15-440 Distributed Systems

Lecture 20 – DNS and CDNs

Outline

- DNS Design
- DNS Today
- Content Distribution Networks

Naming

- How do we efficiently locate resources?
  - DNS: name → IP address
- Challenge
  - How do we scale this to the wide area?

Obvious Solutions (1)

Why not use /etc/hosts?

- Original Name to Address Mapping
  - Flat namespace
  - /etc/hosts
  - SRI kept main copy
  - Downloaded regularly
- Count of hosts was increasing: machine per domain → machine per user
  - Many more downloads
  - Many more updates

Obvious Solutions (2)

Why not centralize DNS?

- Single point of failure
- Traffic volume
- Distant centralized database
- Single point of update
- Doesn't *scale!*

Domain Name System Goals

- Basically a wide-area distributed database
- Scalability
- Decentralized maintenance
- Robustness
- Global scope
  - Names mean the same thing everywhere
- Don't need
  - Atomicity
  - Strong consistency

Programmer's View of DNS

- Conceptually, programmers can view the DNS database as a collection of millions of *host entry structures*:

```
/* DNS host entry structure */
struct addrinfo {
    int    ai_family;              /* host address type (AF_INET) */
    size_t ai_addrlen;             /* length of an address, in bytes */
    struct sockaddr *ai_addr;      /* address! */
    char   *ai_canonname;          /* official domain name of host */
    struct addrinfo *ai_next;      /* other entries for host */
};
```

- Functions for retrieving host entries from DNS:
  - `getaddrinfo`: query key is a DNS host name.
  - `getnameinfo`: query key is an IP address.

DNS Message Format

12 bytes	Identification	Flags
	No. of Questions	No. of Answer RRs
	No. of Authority RRs	No. of Additional RRs
Name, type fields for a query	Questions (variable number of answers)	
RRs in response to query	Answers (variable number of resource records)	
Records for authoritative servers	Authority (variable number of resource records)	
Additional "helpful info that may be used	Additional Info (variable number of resource records)	

DNS Header Fields

- Identification
  - Used to match up request/response
- Flags
  - 1-bit to mark query or response
  - 1-bit to mark authoritative or not
  - 1-bit to request recursive resolution
  - 1-bit to indicate support for recursive resolution

DNS Records

RR format: **(class, name, value, type, ttl)**

- DB contains tuples called resource records (RRs)
  - Classes = Internet (IN), Chaosnet (CH), etc.
  - Each class defines value associated with type

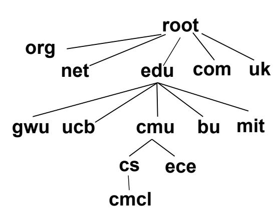
FOR IN class:

- Type=A
  - **name** is hostname
  - **value** is IP address
- Type=NS
  - **name** is domain (e.g. foo.com)
  - **value** is name of authoritative name server for this domain
- Type=CNAME
  - **name** is an alias name for some "canonical" (the real) name
  - **value** is canonical name
- Type=MX
  - **value** is hostname of mailserver associated with **name**

Properties of DNS Host Entries

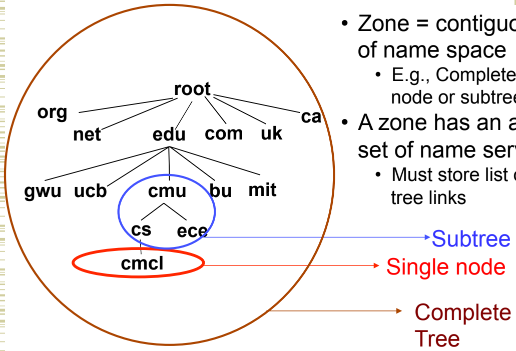
- Different kinds of mappings are possible:
  - Simple case: 1-1 mapping between domain name and IP addr:
    - `kittyhawk.cmcl.cs.cmu.edu` maps to `128.2.194.242`
  - Multiple domain names maps to the same IP address:
    - `eecs.mit.edu` and `cs.mit.edu` both map to `18.62.1.6`
  - Single domain name maps to multiple IP addresses:
    - `aol.com` and `www.aol.com` map to multiple IP addrs.
  - Some valid domain names don't map to any IP address:
    - for example: `cmcl.cs.cmu.edu`

DNS Design: Hierarchy Definitions



- Each node in hierarchy stores a list of names that end with same suffix
  - Suffix = path up tree
- E.g., given this tree, where would following be stored:
  - Fred.com
  - Fred.edu
  - Fred.cmu.edu
  - Fred.cmcl.cs.cmu.edu
  - Fred.cs.mit.edu

DNS Design: Zone Definitions



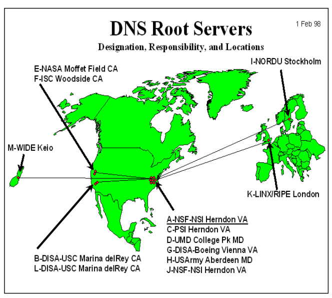
- Zone = contiguous section of name space
  - E.g., Complete tree, single node or subtree
- A zone has an associated set of name servers
  - Must store list of names and tree links

DNS Design: Cont.

