Internet Technology

03. Application layer protocols

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Spring 2016

Today we'll examine

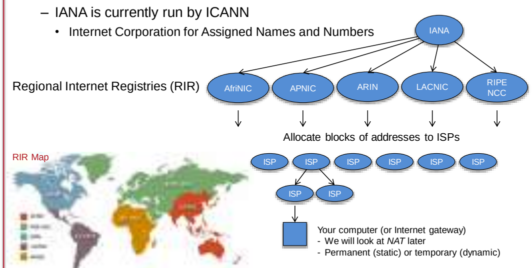
- DNS: Domain Name System
- HTTP: Hypertext Transfer Protocol
- FTP: File Transfer Protocol

Domain Name System

How are IP addresses assigned?

IP addresses are distributed hierarchically

- Internet Assigned Numbers Authority (IANA) at the top
  - IANA is currently run by ICANN
    - Internet Corporation for Assigned Names and Numbers

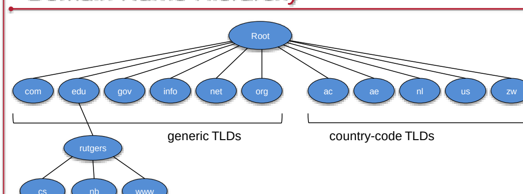


How are machine names assigned?

- Early ARPANET
  - Globally unique names for each machine (e.g., UCBVAX)
  - Kept track at the Network Information Center at the Stanford Research Institute (SRI NIC)
- That doesn't scale!
- A domain hierarchy was created in 1984 (RFC 920)
  - Domains are administrative entities: divide name management
  - Tree-structured global name space
  - Textual representation of domain names

    www.cs.rutgers.edu

Domain Name Hierarchy



Top Level Domains (TLDs)

ccTLD
Country-code domains
ISO 3166 codes
e.g., .us, .de, .ca, .es

IDN ccTLD
Internationalized country-code domains
e.g., .السعودية, .中國 , .рф

gTLD
Generic top-level domains
e.g., .biz, .com, .edu, .gov, .info, .net, .org

There are currently 1,239 top-level domains

Each top-level domain has an administrator assigned to it

Assignment is delegated to various organizations by the Internet Assigned Numbers Authority (IANA)

See http://www.iana.org/domains/root/db for the latest count

Shared registration

- **Domain name registry**: *this is the database*
  - Keeps track of all domain names registered in a top-level domain
- **Domain name registry operator**: *this is the company that runs the db*
  - NIC = Network Information Center – organization that keeps track of the registration of domain names under a top-level domain
  - keeps the database of domain names
- **Domain name registrar**: *this is the company you use to register*
  - Company that lets you register a domain name

Shared registration

- **Until 1999**: Network Solutions Inc. operated the .com, .org, .net registries
- **Now**
  - Multiple domain registrars provide domain registration services
  - Around 1,000 of these companies – each is accredited by the ICANN
    - 2,124 as of February 2016, including 701 unique DropCatch.com registrars
- The registrar you choose becomes the designated registrar for your domain
  - Maximum period of registration for a domain name = 10 years
- The registry operator keeps the central registry database for the top-level domain
- Only the designated registrar can change information about domain names
  - A domain name owner may invoke a domain transfer process

Example
- *Namecheap* is the designated registrar for *poopybrain.com*
- *VeriSign* is the registry operator for the *.com* gTLD

See https://www.icann.org/registrar-reports/accredited-list.html for the latest list of registrars

The problem

Every device connected to the Internet has a unique Internet Protocol (IP) address

How do you resolve user-friendly machine names to IP addresses?

www.cs.rutgers.edu ⟶ 128.6.4.24

Original solution

Through the 1980s

- Search `/etc/hosts` file for machine name (see RFC 606)
- File periodically downloaded from Network Information Center (NIC) at the Stanford Research Institute (SRI)
- This was not sustainable with millions of hosts on the Internet
  - A lot of data
  - A lot of churn in the data
    - new hosts added, deleted, addresses changed
  - Maintenance
  - Traffic volume

Solution doesn't scale!

