Naming and DNS
September 19, 2019
Reading Quiz
Last class

• Distributed systems architectures
  – Client-Server
  – Peer-to-Peer

• Challenges in designing distributed systems
  – Partial failures
Today

• Identifiers and addressing

• Domain Name System
  – History
  – Query sequences
  – Record types
  – Load balancing
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.google.com - used by humans

How do we map between IP address and name, and vice versa?
DNS: domain name system

- distributed database implemented in hierarchy of many name servers.
- application-layer protocol: hosts, name servers communicate to resolve names → addresses
  - core Internet function, implemented as application-layer protocol
  - complexity at network’s “edge”
Recall: Addressing and Encapsulation

• Higher layer within lower layer

• Each layer has different concerns, provides abstract services to those above
Recall: Addressing and Encapsulation

Human-readable strings: www.example.com

Application: HTTP

Assigning ports to socket ID

Transport: TCP
data

IP addresses (IPv4, IPv6)

Network: IP
data

Link: Ethernet
data

(Network dependent) Ethernet:
48-bit MAC address
TCP/IP Protocol Stack

- **Application Layer**
  - HTTP
  - TCP
  - IP
- **Transport Layer**
  - IP
  - Ethernet interface
  - SONET interface
- **Network Layer**
  - IP
  - Ethernet interface
  - SONET interface
- **Link Layer**
  - Ethernet interface
  - SONET interface

Hosts, routers, and interfaces are connected as shown in the diagram.
Recall: TCP/IP Protocol Stack

- HTTP
- TCP
- IP
- Ethernet interface

- Human-readable strings: www.example.com

- (Not much addressing here, ports to ID socket)

- IP addresses (32-bit IPv4, 128-bit IPv6)

- (Network dependent) Ethernet: 48-bit MAC address
Why do we need to map names to IP addresses? Why not route on names at the network layer?

A. Domain names are hierarchical, so we can route on domain names too.

B. Domain names are variable length, vs IP are fixed length, some changes will be required to switch.

C. With domain names we wouldn’t know where to route to geographically.

D. Some other reason.
What’s in a name?

• Host name (e.g., www.swarthmore.edu)
  – Used by humans to specify host of interest
  – Unique, selected by host administrator
  – Hierarchical, variable-length string of alphanumeric characters
What’s in a name?

• IP address (e.g., 130.58.68.164)
  – Used by routers to forward packets
  – Unique, topologically meaningful locator
  – Hierarchical namespace of 32 bits
What’s in a name?

• MAC address (e.g., D8:D3:85:94:5F:1E)
  – Used by network adaptors to identify frames
  – Unique, hard-coded identifier burned into network adaptor
  – Flat name space (of 48 bits in Ethernet)
Identifiers

- Host name: web.cs.swarthmore.edu
  - Domain: registrar for each top-level domain (e.g., .edu)
  - Host name: local administrator assigns to each host

- IP addresses: 130.58.68.164
  - Prefixes: ICANN, regional Internet registries, and ISPs
  - Hosts: static configuration, or dynamic using DHCP

  - OIDs: assigned to vendors by the IEEE
  - Adapters: assigned by the vendor from its block
Identifiers

- **Host name**: `web.cs.swarthmore.edu` (today)
  - **Domain**: registrar for each top-level domain (e.g., `.edu`)
  - **Host name**: local administrator assigns to each host

- **IP addresses**: `130.58.68.164` (a few weeks)
  - **Prefixes**: ICANN, regional Internet registries, and ISPs
  - **Hosts**: static configuration, or dynamic using DHCP

- **MAC addresses**: `D8:D3:85:94:5F:1E` (after fall break)
  - **OIDs**: assigned to vendors by the IEEE
  - **Adapters**: assigned by the vendor from its block
Mapping Between Identifiers

- Domain Name System (DNS)
  - Given a host name, provide the IP address
  - Given an IP address, provide the host name

- Address Resolution Protocol (ARP)
  - Given an IP address, provide the MAC address
  - To enable communication within the Local Area Network

- Dynamic Host Configuration Protocol (DHCP)
  - Automates host boot-up process
  - Given a MAC address, assign a unique IP address
  - ... and tell host other stuff about the Local Area Network
What’s the biggest challenge for DNS?
What’s the biggest challenge for DNS?

A. It’s old.

B. The fact that the Internet is global.

C. The fact that DNS is now critical infrastructure.

D. The sheer number of name lookups happening at any given time.

E. How and when the name -> IP address mapping should change.
In the old days...

- Pre-1982, everyone downloads a “hosts.txt” file from SRI
- Pre-1998, Jon Postel, researcher at USC, runs the Internet Assigned Numbers Authority (IANA)
  - RFCs 882 & 883 in 1983
  - RFCs 1034 & 1035 in 1987

Emailed 8/12 root DNS servers, asked change to his authority. They did.

http://www.wired.com/wiredenterprise/2012/10/joe-postel/
Since 1998...