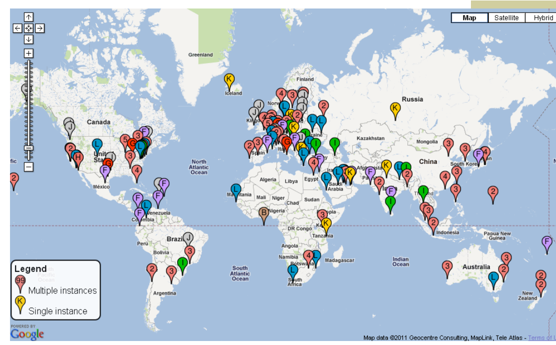
- Zones are created by convincing owner node to create/delegate a subzone
  - Records within zone stored multiple redundant name servers
  - Primary/master name server updated manually
  - Secondary/redundant servers updated by zone transfer of name space
    - Zone transfer is a bulk transfer of the “configuration” of a DNS server – uses TCP to ensure reliability
- Example:
  - CS.CMU.EDU created by CMU.EDU administrators
  - Who creates CMU.EDU or .EDU?

DNS: Root Name Servers

- Responsible for “root” zone
- Approx. 13 root name servers worldwide
  - Currently {a-m}.root-servers.net
- Local name servers contact root servers when they cannot resolve a name
  - Configured with well-known root servers
  - Newer picture → www.root-servers.org



Physical Root Name Servers

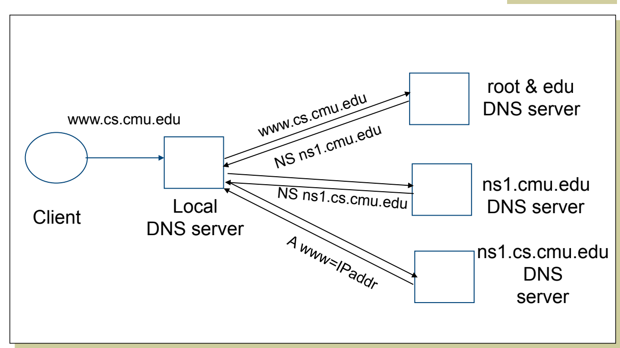


- Several root servers have multiple physical servers
- Packets routed to “nearest” server by “Anycast” protocol
- 346 servers total

Servers/Resolvers

- Each host has a resolver
  - Typically a library that applications can link to
  - Local name servers hand-configured (e.g. /etc/resolv.conf)
- Name servers
  - Either responsible for some zone or…
  - Local servers
    - Do lookup of distant host names for local hosts
    - Typically answer queries about local zone

Typical Resolution



Typical Resolution

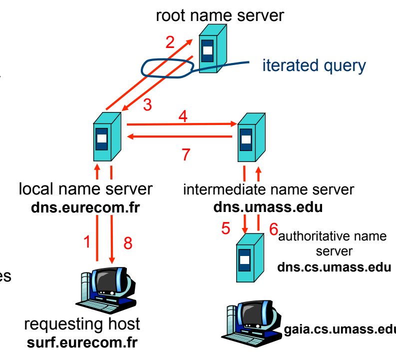
- Steps for resolving www.cmu.edu
  - Application calls gethostbyname() (RESOLVER)
  - Resolver contacts local name server (S_1)
  - S_1 queries root server (S_2) for (www.cmu.edu)
  - S_2 returns NS record for cmu.edu (S_3)
  - What about A record for S_3?
    - This is what the additional information section is for (PREFETCHING)
  - S_1 queries S_3 for www.cmu.edu
  - S_3 returns A record for www.cmu.edu

Lookup Methods

Recursive query:
- Server goes out and searches for more info (recursive)
- Only returns final answer or "not found"

Iterative query:
- Server responds with as much as it knows (iterative)
- "I don't know this name, but ask this server"

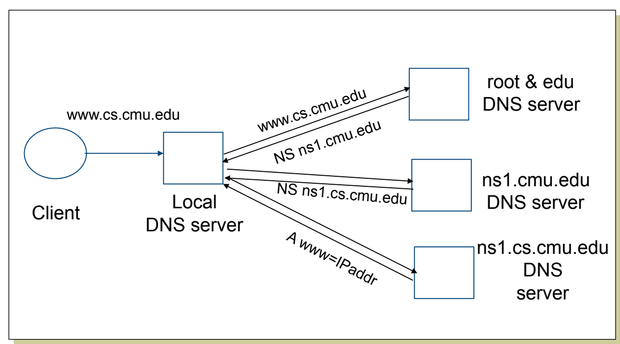
Workload impact on choice?
- Local server typically does recursive
- Root/distant server does iterative



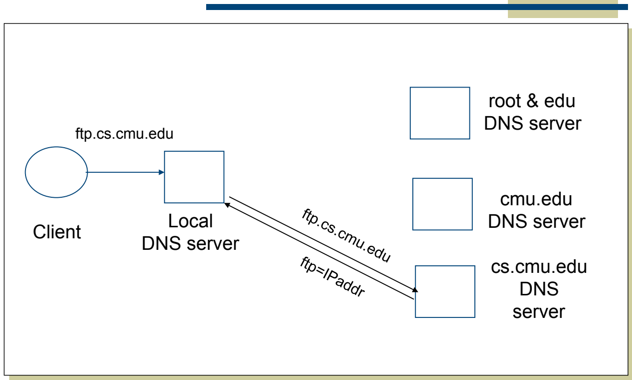
Workload and Caching

- Are all servers/names likely to be equally popular?
  - Why might this be a problem? How can we solve this problem?
- DNS responses are cached
  - Quick response for repeated translations
  - Other queries may reuse some parts of lookup
    - NS records for domains
- DNS negative queries are cached
  - Don't have to repeat past mistakes
  - E.g. misspellings, search strings in resolv.conf
- Cached data periodically times out
  - Lifetime (TTL) of data controlled by owner of data
  - TTL passed with every record

