Application Layer

Goals:

- Conceptual aspects of network application protocols
  - Client server paradigm
  - Service models
- Review protocols by examining popular application-level protocols
  - HTTP
  - DNS
Applications and Application-Layer Protocols

Application: communicating, distributed processes
- Running in network hosts in “user space”
- Exchange messages to implement app
- E.g., email, file transfer, the Web

Application-layer protocols
- One “piece” of an app
- Define messages exchanged by apps and actions taken
- User services provided by lower layer protocols
Client-Server Paradigm

Typical network app has two pieces: client and server

Client:
- Initiates contact with server ("speaks first")
- Typically requests service from server,
  - E.g., request WWW page, send email

Server:
- Provides requested service to client
  - E.g., sends requested WWW page, receives/stores received email
Services Provided by Internet Transport Protocols

TCP service:
- **Connection-oriented**: setup required between client, server
- **Reliable transport** between sending and receiving process
- **Flow control**: sender won’t overwhelm receiver
- **Congestion control**: throttle sender when network overloaded
- **Does not providing**: timing, minimum bandwidth guarantees

UDP service:
- Unreliable data transfer between sending and receiving process
- Does not provide: connection setup, reliability, flow control, congestion control, timing, or bandwidth guarantee
The HTTP Protocol

HTTP: Hypertext transfer protocol

- Application layer protocol for the Web
- Client/server model
  - **Client**: browser that requests, receives, “displays” web objects
  - **Server**: Web server sends objects in response to requests
- Also used as part of many other application layer protocols
HTTP Development Timeline

- Mar 1990  CERN labs document proposing Web
- Jan 1992  HTTP/0.9 specification
- Dec 1992  Proposal to add MIME to HTTP
- Feb 1993  UDI (Universal Document Identifier) Network
- Mar 1993  HTTP/1.0 first draft
- Jun 1993  HTML (1.0 Specification)
- Oct 1993  URL specification
- Nov 1993  HTTP/1.0 second draft
- Mar 1994  URI in WWW
- May 1996  HTTP/1.0 Informational, RFC 1945
- Jan 1997  HTTP/1.1 Proposed Standard, RFC 2068
- Jun 1999  HTTP/1.1 Draft Standard, RFC 2616
- 2001      HTTP/1.1 Formal Standard
- ...ongoing HTTP/2 Drafts and Standardization
The HTTP Protocol: Basics

HTTP: TCP transport service
- Client initiates TCP connection (creates socket) to server, port 80
- Server accepts TCP connection from client
- http messages (application-layer protocol messages) exchanged between browser (http client) and Web server (http server)
- TCP connection closed

HTTP is “stateless”
- Server maintains no information about past client requests

Protocols that maintain “state” are complex!
- Past history (state) must be maintained
- If server/client crashes, their views of “state” may be inconsistent, must be reconciled
HTTP Message Format: Request

- Two types of http messages: *Request*, *response*
- http request message:
  - ASCII (human-readable format)

```
GET /somedir/page.html HTTP/1.1
Connection: close
User-agent: Mozilla/4.0
Accept: text/html, image/gif, image/jpeg
Accept-language: fr
```
(extra carriage return, line feed)

(request line (GET, POST, HEAD commands))

(header lines)

Carriage return, line feed indicates end of message
HTTP Request Methods

Methods for HTTP/1.1

- GET
- HEAD
- POST
- PUT
- Delete
- Trace
- Connect
HTTP Message Format: Response

status line
(protocol status code status phrase)

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

data data data data data data data ...

data, e.g., requested html file

header lines

status line
(protocol status code status phrase)
HTTP Response Status Codes

In first line in server → client response message.
A few sample codes:

200 OK
  o Request succeeded, requested object later in this message

301 Moved Permanently
  o Requested object moved, new location specified later in this message (Location:)

400 Bad Request
  o Request message not understood by server

404 Not Found
  o Requested document not found on this server

505 HTTP Version Not Supported
The HTTP Protocol: Connections

- **Non-persistent connection:**
  One object in each TCP connection
  - Some browsers create multiple TCP connections *simultaneously* – one per object

- **Persistent connection (HTTP/1.0):**
  Multiple objects transferred within one TCP connection

- **Pipelined persistent connections (HTTP/1.1):**
  Multiple requests issued without waiting for response
  Responses are in order of the requests

- **Persistent connection with out-of-order delivery (HTTP/2):**
  Multiple requests issued. Server can return the objects in arbitrary order. Typically according to server priority. In addition the server may send additional objects.
User-Server Interaction: Authentication

Authentication goal: Control access to server documents

- Stateless: Client must present authorization in each request
- Authorization: Typically name, password
  - Authorization: header line in request
  - If no authorization, server refuses access, sends `WWW authentication:` header line in response

**Diagram:**
- **Client:**
  - Usual HTTP request msg
  - WWW authentication:
  - 401: authorization req.
  - Authorization: header line in request
  - Usual HTTP request msg + Authorization: line
- **Server:**
  - Usual HTTP response msg
  - WWW authentication:
  - Usual HTTP response msg

Time
Goal: Don’t send object if client has up-to-date stored (cached) version.

Client: Specify date of cached copy in http request.