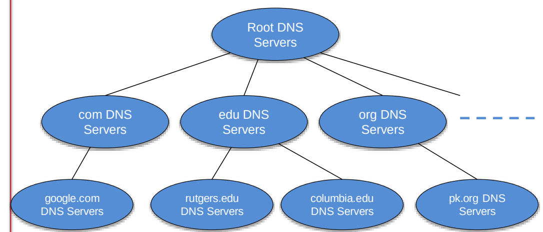
DNS: Domain Name System

- Distributed database
  - Hierarchy of name servers
- DNS is an application-layer protocol
  - Name-address resolution is handled at the edge
  - The network core is unaware of host names

DNS provides

- Name to IP address translation
- Aliasing of names (called canonical names)
- Identification of name servers
- Mail server names
- Load distribution:
  - Multiple name servers that can handle a query for a domain
  - Caching
  - Ability to provide a set of IP addresses for a name

DNS is a distributed, hierarchical database



A collection of DNS servers

Authoritative DNS server

- An authoritative name server is responsible for answering queries about its zone
  - Configured by the administrator
- Zone = group of machines under a node in the tree
  E.g., rutgers.edu

A DNS server returns answers to queries

Key data that a DNS server maintains (partial list)

Information	Abbreviation	Description
Host	A	Host address (name to address) Includes name, IP address, time-to-live (TTL)
Canonical name	CNAME	Name for an alias
Mail exchanger	MX	Host that handles email for the domain
Name server	NS	Identifies the name server for the zone: tell other servers that yours is the authority for info within the domain
Start of Zone Authority	SOA	Specifies authoritative server for the zone. Identifies the zone, time-to-live, and primary name server for the zone

Finding your way

- How do you find the DNS Server for rutgers.edu?
  - That's what the domain registry keeps track of
  - When you register a domain, you supply the addresses of at least two DNS servers that can answer queries for your zone
- So how do you find it?
  - Start at the root

Root name servers

- The root name server answers can return a list of authoritative name servers for top-level domains
- 13 root name servers
  - `A.ROOT-SERVERS.NET`, `B.ROOT-SERVERS.NET`, …
  - Each has redundancy (via *anycast* routing or load balancing)

Download the latest list at http://www.internic.net/domain/named.root

DNS Queries

- Iterative (non-recursive) name resolution
  - DNS server will return a definitive answer or a **referral** to another DNS server
    - *referral* = reference to a DNS server for a lower level of the queried namespace
    - Server returns intermediate results to the client
    1. Send query to a root name server
    2. Send query to a edu name server
    3. Send query to a rutgers name server
  - Advantage: stateless
- Recursive DNS name resolution
  - Name server will take on the responsibility of fully resolving the name
    - May query multiple other DNS servers on your behalf
  - DNS server cannot refer the client to a different server
  - Disadvantage: name server has more work; has to keep track of state
  - Advantages: Caching opportunities, less work for the client!

Most top-level DNS servers only support iterative queries

DNS Resolvers: local name server

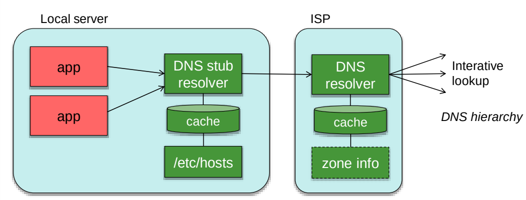
- DNS Resolver
  - Not really a part of the DNS hierarchy
  - Acts as an intermediary between programs that need to resolve names and the name servers
  - A resolver is responsible for performing the full resolution of the query
- Where are they?
  - Local system has one: that's what applications contact
    - Local cache; may be a process or a library
    - On Linux & Windows, these are limited DNS servers (called stub resolvers): they are not capable of handling referrals and expect to talk with a name server that can handle recursion (full resolution)
  - ISPs (and organizations) run them on behalf of their customers
    - Including a bunch of free ones (OpenDNS, Google Public DNS)
- Resolvers cache past lookups – not responsible for zones

Using a DNS resolver

To look up a name:
- Send a DNS query to the local resolver (recursion requested)