Typical Resolution



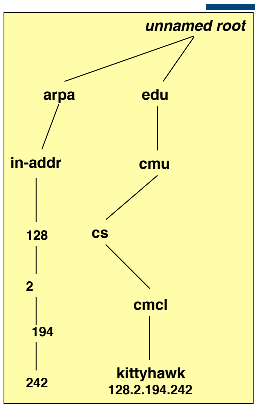
Subsequent Lookup Example



Reliability

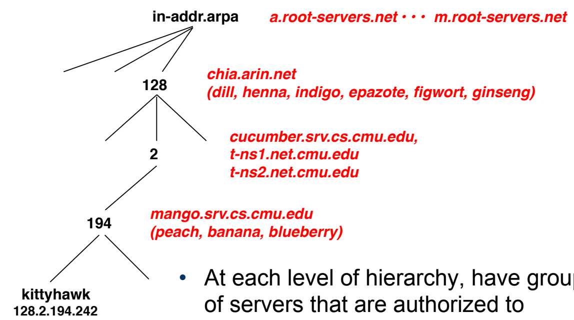
- DNS servers are replicated
  - Name service available if ≥ one replica is up
  - Queries can be load balanced between replicas
- UDP used for queries
  - Need reliability → must implement this on top of UDP!
  - Why not just use TCP?
- Try alternate servers on timeout
  - Exponential backoff when retrying same server
- Same identifier for all queries
  - Don't care which server responds

Reverse DNS



- Task
  - Given IP address, find its name
- Method
  - Maintain separate hierarchy based on IP names
  - Write 128.2.194.242 as 242.194.2.128.in-addr.arpa
    - Why is the address reversed?
- Managing
  - Authority manages IP addresses assigned to it
  - E.g., CMU manages name space 128.2.in-addr.arpa

.arpa Name Server Hierarchy



- At each level of hierarchy, have group of servers that are authorized to handle that region of hierarchy

Tracing Hierarchy (1)

- Dig Program
  - Use flags to find name server (NS)
  - Disable recursion so that operates one step at a time

```
unix> dig +norecurse @a.root-servers.net NS
greatwhite.ics.cs.cmu.edu

;; ADDITIONAL SECTION:
a.edu-servers.net     172800  IN    A       192.5.6.30
c.edu-servers.net.    172800  IN    A       192.26.92.30
d.edu-servers.net.    172800  IN    A       192.31.80.30
f.edu-servers.net.    172800  IN    A       192.35.51.30
g.edu-servers.net.    172800  IN    A       192.42.93.30
g.edu-servers.net.    172800  IN    AAAA    2001:503:cc2c::2:36
l.edu-servers.net.    172800  IN    A       192.41.162.30
```

IP v6 address

- All .edu names handled by set of servers

Prefetching

- Name servers can add additional data to response
- Typically used for prefetching
  - CNAME/MX/NS typically point to another host name
  - Responses include address of host referred to in “additional section”

Tracing Hierarchy (2)

- 3 servers handle CMU names

```
unix> dig +norecurse @g.edu-servers.net NS
greatwhite.ics.cs.cmu.edu

;; AUTHORITY SECTION:
cmu.edu.          172800  IN      NS        ny-server-03.net.cmu.edu.
cmu.edu.          172800  IN      NS        nsauth1.net.cmu.edu.
cmu.edu.          172800  IN      NS        nsauth2.net.cmu.edu.
```


Tracing Hierarchy (3 & 4)

- 3 servers handle CMU CS names

```
unix> dig +norecurse @nsauth1.net.cmu.edu NS greatwhite.ics.cs.cmu.edu

;; AUTHORITY SECTION:
cs.cmu.edu.     600     IN      NS      AC-DDNS-2.NET.cs.cmu.edu.
cs.cmu.edu.     600     IN      NS      AC-DDNS-1.NET.cs.cmu.edu.
cs.cmu.edu.     600     IN      NS      AC-DDNS-3.NET.cs.cmu.edu.
```

```
unix>dig +norecurse @AC-DDNS-2.NET.cs.cmu.edu NS
greatwhite.ics.cs.cmu.edu

;; AUTHORITY SECTION:
cs.cmu.edu.     300     IN      SOA
PLANISPHERE.FAC.cs.cmu.edu.
```

DNS Hack #1

- Can return multiple A records → what does this mean?
- Load Balance
  - Server sends out multiple A records
  - Order of these records changes per-client

Server Balancing Example

- DNS Tricks

```
unix1> dig www.google.com

;; ANSWER SECTION:
www.google.com.          87775   IN      CNAME   www.l.google.com.
www.l.google.com.        81      IN      A       72.14.204.104
www.l.google.com.        81      IN      A       72.14.204.105
www.l.google.com.        81      IN      A       72.14.204.147
www.l.google.com.        81      IN      A       72.14.204.99
www.l.google.com.        81      IN      A       72.14.204.103
```

```
unix2> dig www.google.com

;; ANSWER SECTION:
www.google.com.          603997  IN      CNAME   www.l.google.com.
www.l.google.com.        145     IN      A       72.14.204.99
www.l.google.com.        145     IN      A       72.14.204.103
www.l.google.com.        145     IN      A       72.14.204.104
www.l.google.com.        145     IN      A       72.14.204.105
www.l.google.com.        145     IN      A       72.14.204.147
```