- Control of Internet Assigned Numbers Authority (IANA) transferred to Internet Corporation for Assigned Names and Numbers (ICANN)
  - ICANN is a private non-profit (formerly) blessed by US DOC
  - Global advisory committee for dealing with international issues
  - 2000’s: Many efforts for UN control, US resisted
  - 2016: ICANN no longer partnered with DOC
Who should control DNS?

A. US government

B. UN / International government

C. Private corporation

D. Someone else
Recent Controversy

- Is ICANN working in the world’s best interest?
- New “top level domains” added, for auction
Contributing to change?

RFCs
Memos in the RFC document series contain technical and organizational notes about the Internet.

Division of Computer and Network Systems (CNS)
CNS invents new computing and networking technologies, while ensuring their security and privacy, and finds new ways to make use of current technologies.

https://www.whitehouse.gov/ostp/  https://www.nsf.gov/cise/cns/about.jsp
https://www.icann.org/public-comments#open-public
https://www.ietf.org/standards/rfcs/
DNS Services

- DNS is an application-layer protocol. E2E design!
- It provides:
  - Hostname to IP address translation
  - Host aliasing (canonical and alias names)
  - Mail server aliasing
  - Load distribution (one name may resolve to multiple IP addresses)
  - Lots of other stuff that you might use a directory service to find. (Wikipedia: List of DNS record types)
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
- **value** is canonical name

www.ibm.com is really servereast.backup2.ibm.com

type=MX
- **value** is name of mailserver associated with name
DNS protocol, messages

- query and reply messages, both with same message format

<table>
<thead>
<tr>
<th>identification</th>
<th>flags</th>
</tr>
</thead>
<tbody>
<tr>
<td># questions</td>
<td># answer RRs</td>
</tr>
<tr>
<td># authority RRs</td>
<td># additional RRs</td>
</tr>
</tbody>
</table>

questions (variable # of questions)

answers (variable # of RRs)

authority (variable # of RRs)

additional info (variable # of RRs)
DNS protocol, messages

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

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

**Sent via UDP!**
- No connection established
- Not reliable
Domain Name System (DNS)

• Distributed administrative control
  – Hierarchical name space divided into zones
  – Distributed over a collection of DNS servers

• Hierarchy of DNS servers
  – Root servers
  – Top-level domain (TLD) servers
  – Authoritative DNS servers

• Performing the translations
  – Local DNS servers
  – Resolver software
DNS: a distributed, hierarchical database
DNS: a distributed, hierarchical database

Root DNS Servers

com DNS servers
- yahoo.com DNS servers
- amazon.com DNS servers

org DNS servers
- pbs.org DNS servers

edu DNS servers
- swarthmore.edu DNS servers
- umass.edu DNS servers
- cs.swarthmore.edu DNS servers
DNS: a distributed, hierarchical database

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- yahoo.com DNS servers
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org DNS servers
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edu DNS servers
- swarthmore.edu DNS servers
- umass.edu DNS servers

- cs.swarthmore.edu DNS servers

- allspice.cs.swarthmore.edu (other cs hosts)

Host

- allspice.cs.swarthmore.edu

• allspice.cs.swarthmore.edu.

Nameless root, Usually implied.
Why do we structure DNS like this? Which of these helps the most? Drawbacks?

A. It divides up responsibility among parties.

B. It improves performance of the system.

C. It reduces the size of the state that a server needs to store.

D. Some other reason.
DNS: a distributed, hierarchical database

- Root DNS Servers
  - ... (omitted)
  - com DNS servers
    - yahoo.com DNS servers
  - org DNS servers
    - amazon.com DNS servers
    - pbs.org DNS servers
  - edu DNS servers
    - swarthmore.edu DNS servers
      - cs.swarthmore.edu DNS servers
      - allspice.cs.swarthmore.edu Host
    - umass.edu DNS servers
      (other cs hosts)
DNS: Root Name Servers

• Root name server:
  – Knows how to find top-level domains (.com, .edu, .gov, etc.)
  – How often does the location of a TLD change?

c. Cogent, Herndon, VA (5 other sites)
d. U Maryland College Park, MD
h. ARL Aberdeen, MD
j. Verisign, Dulles VA (69 other sites)
e. NASA Mt View, CA
f. Internet Software C.
Palo Alto, CA (and 48 other sites)
a. Verisign, Los Angeles CA (5 other sites)
b. USC-ISI Marina del Rey, CA
l. ICANN Los Angeles, CA (41 other sites)
g. US DoD Columbus, OH (5 other sites)
k. RIPE London (17 other sites)
i. Netnod, Stockholm (37 other sites)
m. WIDE Tokyo (5 other sites)