- **Local resolver**
  - If the local resolver has cached results, it can return the answer
  - Otherwise, consult a local hosts file (e.g., /etc/hosts) to return locally-configured name→address mappings
  - Otherwise contact a DNS server that the client knows about – this is typically another resolver that is provided by the ISP
    - The local system is configured with one or more addresses of external name servers
- **ISP Resolver**
  - Check cache
  - Check a locally-configured zone file (if any). If the desired data is there, return an authoritative answer
  - Otherwise, do an iterative set of queries to traverse the hierarchy to find the desired name server and get results

DNS Resolvers in action



Local stub resolver:
- check local cache
- check local hosts file
- send request to external resolver

External resolver
- DNS server that accepts recursion
- Running at ISP, Google Public DNS, OpenDNS, etc.

E.g., on Linux: resolver is configured via the /etc/resolv.conf file

Sample query

- Rutgers registered rutgers.edu with the .edu domain
  - educause.net is the domain registry for the .edu gTLD
- The root name server contains addresses for the name servers of all the top-level domains
- The local name server is provided the list of addresses of root name servers

Sample Query

Submit query to a local *DNS resolver:*

1. Send query(cs.rutgers.edu) → root name server
   root name servers identify authoritative servers for top-level domains
   send query to c.root-servers.net: 192.33.4.12
2. *Receive referral* to a list of DNS servers for *edu*
   a.edu-servers.net: 192.5.6.30
   g.edu-servers.net: 192.42.93.30
3. Send query(cs.rutgers.edu) → edu name server
   send query to g.edu-servers.net: 192.41.162.32
4. *Receive referral to rutgers.edu* name servers:
   - ns87.a0.incapsecuredns.net 192.230.121.86
   - ns8.a1.incapsecuredns.net. 192.230.122.7
   - ns124.a2.incapsecuredns.net 192.230.123.123
5. query(cs.rutgers.edu) → rutgers name server
   send query to 192.230.122.7
6. The rutgers name server returns
   A: 128.6.4.2 *address*
   MX: dragon.rutgers.edu *domain name for email*

Caching

- Starting every query at the root would place a huge load on root name servers
- A name server can be configured to cache results of previous queries
  - Save query results for a *time-to-live* amount of time
  - The time-to-live value is specified in the domain name record by an authoritative name server
- Caching name servers are recursive name servers

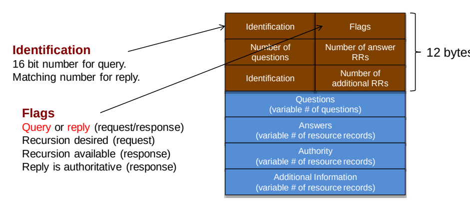
The DNS Query Protocol

DNS Records

- DNS servers store resource records (RRs)
- Format
  - Name, value, type of record, TTL (time to live)
- Common types
  - Address: A
    - Name: hostname
    - Value: IP address
  - Canonical name: CNAME
    - Name: alias hostname
    - Value: real hostname
  - Name Server: NS
    - Name: domain (rutgers.edu)
    - Value: hostname of authoritative name server for the domain
  - Mail Exchanger: MX
    - Name: hostname
    - Value: mail server for hostname

DNS Protocol

- DNS is a service that listens to requests on TCP or UDP port 53
- Protocol consists of *query* and *reply* messages
  - Both messages have the same format and header



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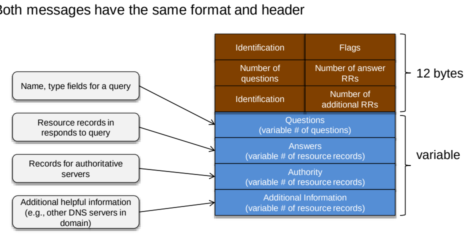
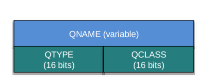


DNS Queries

- Questions field contains a sequence or DNS queries
- Query name
  - Encoded form of the name for which we want an address
- Query type
  - 1 = IP address, 2 = name server, 0x0f = mail server, …
- Query class
  - 1 = Internet addresses, 2 = CSNET



