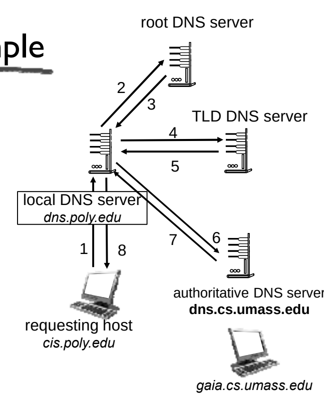
Local DNS name server

- does not strictly belong to hierarchy
- each ISP (residential ISP, company, university) has one
  - also called "default name server"
- when host makes DNS query, query is sent to its local DNS server
  - has local cache of recent name-to-address translation pairs (but may be out of date!)
  - acts as proxy, forwards query into hierarchy

DNS name resolution example

- host at cis.poly.edu wants IP address for gaia.cs.umass.edu

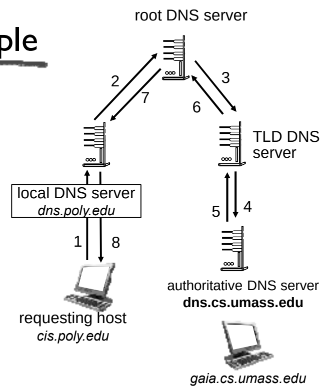
iterated query:
- contacted server replies with name of server to contact
- "I don't know this name, but ask this server"



DNS name resolution example

recursive query:

- puts burden of name resolution on contacted name server
- heavy load at upper levels of hierarchy?



DNS: caching, updating records

- once (any) name server learns mapping, it *caches* mapping
  - cache entries timeout (disappear) after some time (TTL)
  - TLD servers typically cached in local name servers
    - thus root name servers not often visited
- cached entries may be *out-of-date* (best effort name-to-address translation!)
  - if name host changes IP address, may not be known Internet-wide until all TTLs expire
- update/notify mechanisms proposed IETF standard
  - RFC 2136

DNS records

DNS: distributed db storing resource records (RR)

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

type=A
- `name` is hostname
- `value` is IP address

type=NS
- `name` is domain (e.g., foo.com)
- `value` is hostname of authoritative name server for this domain

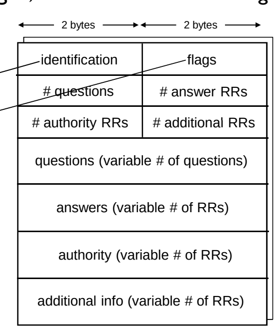
type=CNAME
- `name` is alias name for some "canonical" (the real) name
- `www.ibm.com` is really `servereast.backup2.ibm.com`
- `value` is canonical name

type=MX
- `value` is name of mailserver associated with `name`

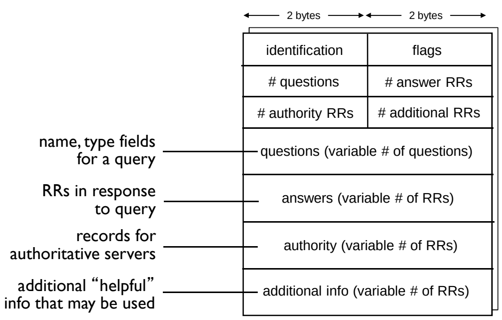
DNS protocol, messages

- *query* and *reply* messages, both with same *message format*

msg header
- identification: 16 bit # for query, reply to query uses same #
- flags:
  - query or reply
  - recursion desired
  - recursion available
  - reply is authoritative



DNS protocol, messages



Inserting records into DNS

- example: new startup "Network Utopia"
- register name networkuptopia.com at *DNS registrar* (e.g., Network Solutions)
  - provide names, IP addresses of authoritative name server (primary and secondary)
  - registrar inserts two RRs into .com TLD server:
    `(networkutopia.com, dns1.networkutopia.com, NS)`
    `(dns1.networkutopia.com, 212.212.212.1, A)`
- create authoritative server type A record for www.networkuptopia.com; type MX record for networkutopia.com

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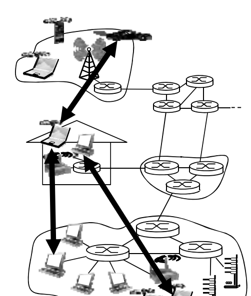
Pure P2P architecture

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

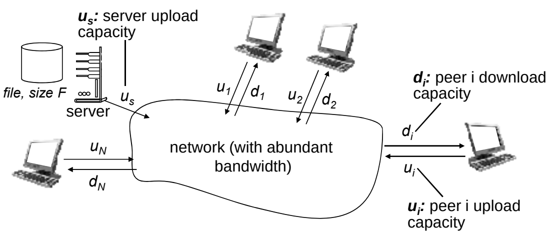
examples:
- file distribution (BitTorrent)
- Streaming (KanKan)
- VoIP (Skype)



File distribution: client-server vs P2P

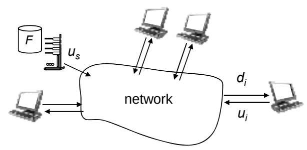
Question: how much time to distribute file (size *F*) from one server to *N* peers?