Outline

- DNS Design
- DNS Today
- Content Distribution Networks

Root Zone

- Generic Top Level Domains (gTLD) = .com, .net, .org, etc…
- Country Code Top Level Domain (ccTLD) = .us, .ca, .fi, .uk, etc…
- Root server ({a-m}.root-servers.net) also used to cover gTLD domains
  - Load on root servers was growing quickly!
  - Moving .com, .net, .org off root servers was clearly necessary to reduce load → done Aug 2000

gTLDs

- Unsponsored
  - .com, .edu, .gov, .mil, .net, .org
  - .biz → businesses
  - .info → general info
  - .name → individuals
- Sponsored (controlled by a particular association)
  - .aero → air-transport industry
  - .cat → catalan related
  - .coop → business cooperatives
  - .jobs → job announcements
  - .museum → museums
  - .pro → accountants, lawyers, and physicians
  - .travel → travel industry
- Starting up
  - .mobi → mobile phone targeted domains
  - .post → postal
  - .tel → telephone related
- Proposed
  - .asia, .cym, .geo, .kid, .mail, .sco, .web, .xxx

New Registrars

- Network Solutions (NSI) used to handle all registrations, root servers, etc…
  - Clearly not the democratic (Internet) way
  - Large number of registrars that can create new domains → However NSI still handles A root server

Do you trust the TLD operators?

- Wildcard DNS record for all .com and .net domain names not yet registered by others
  - September 15 – October 4, 2003
  - February 2004: Verisign sues ICANN
- Redirection for these domain names to Verisign web portal (SiteFinder)
- What services might this break?

Protecting the Root Nameservers

Attack On Internet Called Largest Ever

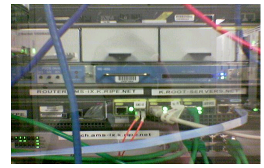
By David McGuire and Brian Krebs
washingtonpost.com Staff Writers
Tuesday, October 22, 2002; 5:40 PM

The heart of the Internet sustained its largest and most sophisticated attack ever, starting late Monday, according to officials at key online backbone organizations.

Around 5:00 p.m. EDT on Monday, a "distributed denial of service" (DDOS) attack struck the 13 "root servers" that provide the primary roadmap for almost all Internet communications. Despite the scale of the attack, which lasted about an hour, Internet users worldwide were largely unaffected, experts said.

Sophisticated?
Why did nobody notice?

seshan.org. 13759 NS www.seshan.org.



Defense Mechanisms

- Redundancy: 13 root nameservers
- IP Anycast for root DNS servers {c,f,i,j,k}.root-servers.net
  - RFC 3258
  - Most *physical* nameservers lie outside of the US

Defense: Replication and Caching

Letter	Old name	Operator	Location
A	ns.internic.net	VeriSign	Dulles, Virginia, USA
B	ns1.isi.edu	ISI	Marina Del Rey, California, USA
C	c.psi.net	Cogent Communications	distributed using anycast
D	terp.umd.edu	University of Maryland	College Park, Maryland, USA
E	ns.nasa.gov	NASA	Mountain View, California, USA
F	ns.isc.org	ISC	distributed using anycast
G	ns.nic.ddn.mil	U.S. DoD NIC	Columbus, Ohio, USA
H	aos.arl.army.mil	U.S. Army Research Lab	Aberdeen Proving Ground, Maryland, USA
I	nic.nordu.net	Autonomica	distributed using anycast
J		VeriSign	distributed using anycast
K		RIPE NCC	distributed using anycast
L		ICANN	Los Angeles, California, USA
M		WIDE Project	distributed using anycast

source: wikipedia

DNS (Summary)

- Motivations → large distributed database
  - Scalability
  - Independent update
  - Robustness
- Hierarchical database structure
  - Zones
  - How is a lookup done
- Caching/prefetching and TTLs
- Reverse name lookup
- What are the steps to creating your own domain?

Outline

- DNS Design
- DNS Today
- Content Distribution Networks

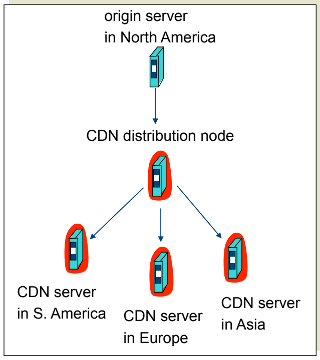
Typical Workload (Web Pages)

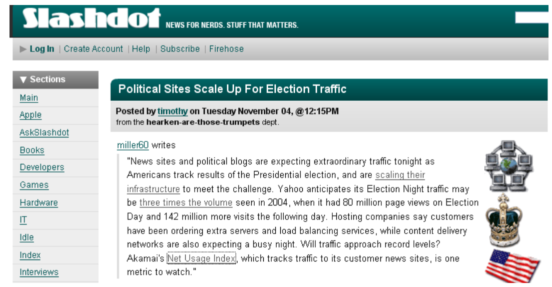
- Multiple (typically small) objects per page
- File sizes are heavy-tailed
- Embedded references
- This plays havoc with performance. Why?
- Solutions?