Reverse DNS

- What if we have an IP address and want the name?
- Special domain for reverse lookups
  - in-addr.arpa
  - ARPA = *Address & Routing Parameter Area*, not *Advanced Research Projects Agency* (e.g., ARPANET)

www.cs.rutgers.edu → 128.6.4.24

24.4.6.128.in-addr.arpa → www.cs.rutgers.edu

Setting up reverse DNS

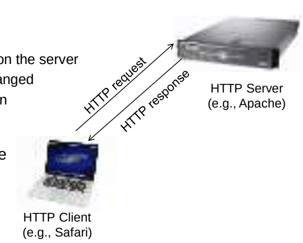
- Different query path than regular DNS queries
- On a DNS server
  - Configure PTR (pointer) records that map IP addresses to names
- Let the world find out
  - ISP allocated IP addresses to you
  - You tell the ISP what DNS servers are responsible for reverse DNS entries
- Example query path
  - DNS resolver contacts root servers
  - Root server refers to ARIN (North American IP registry) RDNS server
  - ARIN refers to local ISP RDNS server, which refers to your server

Root server → RIR (e.g., ARIN) DNS server → ISP DNS server

Web and HTTP

HTTP Basics

- HTTP: Hypertext Transfer Protocol (RFC 2616)
  - Web's application-layer protocol
  - Client-server model
  - TCP-based protocol
    - Client connects to port 80 on the server
    - HTTP messages are exchanged
    - Client closes the connection
- HTTP is stateless
  - Server does not store state on previous requests
  - Simplifies design
    - Easier failure recovery
    - Simplifies load balancing



URLs

- Requests for objects are URLs
- URL = Uniform Resource Locator

```
http://domain_name:port/path/path/object
```

protocol | server | port # | path to object | object

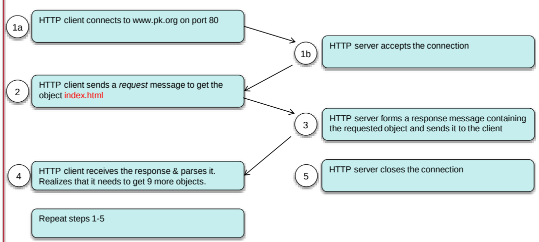
```
http://box.pk.org:8080/secret/demo/mystuff.html
```


Types of connections

- Non-persistent HTTP (HTTP 1.0)
  - At most one object is sent over a TCP connection
  - Request/response
- Persistent HTTP (HTTP 1.1)
  - Multiple objects can be sent over a single connection

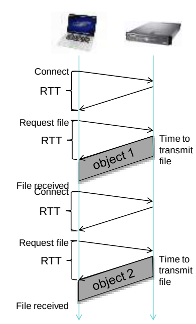
Non-persistent HTTP

- www.pk.org/index.html is one file that references:
  - Five CSS (cascading style sheet) files
  - Four image files



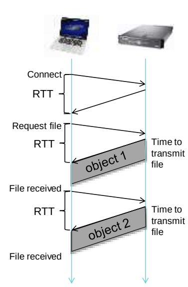
Non-persistent HTTP: Response time

- Round-trip time (RTT)
  - Time for a small packet to travel from the client to the server & back to the client
- Response time
  - One RTT to initiate the connection
  - One RTT for request & start of response
  - File transmission time
- Total time =
  \# objects × (2×RTT + transit_time)



Persistent HTTP: Response time

- Server leaves connection open after sending response
  - Subsequent HTTP messages are sent over the same open connection
  - One RTT for each referenced object once the connection is set up
- Response time
  - One RTT to initiate the connection
  - One RTT for request & start of response per object
  - File transmission time per object
- Total $time_{persistent}$ =
  RTT + # objects × (RTT + transit_time)
- Versus Total $time_{non\text{-}persistent}$ =
  \# objects × (2×RTT + transit_time)



HTTP Request Message

- Two classes of messages: ***request*** & ***response***
- HTTP request messages are human-readable ASCII text

Browser request for a URL (Uniform Resource Locator):