- peer upload/download capacity is limited resource



File distribution time: client-server

- *server transmission:* must sequentially send (upload) *N* file copies:
  - time to send one copy: F/u_s
  - time to send N copies: NF/u_s
- *client:* each client must download file copy
  - d_{min} = min client download rate
  - min client download time: F/d_{min}

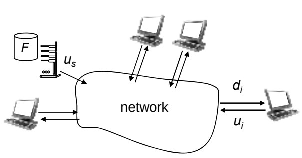


time to distribute F to N clients using client-server approach	$D_{c\text{-}s} \geq max\{NF/u_s, F/d_{min}\}$

increases linearly in N

File distribution time: P2P

- *server transmission:* must upload at least one copy
  - time to send one copy: F/u_s
- *client:* each client must download file copy
  - min client download time: F/d_{min}
- *clients:* as aggregate must download *NF* bits
  - max upload rate (limting max download rate) is $u_s + \Sigma u_i$

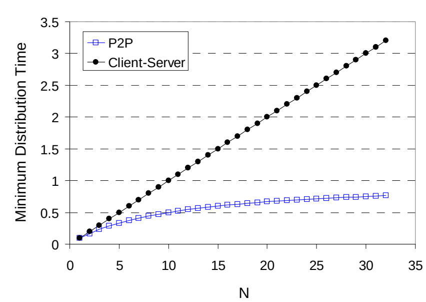


time to distribute F to N clients using P2P approach	$D_{P2P} \geq max\{F/u_s, F/d_{min}, NF/(u_s + \Sigma u_i)\}$

increases linearly in *N* …
… but so does this, as each peer brings service capacity

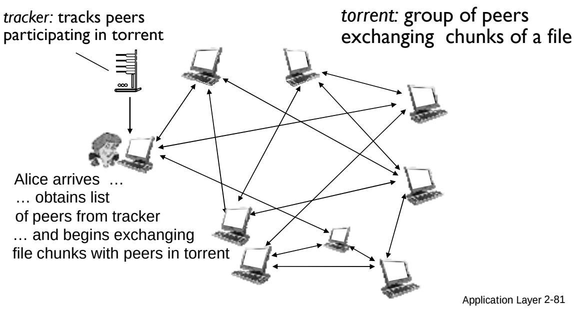
Client-server vs. P2P: example

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

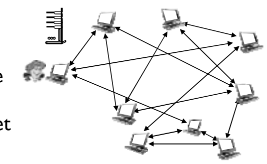


P2P file distribution: BitTorrent

- file divided into 256Kb chunks
- peers in torrent send/receive file chunks



P2P file distribution: BitTorrent



- peer joining torrent:
  - has no chunks, but will accumulate them over time from other peers
  - registers with tracker to get list of peers, connects to subset of peers ("neighbors")
- while downloading, peer uploads chunks to other peers
- peer may change peers with whom it exchanges chunks
- *churn:* peers may come and go
- once peer has entire file, it may (selfishly) leave or (altruistically) remain in torrent

BitTorrent: requesting, sending file chunks

requesting chunks:

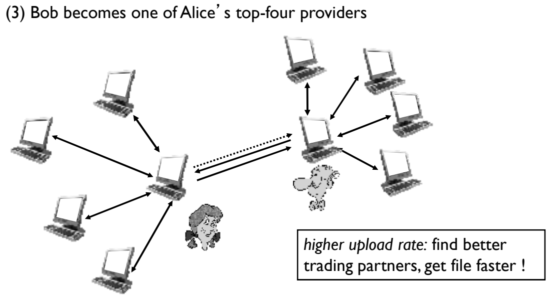
- at any given time, different peers have different subsets of file chunks
- periodically, Alice asks each peer for list of chunks that they have
- Alice requests missing chunks from peers, rarest first

sending chunks: tit-for-tat

- Alice sends chunks to those four peers currently sending her chunks *at highest rate*
  - other peers are choked by Alice (do not receive chunks from her)
  - re-evaluate top 4 every10 secs
- every 30 secs: randomly select another peer, starts sending chunks
  - "optimistically unchoke" this peer
  - newly chosen peer may join top 4

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



Distributed Hash Table (DHT)

- DHT: a *distributed P2P database*
- database has (key, value) pairs; examples:
  - key: ss number; value: human name
  - key: movie title; value: IP address
- Distribute the (key, value) pairs over the (millions of peers)
- a peer queries DHT with key
  - DHT returns values that match the key
- peers can also insert (key, value) pairs

Q: how to assign keys to peers?