- Lots of small objects & TCP
  - 3-way handshake
  - Lots of slow starts
  - Extra connection state

Content Distribution Networks (CDNs)

- The content providers are the CDN customers.
- Content replication
- CDN company installs hundreds of CDN servers throughout Internet
  - Close to users
- CDN replicates its customers' content in CDN servers. When provider updates content, CDN updates servers

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Sections: Main, Apple, AskSlashdot, Books, Developers, Games, Hardware, IT, Idle, Index, Interviews

Political Sites Scale Up For Election Traffic

Posted by timothy on Tuesday November 04, @12:15PM
from the hearken-are-those-trumpets dept.

miller60 writes

"News sites and political blogs are expecting extraordinary traffic tonight as Americans track results of the Presidential election, and are scaling their infrastructure to meet the challenge. Yahoo anticipates its Election Night traffic may be three times the volume seen in 2004, when it had 80 million page views on Election Day and 142 million more visits the following day. Hosting companies say customers have been ordering extra servers and load balancing services, while content delivery networks are also expecting a busy night. Will traffic approach record levels? Akamai's Net Usage Index, which tracks traffic to its customer news sites, is one metric to watch."

http://www.akamai.com/html/technology/nui/news/index.html

Content Distribution Networks & Server Selection

- Replicate content on many servers
- Challenges
  - How to replicate content
  - Where to replicate content
  - How to find replicated content
  - How to choose among known replicas
  - How to direct clients towards replica

Server Selection

- Which server?
  - Lowest load → to balance load on servers
  - Best performance → to improve client performance
    - Based on Geography? RTT? Throughput? Load?
  - Any alive node → to provide fault tolerance
- How to direct clients to a particular server?
  - As part of routing → anycast, cluster load balancing
    - Not covered ☹
  - As part of application → HTTP redirect
  - As part of naming → DNS

Application Based

- HTTP supports simple way to indicate that Web page has moved (30X responses)
- Server receives Get request from client
  - Decides which server is best suited for particular client and object
  - Returns HTTP redirect to that server
- Can make informed application specific decision
- May introduce additional overhead → multiple connection setup, name lookups, etc.
- While good solution in general, but…
  - HTTP Redirect has some design flaws – especially with current browsers

Naming Based

- Client does name lookup for service
- Name server chooses appropriate server address
  - A-record returned is "best" one for the client
- What information can name server base decision on?
  - Server load/location → must be collected
  - Information in the name lookup request
    - Name service client → typically the local name server for client

How Akamai Works

- Clients fetch html document from primary server
  - E.g. fetch index.html from cnn.com
- URLs for replicated content are replaced in html
  - E.g. <img src="http://cnn.com/af/x.gif"> replaced with <img src="http://a73.g.akamaitech.net/7/23/cnn.com/af/x.gif">
- Client is forced to resolve aXYZ.g.akamaitech.net hostname

Note: Nice presentation on Akamai at www.cs.odu.edu/~mukka/cs775s07/Presentations/mklein.pdf

How Akamai Works

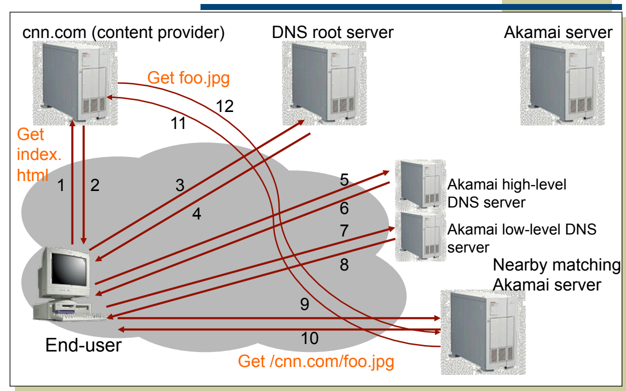
- How is content replicated?
- Akamai only replicates static content (*)
- Modified name contains original file name
- Akamai server is asked for content
  - First checks local cache
  - If not in cache, requests file from primary server and caches file

* (At least, the version we're talking about today. Akamai actually lets sites write code that can run on Akamai's servers, but that's a pretty different beast)

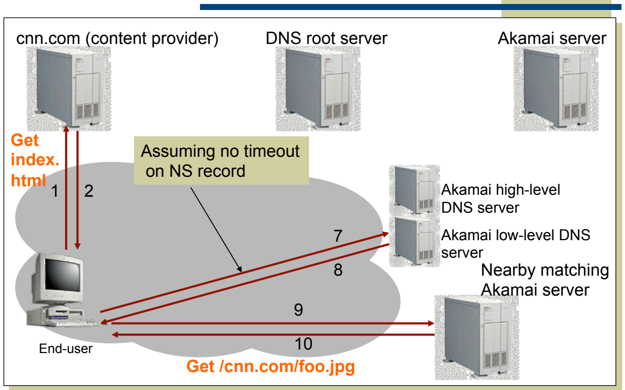
How Akamai Works

- Root server gives NS record for akamai.net
- Akamai.net name server returns NS record for g.akamaitech.net
  - Name server chosen to be in region of client's name server
  - TTL is large
- G.akamaitech.net nameserver chooses server in region
  - Should try to chose server that has file in cache - How to choose?
  - Uses aXYZ name and hash
  - TTL is small → why?

How Akamai Works



Akamai – Subsequent Requests



Simple Hashing

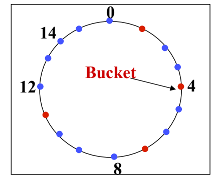
- Given document XYZ, we need to choose a server to use
- Suppose we use modulo
- Number servers from 1…n
  - Place document XYZ on server (XYZ mod n)
  - What happens when a servers fails? n → n-1
    - Same if different people have different measures of n
  - Why might this be bad?