`http://box.pk.org:12345/this/is/a/test.html`

Creates an HTTP request — Request line: GET, POST, HEAD, … commands

```
GET /this/is/a/test.html HTTP/1.1
Host: box.pk.org:12345
User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_8_2) AppleWebKit/536.26.17
        (KHTML, like Gecko) Version/6.0.2 Safari/536.26.17
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Language: en-us
Accept-Encoding: gzip, deflate
Connection: keep-alive
```

headers

Carriage return, line feed (0x0d, 0x0a) indicates end of header … and end of message in this case

HTTP Response Message

Status line:
Protocol, status code, status text

```
HTTP/1.1 200 OK
Date: Mon, 11 Feb 2013 19:31:58 GMT
Server: Apache/2.2.22 (Ubuntu)
Last-Modified: Thu, 31 Jan 2013 01:18:12 GMT
ETag: "3c0549-17df-4d48b667f3d00"
Accept-Ranges: bytes
Content-Length: 6111
Vary: Accept-Encoding
Connection: close
Content-Type: text/html

Data (e.g., web page content)
```

headers

Carriage return, line feed (0x0d, 0x0a) indicates end of header

Uploading form input

- HTTP POST method
  - Web pages may include form input
  - Input is uploaded to the server in the body of the request
- URL method
  - Parameter/value pairs are encoded in the URL (query string)
  - HTTP GET request is sent
  - Format
    - **`http://server/path/page?query_string`**
    - query_string is of the form $item_0$=$value_0$&$item_1$=$value_1$...

HTTP Methods

HTTP/1.0

- **GET**
  - Request a resource
- **POST**
  - Send data in the request message's body to the server
- **HEAD**
  - Like GET, but only send the headers

HTTP/1.1

- **GET**, **POST**, **HEAD**
- **PUT**
  - Uploads file to the path specified in the URL field
- **DELETE**
  - Deletes the file specified in the URL field

Some HTTP response codes

- `200 OK`
  - Request succeeded; requested object is in the message
- `301 Moved Permanently`
  - Requested object moved; new location specified in a Location: header in the list of headers
- `400 Bad Request`
  - The server could not understand the request
- `404 Not Found`
  - The requested content is not found on the server
- `505 HTTP Version Not Supported`
  - Unsupported version

Try it out yourself

Talk to a server

- Run
  - `telnet cnn.com 80`
- Type in a basic GET request
  - `GET /index.html HTTP/1.1`
  - Followed by an blank line
- Look at the response

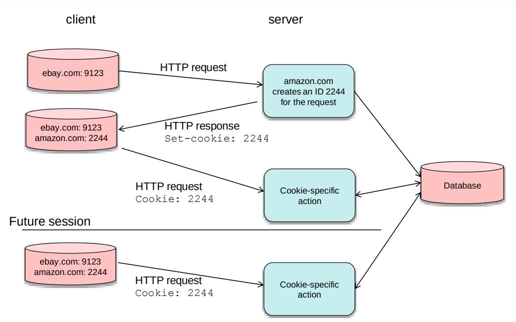
Listen to a client

- Run demo TCP server
  - `java TCPServer`
- Start a browser and connect to it:
  - `http://localhost:12345/a/b/c`
  - The server will print all the data it gets from the client

Keeping state: cookies

- HTTP is stateless
- Cookies provide a mechanism for web servers to store state
- Four parts to cookies:
  1. Cookie header line in the HTTP response message
  2. Cookie header line in subsequent HTTP request messages
  3. Cookie file stored on user's host & managed by browser
  4. Back-end database at the web server host
- Example
  - You visit an e-commerce site
  - When the site receives your request, it creates a unique ID and an entry in the database identified by that ID.
  - The HTTP response tells your browser to set a cookie. The cookie is sent with future messages to that server

Cookies in use

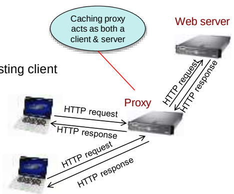


Maintaining state with cookies

- Cookies can help a server store & access
  - Shopping cart info
  - Login name, authorization credentials
  - Preferences (e.g., town name for weather)
  - Session state (e.g., web-based email)
  - History of web pages you visited on the site
- First-party cookies
  - Placed by the website you visit
- Third-party cookies
  - Placed by sites other than the one you visit – mostly ads