- central issue:
  - assigning (key, value) pairs to peers.
- basic idea:
  - convert each key to an integer
  - Assign integer to each peer
  - put (key,value) pair in the peer that is closest to the key

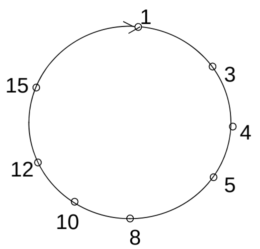
DHT identifiers

- assign integer identifier to each peer in range $[0,2^n-1]$ for some *n*.
  - each identifier represented by *n* bits.
- require each key to be an integer in same range
- to get integer key, hash original key
  - *e.g.*, key = hash("Led Zeppelin IV")
  - this is why its is referred to as a *distributed "hash" table*

Assign keys to peers

- rule: assign key to the peer that has the *closest* ID.
- convention in lecture: closest is the *immediate successor* of the key.
- e.g., *n*=4; peers: 1,3,4,5,8,10,12,14;
  - key = 13, then successor peer = 14
  - key = 15, then successor peer = 1

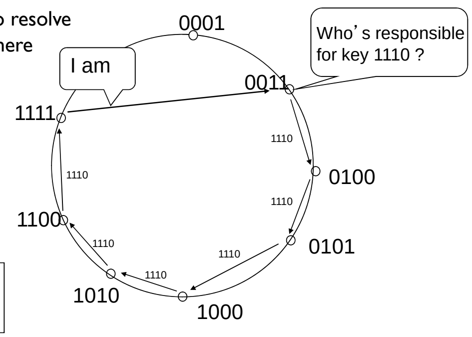
Circular DHT (1)



- each peer *only* aware of immediate successor and predecessor.
- "overlay network"

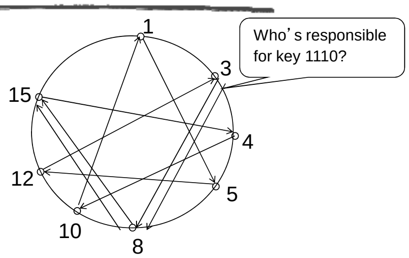
Circular DHT (1)

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



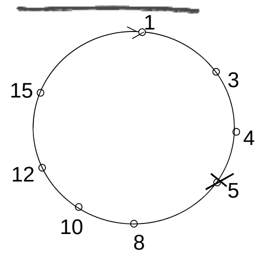
Define <u>closest</u> as closest successor

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



handling peer churn:
- peers may come and go (churn)
- each peer knows address of its two successors
- each peer periodically pings its two successors to check aliveness
- if immediate successor leaves, choose next successor as new immediate successor

example: peer 5 abruptly leaves
- peer 4 detects peer 5 departure; 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?

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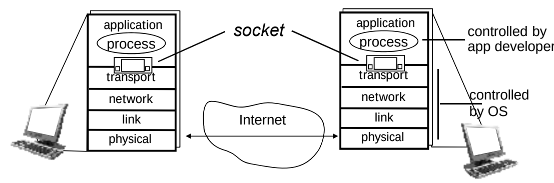
Socket programming

goal: learn how to build client/server applications that communicate using sockets

socket: door between application process and end-end-transport protocol



Socket programming

Two socket types for two transport services:
- *UDP:* unreliable datagram
- *TCP:* reliable, byte stream-oriented

Application Example:
1. Client reads a line of characters (data) from its keyboard and sends the data to the server.
2. The server receives the data and converts characters to uppercase.
3. The server sends the modified data to the client.
4. The client receives the modified data and displays the line on its screen.