Consistent Hash

- "view" = subset of all hash buckets that are visible
- Desired features
  - Smoothness – little impact on hash bucket contents when buckets are added/removed
  - Spread – small set of hash buckets that may hold an object regardless of views
  - Load – across all views # of objects assigned to hash bucket is small

Consistent Hash – Example

- Construction
  - Assign each of C hash buckets to random points on mod 2^n circle, where, hash key size = n.
  - Map object to random position on unit interval
  - Hash of object = closest bucket



- Monotone → addition of bucket does not cause movement between existing buckets
- Spread & Load → small set of buckets that lie near object
- Balance → no bucket is responsible for large number of objects

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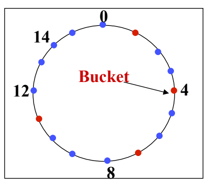

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- Spread & Load → small set of buckets that lie near object
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Consistent Hashing not just for CDN

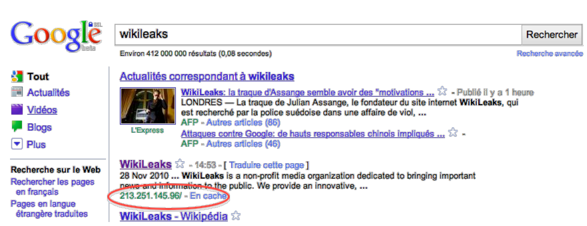
- Finding a nearby server for an object in a CDN uses centralized knowledge.
- Consistent hashing can also be used in a distributed setting
- P2P systems like BitTorrent, e.g., project 3, need a way of finding files.
- Consistent Hashing to the rescue.

Summary

- DNS
- Content Delivery Networks move data closer to user, maintain consistency, balance load
  - Consistent Caching maps keys AND buckets into the same space
  - Consistent caching can be fully distributed, useful in P2P systems using structured overlays

A rose by any other name….

- "DNS Is Sexy: Making Things Go While Making It Fun" (http://dyn.com/dns-is-sexy/)
  - If you can convince yourself that something like DNS is sexy, then Dyn must be a great place to work
- TheGoodThingAboutDomainNameJokesISThatAllTheGoodShortOnesHaveBeenTold.com unless you're being creati.ve



Tracing Hierarchy (1)

- Dig Program
  - Allows querying of DNS system
  - Use flags to find name server (NS)
  - Disable recursion so that operates one step at a time

unix> *dig +norecurse @a.root-servers.net NS kittyhawk.cmcl.cs.cmu.edu*

;; AUTHORITY SECTION:

edu.	172800	IN	NS	L3.NSTLD.COM.
edu.	172800	IN	NS	D3.NSTLD.COM.
edu.	172800	IN	NS	A3.NSTLD.COM.
edu.	172800	IN	NS	E3.NSTLD.COM.
edu.	172800	IN	NS	C3.NSTLD.COM.
edu.	172800	IN	NS	F3.NSTLD.COM.
edu.	172800	IN	NS	G3.NSTLD.COM.
edu.	172800	IN	NS	B3.NSTLD.COM.
edu.	172800	IN	NS	M3.NSTLD.COM.

- All .edu names handled by set of servers

Tracing Hierarchy (2)

- 3 servers handle CMU names

unix> *dig +norecurse @e3.nstld.com NS kittyhawk.cmcl.cs.cmu.edu*

;; AUTHORITY SECTION:

cmu.edu.	172800	IN	NS	CUCUMBER.SRV.cs.cmu.edu.
cmu.edu.	172800	IN	NS	T-NS1.NET.cmu.edu.
cmu.edu.	172800	IN	NS	T-NS2.NET.cmu.edu.

Tracing Hierarchy (3 & 4)

- 4 servers handle CMU CS names

unix> *dig +norecurse @t-ns1.net.cmu.edu NS kittyhawk.cmcl.cs.cmu.edu*

;; AUTHORITY SECTION:

cs.cmu.edu.	86400	IN	NS	MANGO.SRV.cs.cmu.edu.
cs.cmu.edu.	86400	IN	NS	PEACH.SRV.cs.cmu.edu.
cs.cmu.edu.	86400	IN	NS	BANANA.SRV.cs.cmu.edu.
cs.cmu.edu.	86400	IN	NS	BLUEBERRY.SRV.cs.cmu.edu.

- Quasar is master NS for this zone

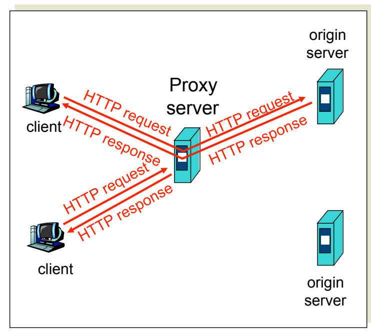
unix>*dig +norecurse @blueberry.srv.cs.cmu.edu NS kittyhawk.cmcl.cs.cmu.edu*

;; AUTHORITY SECTION:

cs.cmu.edu.	300	IN	SOA	QUASAR.FAC.cs.cmu.edu.