Web caching: proxy servers

- Caching proxy
- User sends all HTTP requests to a proxy server
- Proxy server:
  - Checks its cache
  - If the response is cached, it returns an HTTP response
  - If not, it contacts the server
    - Server sends a response
    - Proxy caches it
    - Proxy forwards the response to the requesting client
- Advantages
  - Reduce response time if proxy is closer/faster
  - Reduce traffic on the web server
  - Reduce traffic on the organization's link



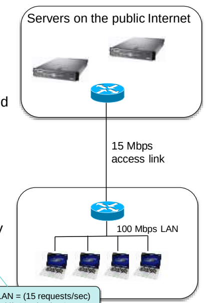
Caching example

- Assume
  - Average object size = 1 Mbit (~ 122KB)
  - Average request rate from institution's browsers to servers = 15/s
  - Delay from institutional router to a server and back to router = 2 sec
- Consequences
  - Utilization on LAN = 1.5%
  - Utilization on access link = 100%
  - Total delay =
    Internet delay + access delay + LAN delay

2 sec | 2 sec | minutes | msec

Traffic intensity on access link = (15 requests/sec) × (1 Mbits/request)/(15 Mbps) = 1

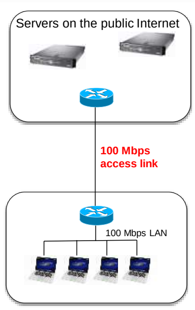
Traffic intensity on LAN = (15 requests/sec) × (1 Mbits/request)/(100 Mbps) = 0.15



Traffic intensity ~ 1 = BAD → delay grows without bound (minutes!)

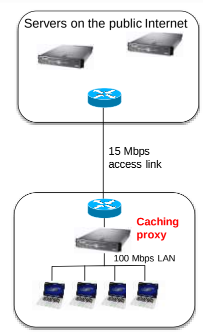
Caching example: improve access link

- Assume
  - Access link is now 100 Mbps
- Consequences
  - Utilization on LAN = 1.5%
  - Utilization on access link = 15%
  - Total delay =
    Internet delay + access delay + LAN delay
    = 2 sec + msec + msec
  - But increasing the access link can be a costly upgrade



Caching example: add a caching proxy

- Assume
  - Access link remains at 15 Mbps
  - Install a caching proxy
  - Assume hit rate is 0.4 (40% hits)
- Consequences
  - 40% of requests satisfied by proxy (quick – e.g., 10 ms)
  - 60% have to go to outside servers
  - Use of access link reduced to 60%
  - Total average delay =
    Internet delay + access delay + LAN delay
    = 0.6*(2.01 s)+ 0.4*(10 ms) + puny ms
    = < ~1.4 seconds



HTTP control for caching

Conditional GET

- Request an object BUT don't send it if the cache has an up-to-date version

HTTP Request

GET /index.html HTTP/1.1
Host: box.pk.org

HTTP Response

HTTP/1.1 200 OK
Date: Mon, 11 Feb 2013 21:01:16 GMT
Server: Apache/2.2.22 (Ubuntu)
Last-Modified: Thu, 31 Jan 2013 01:18:12 GMT
ETag: "3c0549-17df-4d48b667f3d00"
Accept-Ranges: bytes
Content-Length: 6111
Vary: Accept-Encoding
Content-Type: text/html

Content…

Timestamp of file modification on server

Unique string for that version of the file; typically a hash of the file

To cache, store the file, Last-Modified timestamp, and ETag.

HTTP control for caching

Next time you request the file, include two headers in your request

`If-Modified-Since`: *time from Last-Modified*
`If-None-Match`: *value from Etag*

HTTP Request

GET /index.html HTTP/1.1
Host: box.pk.org
If-Modified-Since: Thu, 31 Jan 2013 01:18:12 GMT
If-None-Match: "3c0549-17df-4d48b667f3d00"

HTTP Response

HTTP/1.1 304 Not Modified
Date: Mon, 11 Feb 2013 21:11:32 GMT
Server: Apache/2.2.22 (Ubuntu)
ETag: "3c0549-17df-4d48b667f3d00"
Vary: Accept-Encoding

This means the file was not modified since the cached copy.