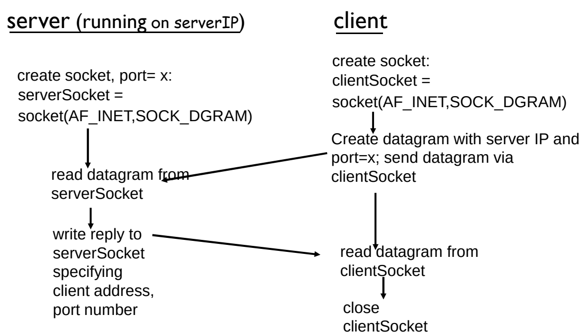
Socket programming *with UDP*

UDP: no "connection" between client & server
- no handshaking before sending data
- sender explicitly attaches IP destination address and port # to each packet
- rcvr extracts sender IP address and port# from received packet

UDP: transmitted data may be lost or received out-of-order

Application viewpoint:
- UDP provides *unreliable* transfer of groups of bytes ("datagrams") between client and server

Client/server socket interaction: UDP



Example app: UDP client

Python UDPClient

include Python's socket library	`from socket import *`
	`serverName = 'hostname'`
	`serverPort = 12000`
create UDP socket for server	`clientSocket = socket(socket.AF_INET, socket.SOCK_DGRAM)`
get user keyboard input	`message = raw_input('Input lowercase sentence:')`
Attach server name, port to message; send into socket	`clientSocket.sendto(message,(serverName, serverPort))`
read reply characters from socket into string	`modifiedMessage, serverAddress = clientSocket.recvfrom(2048)`
print out received string and close socket	`print modifiedMessage`
	`clientSocket.close()`

Example app: UDP server

Python UDPServer

	`from socket import *`
	`serverPort = 12000`
create UDP socket	`serverSocket = socket(AF_INET, SOCK_DGRAM)`
bind socket to local port number 12000	`serverSocket.bind(('', serverPort))`
	`print "The server is ready to receive"`
loop forever	`while 1:`
Read from UDP socket into message, getting client's address (client IP and port)	`message, clientAddress = serverSocket.recvfrom(2048)`
	`modifiedMessage = message.upper()`
send upper case string back to this client	`serverSocket.sendto(modifiedMessage, clientAddress)`

Socket programming *with TCP*

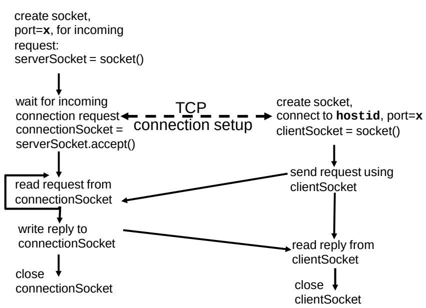
client must contact server
- server process must first be running
- server must have created socket (door) that welcomes client's contact

client contacts server by:
- Creating TCP socket, specifying IP address, port number of server process
- *when client creates socket:* client TCP establishes connection to server TCP

- when contacted by client, *server TCP creates new socket* for server process to communicate with that particular client
  - allows server to talk with multiple clients
  - source port numbers used to distinguish clients (more in Chap 3)

application viewpoint:
TCP provides reliable, in-order byte-stream transfer ("pipe") between client and server

Client/server socket interaction: TCP



Example app: TCP client

Python TCPClient

```
from socket import *
serverName = 'servername'
serverPort = 12000
clientSocket = socket(AF_INET, SOCK_STREAM)
clientSocket.connect((serverName,serverPort))
sentence = raw_input('Input lowercase sentence:')
clientSocket.send(sentence)
modifiedSentence = clientSocket.recv(1024)
print 'From Server:', modifiedSentence
clientSocket.close()
```

create TCP socket for server, remote port 12000

No need to attach server name, port

Example app: TCP server

Python TCPServer

```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET,SOCK_STREAM)
serverSocket.bind(('',serverPort))
serverSocket.listen(1)
print 'The server is ready to receive'
while 1:
    connectionSocket, addr = serverSocket.accept()

    sentence = connectionSocket.recv(1024)
    capitalizedSentence = sentence.upper()
    connectionSocket.send(capitalizedSentence)
    connectionSocket.close()
```

create TCP welcoming socket

server begins listening for incoming TCP requests

loop forever

server waits on accept() for incoming requests, new socket created on return

read bytes from socket (but not address as in UDP)

close connection to this client (but *not* welcoming socket)

Chapter 2: summary

our study of network apps now complete!

- application architectures
  - client-server
  - P2P
- application service requirements:
  - reliability, bandwidth, delay
- Internet transport service model
  - connection-oriented, reliable: TCP
  - unreliable, datagrams: UDP
- specific protocols:
  - HTTP
  - FTP
  - SMTP, POP, IMAP
  - DNS
  - P2P: BitTorrent, DHT
- socket programming: TCP, UDP sockets

Chapter 2: summary

most importantly: learned about protocols!

- typical request/reply message exchange:
  - client requests info or service
  - server responds with data, status code
- message formats:
  - headers: fields giving info about data
  - data: info being communicated

important themes:

- control vs. data msgs
  - in-band, out-of-band
- centralized vs. decentralized
- stateless vs. stateful
- reliable vs. unreliable msg transfer
- "complexity at network edge"