13 root name “servers” worldwide
DNS: Root Name Servers

- Root name server:
  - Knows how to find top-level domains (.com, .edu, .gov, etc.)
  - How often does the location of a TLD change?
  - approx. 400 total root servers
  - Significant amount of traffic is not legitimate

13 root name “servers” worldwide
DNS: a distributed, hierarchical database

Root DNS Servers

... ... ...

com DNS servers

org DNS servers

esu DNS servers

yahoo.com DNS servers

amazon.com DNS servers

pbs.org DNS servers

swarthmore.edu DNS servers

umass.edu DNS servers

cs.swarthmore.edu DNS servers

allspice.cs.swarthmore.edu (other cs hosts)

Host
Top Level Domains

Top-level domain (TLD) servers:

- Responsible for com, org, net, edu, gov, aero, jobs, museums, and all top-level country domains, e.g.: uk, fr, de, ca, jp, etc.
- Verisign maintains servers for .com and .net TLD
- Educause for .edu TLD (Verisign actually runs backend)
- Others managed by corresponding entity (e.g., local governments or companies)
DNS: a distributed, hierarchical database

Root DNS Servers

... ... ...

com DNS servers
org DNS servers
edu DNS servers

yahoo.com DNS servers
amazon.com DNS servers
pbs.org DNS servers
swarthmore.edu DNS servers
umass.edu DNS servers

cs.swarthmore.edu DNS servers

allspice.cs.swarthmore.edu Host
(other cs hosts)
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, easily changing entries
- Often, but not always, acts as organization’s local name server (for responding to look-ups)
Resolution Process

- End host wants to look up a name, who should it contact?
  - It could traverse the hierarchy, starting at a root
  - More efficient for ISP to provide a local server

- ISP’s local server for handling queries not necessarily a part of the pictured hierarchy
Local DNS Name Server

• Each ISP (residential ISP, company, university) has (at least) 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 #1**

- allspice wants IP address for gaia.cs.umass.edu

**iterative query:**
- contacted server replies with name of server to contact
- “I don’t know this name, but ask this server”
recursive query:

- each server asks the next one, in a chain
Which would you use? Why?

A. Iterative

- root DNS server
- TLD DNS server
- local DNS server
- authoritative DNS server
- requesting host

B. Recursive

- root DNS server
- TLD DNS server
- local DNS server
- authoritative DNS server
- requesting host
Example: iterative query using `dig()

dig . ns

dig +norec demo.cs.swarthmore.edu @a.root-servers.net

dig +norec demo.cs.swarthmore.edu @a.edu-servers.net

dig +norec demo.cs.swarthmore.edu @ibext.its.swarthmore.edu

demo.cs.swarthmore.edu. 259200 IN A 130.58.68.26
Caching

• Once (any) name server learns a mapping, it **caches** mapping
  – cache entries timeout (disappear) after some time (TTL: time to live)
  – TLD servers typically cached in local name servers
  – Thus root name servers not often (legitimately) visited
Caching

• Once (any) name server learns a mapping, it caches mapping
  – cache entries timeout (disappear) after some time (TTL: time to live)
  – TLD servers typically cached in local name servers.
  – Root name servers not often (legitimately) visited
• (+) Subsequent requests need not burden DNS
• (-) Cached entries may be out-of-date (best effort!)
  – If host’s name or IP address changes, it may not be known Internet-wide until all TTLs expire
The TTL value should be…

A. Short, to make sure that changes are accurately reflected

B. Long, to avoid re-queries of higher-level DNS servers

C. Something else
Inserting (or changing) records

• Example: new startup “Network Utopia”

• Register networkuptopia.com at DNS registrar
  – 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)

• Set up authoritative server at that name/address
  – Create records for the services:
    • type A record for www.networkutopia.com
    • type MX record for @networkutopia.com email
Attacking DNS

DDoS attacks
• Bombard root servers with traffic
  – Not successful to date
  – Traffic Filtering
  – Local DNS servers cache IPs of TLD servers, bypassing root
• Bombard TLD servers
  – Potentially more dangerous

Redirect attacks
• Man-in-middle
  – Intercept queries
• DNS poisoning
  – Send bogus replies to DNS server that caches

Exploit DNS for DDoS
• Send queries with spoofed source address: target IP
• Requires amplification
Summary

• DNS maps human readable names to IP addresses

• DNS arranged into a hierarchy
  – Scalability / distributed responsibility
  – Autonomous control of local name servers

• Caching crucial for performance