– alternatively –

If the content has been modified at the server, then the content is sent as with a normal GET request.

Conditional GET

- Request a file from a server because it's not in your cache
  - Receive the file
  - Headers contain: `Last-Modified` and `Etag`
  - For caching, store both of those along with the file
- Next time you request the file, include two headers in your request
  - If-Modified-Since: <time from `Last-Modified`>
  - If-None-Match: <value from `Etag`>
- If the file has changed since you last requested it, the server will send back the new file. If not, the server will respond with a "304 Not Modified" code

More Optimizations

- Problem: Head-of-line blocking
  - One large (or slow) HTTP request can hold up all other requests from that client
- HTTP/1.x: Parallel connections
  - Open multiple TCP connections to the server
  - But:
    - Hard to deploy with proxies
    - Each connection takes time to open
    - Can use up a lot of connections – extra server memory
  - Parallel connections typically limited to a small number (e.g., 4)
    - Can still lead to head-of-line blocking per connection
- HTTP/1.x: Pipelining
  - Send multiple HTTP requests without waiting for a response from each one
  - But:
    - The server still must send responses in the order requests were sent
    - Requests may be received quicker by the server but responses are still at risk of head-of-line blocking
    - Not supported or turned on in most browsers and proxies

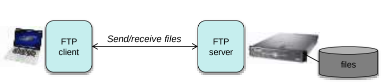
More Optimizations

- HTTP/2 – Multiplexing
  - Multiple request & response messages can be in flight at the same time
  - Messages can be intermingled on one connection
- "Minification"
  - Reduce unnecessary characters form JavaScript & CSS
  - Merge multiple script files into one compressed file
- HTTP/2 – header compression
  - Each HTTP header uses ~1400 bytes – takes 7-8 round trips to move them to the client
- HTTP/2 – server push
  - Server can push content – give the client more than what it requested
  - Why send more data?
    - The browser has to get the first response, parse it, and make requests
    - But … the server knows what a browser will need to render a web page
      - It can send the data before it's requested by the client

FTP: File Transfer Protocol

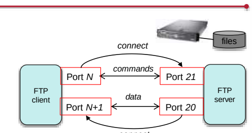
FTP: File Transport Protocol

- Transfer files between computers
- Client/server model
- Client: accepts commands from the user and initiates requests to *get* or *put* files on the server
- Defined in RFC 959
  - Original version RFC 765 – June 1980
  - First proposal dates back to 1971



Separate data & control connections

- Client connects to an FTP server on TCP port 21
  - This is the command channel
  - Client port = some port ≥ 1024 = *N*
- Commands are user requests and include authentication info
- When the server receives a command to transfer data, it initiates a TCP connection to the client on port *N+1* from its local data port (20)
- After transferring one file, the server closes the data connection



Separation between control & data channels
- Out of band control connection

Sample FTP Commands

- Sent as ASCII text over the control channel
- Access commands
  - USER: identify yourself
  - PASS: supply your password
  - CWD (CD): change working directory
  - CDUP (CD ..): change to parent
  - QUIT: log out
- Control commands
  - RETR (GET): retrieve a file
  - STORE (PUT): store a file
  - APPEND: append to a file
  - DELETE: delete a file
  - LIST (DIR): list files
- Error messages
  - Similar to HTTP:
    - Status code & text
  - 331 User name okay, need password.
  - 200 Command okay.
  - 230 User logged in, proceed.
  - 502 Command not implemented.
  - 125 Data connection already open; transfer starting.

Active vs. Passive FTP

- Not all clients can receive incoming connections
  - This was a pain with firewalls and NAT (network address translation)
- Passive mode FTP
  - Client initiates both connections to the server
  - The first connection (for commands) contacts the server on port 21
    - Originating port = N, $N \geq 1024$
  - Then the client then issues a PASV command
    - The server opens a random port $P \geq 1024$
    - Sends back the value P to the client as a response
    - The client then connects from port $N+1$ *to* port P
- Most browsers support only passive mode FTP

The end