If-modified-since: <date>

Server: Response contains no object if cached copy up-to-date:

HTTP/1.0 304 Not Modified

Object not modified

Object modified
User-Side State: Cookies

Most Web sites use cookies

Four components:
1) Cookie header line of HTTP response message
2) Cookie header line in HTTP request message
3) Cookie file kept on user’s host, managed by user’s browser
4) Back-end database at Web site

Example:
- Susan access Internet always from same PC
- She visits a specific e-commerce site for first time
- When initial HTTP requests arrives at site, site creates a unique ID and creates an entry in backend database for ID
Cookies: Keeping State

server

entry in backend database

access

client

usual http request msg

usual http response +
Set-cookie: id=1678

usual http request msg

cookie: id=1678

usual http response msg

usual http request msg

cookie: id=1678

usual http response msg

one week later:

Cookie file

ebay: id=8734

amazon: y=1678

ebay: id=8734

server

creates ID 1678 for user

cookie-specific action

Cookie file

ebay: id=8734

amazon: y=1678

ebay: id=8734

cookie-specific action
Cookies: Keeping State (2)

What cookies can bring:
- Authorization
- Shopping carts
- Recommendations
- User session state (e.g. for Web e-mail)

Cookies and privacy:
- Cookies permit sites to learn a lot about you
- You may supply name and e-mail to sites
- Search engines use redirection & cookies to learn even more
- Advertising companies obtain info across sites

- Users can even be tracked if cookies are turned off
Web Caches (Proxy Servers)

Goal: Satisfy client request without involving origin server

- User sets browser: WWW accesses via web cache
- Client sends all http requests to web cache
  - If object at web cache, web cache immediately returns object in http response
  - Else requests object from origin server, then returns http response to client
Why Web Caching?

Assume: Cache is “close” to client (e.g., in same network)

- Smaller response time: cache “closer” to client
- Decrease traffic to distant servers
  - Link out of institutional/local ISP network often bottleneck
Web 2.0: E.g., AJAX Enabled Apps

- E.g.: Google Maps: A canonical AJAX application
Content Distribution Networks (CDNs)

Content providers are the CDN customers.

**Content replication**

- CDN company installs hundreds of CDN servers throughout Internet
  - In lower-tier ISPs, close to users
- CDN replicates its customers’ content in CDN servers. When provider updates content, CDN updates servers
CDN Example

1. Origin server
2. CDNs authoritative DNS server
3. Nearby CDN server

HTTP request for www.foo.com/sports/sports.html
DNS query for www.cdn.com
HTTP request for www.cdn.com/www.foo.com/sports/ruth.gif

Origin server
- www.foo.com
- Distributes HTML
- Replaces:
  - http://www.foo.com/sports.ruth.gif
  with

CDN company
- cdn.com
- Distributes gif files
- Uses its authoritative DNS server to route redirect requests
More about CDNs

Routing requests

- CDN creates a “map”, indicating distances from leaf ISPs and CDN nodes
- When query arrives at authoritative DNS server
  - Server determines ISP from which query originates
  - Uses “map” to determine best CDN server

Not just Web pages

- Streaming stored audio/video
- Streaming real-time audio/video
  - CDN nodes create application-layer overlay network
DNS: Domain Name System

People: many identifiers:
- SSN, name, Passport #

Internet hosts, routers:
- IP address (32/128 bit) – used for addressing datagrams
- “name”, e.g., gaia.cs.umass.edu – used by humans

Q: How to map between IP addresses and name?
- Domain Name System (DNS)
- RFC1034/RFC1035, RFC3007
DNS: Domain Name System

Domain Name System:

- *Distributed database:* Implemented in hierarchy of many *name servers*
- *Application-layer protocol:* Host, routers, name servers communicate to *resolve* names (address/name translation)
  - Core Internet function implemented as application-layer protocol
  - Complexity at network’s “edge”
DNS Name Servers

Why not centralize DNS?

- Single point of failure
- Traffic volume
- Distant centralized database
- Maintenance

Does not scale!
DNS Name Servers (2)

No server has all name-to-IP address mappings

Local name servers:
- Each ISP, company has local (default) name server
- Host DNS query first goes to local name server

Authoritative name server:
- For a host: stores that host’s IP address, name
- Can perform name/address translation for that host’s name
DNS: Hierarchical Naming Tree
Distributed, Hierarchical Database

Client wants IP for www.amazon.com; 1\textsuperscript{st} approx:
- Client queries a 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
  - Most use anycast addressing

13 root name servers worldwide
TLD and authoritative servers

- Top-level domain (TLD) servers:
  Responsible for com, org, net, edu, etc, and all top-level country domains like uk, fr, ca, jp...
  - Verisign, Inc. maintains servers for .com TLD
  - DENIC maintains servers for .de TLD

- Authoritative DNS servers:
  Organization’s DNS servers, providing authoritative hostname to IP mappings for organization’s servers (e.g., Web and mail).
  - Can be maintained by organization or service provider
Local Name Server (Recursor)

- Does not strictly belong to hierarchy
- Each ISP (residential ISP, company, university) has at least one.
  - Also called “default name server”
- When a host makes a DNS query, query is sent to its local DNS server
  - Acts as a proxy, forwards query into hierarchy.
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 IP address of authoritative name server for this domain

- Type=CNAME
  - for alias

- Type=MX
  - for mail

- Type=AAAA
  - for IPv6
Example

- Host at cis.poly.edu wants IP address for gaia.cs.umass.edu
Recursive queries

Recursive query:
- Puts burden of name resolution on contacted name server
- Heavy load?

Iterated query:
- Contacted server replies with name of server to contact
- “I don’t know this name, but ask this server”
DNS: Iterative Queries

Recursive query:
- Puts burden of name resolution on contacted name server
- Heavy load?

Iterated query:
- Contacted server replies with name of server to contact
- “I don’t know this name, but ask this server”
Mapping IP Address to Names


```
23.220.149.130.in-addr.arpa.
1.a.c.6.d.c.5.8.0.5.6.8.0.6.d.c.1.0.0.0.9.b.6.9.0.7.4.0.1.0.0.2.ip6.arpa.
```