Web Proxy Caches

- User configures browser: Web accesses via cache
- Browser sends all HTTP requests to cache
  - Object in cache: cache returns object
  - Else cache requests object from origin server, then returns object to client

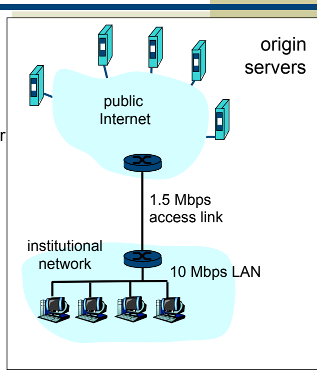


No Caching Example (1)

Assumptions
- Average object size = 100,000 bits
- Avg. request rate from institution's browser to origin servers = 15/sec
- Delay from institutional router to any origin server and back to router = 2 sec

Consequences
- Utilization on LAN = 15%
- Utilization on access link = 100%
- Total delay = Internet delay + access delay + LAN delay

= 2 sec + minutes + milliseconds

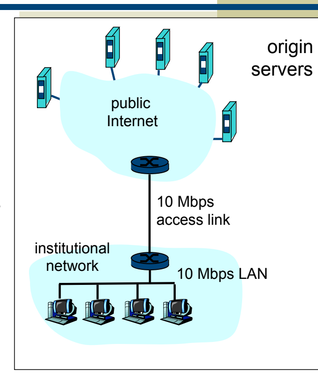


No Caching Example (2)

Possible solution
- Increase bandwidth of access link to, say, 10 Mbps
- Often a costly upgrade

Consequences
- Utilization on LAN = 15%
- Utilization on access link = 15%
- Total delay = Internet delay + access delay + LAN delay

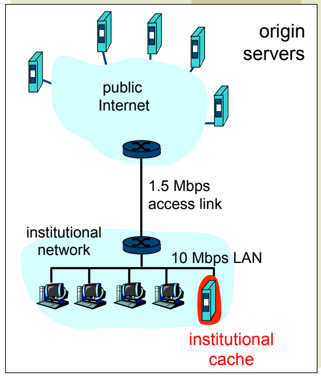
= 2 sec + msecs + msecs



W/Caching Example (3)

Install cache
- Suppose hit rate is .4

Consequence
- 40% requests will be satisfied almost immediately (say 10 msec)
- 60% requests satisfied by origin server
- Utilization of access link reduced to 60%, resulting in negligible delays
- Weighted average of delays
  = .6*2 sec + .4*10msecs < 1.3 secs



HTTP Caching

- Clients often cache documents
  - Challenge: update of documents
  - If-Modified-Since requests to check
    - HTTP 0.9/1.0 used just date
    - HTTP 1.1 has an opaque "entity tag" (could be a file signature, etc.) as well
- When/how often should the original be checked for changes?
  - Check every time?
  - Check each session? Day? Etc?
  - Use Expires header
    - If no Expires, often use Last-Modified as estimate

Example Cache Check Request

GET / HTTP/1.1
Accept: */*
Accept-Language: en-us
Accept-Encoding: gzip, deflate
If-Modified-Since: Mon, 29 Jan 2001 17:54:18 GMT
If-None-Match: "7a11f-10ed-3a75ae4a"
User-Agent: Mozilla/4.0 (compatible; MSIE 5.5; Windows NT 5.0)
Host: www.intel-iris.net
Connection: Keep-Alive

Example Cache Check Response

HTTP/1.1 304 Not Modified
Date: Tue, 27 Mar 2001 03:50:51 GMT
Server: Apache/1.3.14 (Unix) (Red-Hat/Linux) mod_ssl/2.7.1 OpenSSL/0.9.5a DAV/1.0.2 PHP/4.0.1pl2 mod_perl/1.24
Connection: Keep-Alive
Keep-Alive: timeout=15, max=100
ETag: "7a11f-10ed-3a75ae4a"

Problems

- Over 50% of all HTTP objects are uncacheable – why?
- Not easily solvable
  - Dynamic data → stock prices, scores, web cams
  - CGI scripts → results based on passed parameters
- Obvious fixes
  - SSL → encrypted data is not cacheable
    - Most web clients don't handle mixed pages well →many generic objects transferred with SSL
  - Cookies → results may be based on passed data
  - Hit metering → owner wants to measure # of hits for revenue, etc.

Caching Proxies – Sources for Misses

- Capacity
  - How large a cache is necessary or equivalent to infinite
  - On disk vs. in memory → typically on disk
- Compulsory
  - First time access to document
  - Non-cacheable documents
    - CGI-scripts
    - Personalized documents (cookies, etc)
    - Encrypted data (SSL)
- Consistency
  - Document has been updated/expired before reuse

Measurements of DNS

- No centralized caching per site
  - Each machine runs own caching local server
  - Why is this a problem?
  - How many hosts do we need to share cache? → recent studies suggest 10-20 hosts
- "Hit rate for DNS = 80% → 1 - (#DNS/#connections)
  - Is this good or bad?
  - Most Internet traffic was Web with HTTP 1.0
    - What does a typical page look like? → average of 4-5 imbedded objects → needs 4-5 transfers
    - This alone accounts for 80% hit rate!
- Lower TTLs for A records does not affect performance
- DNS performance really relies more on NS-record caching

DNS Experience

- 23% of lookups with no answer
  - Retransmit aggressively → most packets in trace for unanswered lookups!
  - Correct answers tend to come back quickly/with few retries
- 10 - 42% negative answers → most = no name exists
  - Inverse lookups and bogus NS records
- Worst 10% lookup latency got much worse
  - Median 85→97, 90th percentile 447→1176
- Increasing share of low TTL records → what is happening to caching?

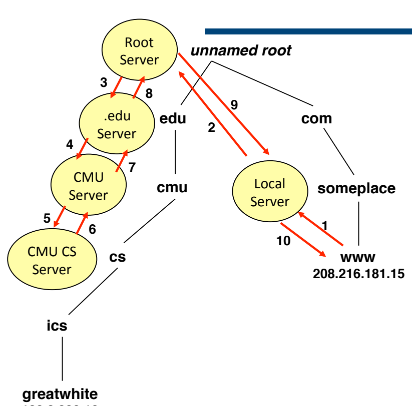
DNS Experience

- Hit rate for DNS = 80% → 1-(#DNS/#connections)
  - Most Internet traffic is Web
  - What does a typical page look like? → average of 4-5 imbedded objects → needs 4-5 transfers → accounts for 80% hit rate!
- 70% hit rate for NS records → i.e. don't go to root/gTLD servers
  - NS TTLs are much longer than A TTLs
  - NS record caching is much more important to scalability
- Name distribution = Zipf-like = $1/x^a$
- A records → TTLs = 10 minutes similar to TTLs = infinite
- 10 client hit rate = 1000+ client hit rate

Mail Addresses

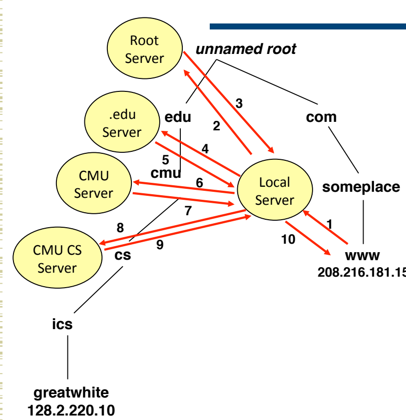
- MX records point to mail exchanger for a name
  - E.g. mail.acm.org is MX for acm.org
- Addition of MX record type proved to be a challenge
  - How to get mail programs to lookup MX record for mail delivery?
  - Needed critical mass of such mailers

Recursive DNS Name Resolution



- Nonlocal Lookup
  - Recursively from root server downward
  - Results passed up
- Caching
  - Results stored in caches along each hop
  - Can shortcircuit lookup when cached entry present

Iterative DNS Name Resolution



- Nonlocal Lookup
  - At each step, server returns name of next server down
  - Local server directly queries each successive server
- Caching
  - Local server builds up cache of intermediate translations
  - Helps in resolving names xxx.cs.cmu.edu, yy.cmu.edu, and z.edu

DNS Hack #2: Blackhole Lists

- First: Mail Abuse Prevention System (MAPS)
  - Paul Vixie, 1997
- Today: Spamhaus, spamcop, dnsrbl.org, etc.

Different addresses refer to different reasons for blocking

% dig 91.53.195.211.bl.spamcop.net

;; ANSWER SECTION:
91.53.195.211.bl.spamcop.net. 2100 IN A 127.0.0.2

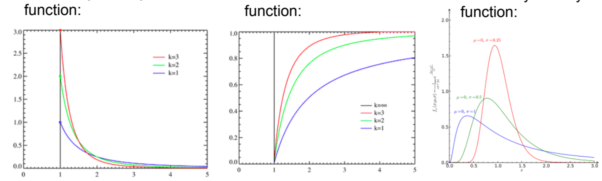
;; ANSWER SECTION:
91.53.195.211.bl.spamcop.net. 1799 IN TXT "Blocked - see http://www.spamcop.net/bl.shtml?211.195.53.91"

File Size and References Distributions

- File sizes
  - Pareto distribution for tail
  - Lognormal for body of distribution
- Number of embedded references also Pareto

Pareto: kx_m^k/x^{k+1} $\Pr(X < x) = 1 - (x_m/x)^k$ Log-Normal

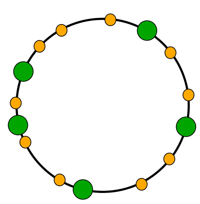
Probability density function: Cumulative distribution function: Probability density function:



Consistent Hashing

- **Main idea:**
  - map both keys and nodes to the same (metric) identifier space
  - find a "rule" how to assign keys to nodes

Ring is one option.



Consistent Hashing

- The consistent hash function assigns each node and key an *m*-bit identifier using SHA-1 as a base hash function
- **Node identifier:** SHA-1 hash of IP address
- **Key identifier:** SHA-1 hash of key

Identifiers

- *m* bit identifier space for both keys and nodes
- **Key identifier:** SHA-1(key)

Key="LetItBe" $\xrightarrow{\text{SHA-1}}$ ID=60

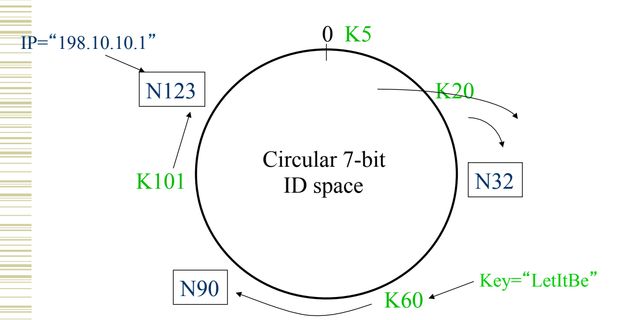
- **Node identifier:** SHA-1(IP address)

IP="198.10.10.1" $\xrightarrow{\text{SHA-1}}$ ID=123

- How to map key IDs to node IDs?

Consistent Hashing Example

Rule: A key is stored at its successor: node with next higher or equal ID



Consistent Hashing Properties

- **Load balance:** all nodes receive roughly the same number of keys
- For *N* nodes and *K* keys, with high probability
  - each node holds at most $(1+\varepsilon)K/N$ keys
  - (provided that K is large enough compared to N)

Load Balance

- Redirector knows all CDN server Ids
- Can track approximate load (or delay)
- To balance load:
  - W_i = Hash(URL, ip of s_i) for all i
  - Sort W_i from high to low
  - find first server with low enough load
- Benefits?
- How should "load" be measured?