Today's class

- Quick examples of other application protocols
  - Mail, telnet, NFS
- Content Distribution Networks (CDN)

Quick descriptions of some other sample applications

- Sending E-mail
  - SMTP
- Remote terminal
  - Telnet, SSH
- Distributed File Systems
  - NFS

Simple Message Transfer Protocol (SMTP)

Like HTTP: TCP connection (port 25), ASCII string commands

Sample session:

HELO cs.ucsd.edu
Hello cs.ucsd.edu [132.239.4.64]
MAIL FROM: savage@cs.ucsd.edu
250 OK
RCPT TO: joe@cs.berkeley.edu
250 OK
DATA
354 Startup mail input; end with <CRLF>.<CRLF>
Hi Joe... how're you doing?
<CRLF><CRLF>
250 OK
QUIT
221 Closing connection

Telnet

- TCP-based protocol (port 23)
  - Telnet client and telnet server
- First negotiate capabilities (e.g. terminal size, speed, line and a time vs character at a time, etc.)
- Then simply send keystrokes from client to server and send data strings from server to client
  - Characters transmitted as 7 bits (8th bit 0)
  - In-band signalling
    - Byte 0xff means "interpret as command"
    - What if you need to send the symbol 0xff? Send it twice.

Network File System (NFS)

- UDP-based protocol
- Remote Procedure Call (RPC) design
  - READ, WRITE, LOOKUP, REMOVE, RENAME, MKDIR, etc...
  - Header describes method and data types, followed by data
  - All requests fit in a single UDP datagram (up to 8k in v2, 64k in V3); fragmentation
  - Errors in data stream?
  - Security?
Content Distribution Networks

- Goal: Improve performance/scalability for downloading content (i.e. Web pages)
- Approach: Replicate content (particularly Web 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
    - DNS, HTTP 304 response, anycast, etc.
- Akamai

How to replicate content

- Push model
  - Proactively copy content to specific replicas
  - How to choose these?
- Pull model
  - Reactively replicate content to nodes that request it
  - Content is replicated to places where it is popular

Server Selection

- How do direct clients to a particular server?
  - As part of routing → anycast, cluster load balancing
  - As part of application → HTTP redirect
  - As part of naming → DNS
- Which server?
  - Lowest load → to balance load on servers
  - Best performance → to improve client performance
    - Based on Geography? RTT? Throughput?
  - Any alive node → to provide fault tolerance

Routing Based

- Anycast
  - Give service a single IP address
  - Each node implementing service advertises route to address
  - Packets get routed from client to “closest” service node
    - Closest is defined by routing metrics
    - May not mirror performance/application needs
  - This is done today (sometimes by accident)

Application Based

- HTTP support simple way to indicate that Web page has moved
- 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.
Naming Based

- Client does name lookup for service
- Name server chooses appropriate server address
- What information can it base decision on?
  - Server load/location must be collected
  - Source address in DNS request
  - Round-robin
    - Randomly choose replica
    - Avoid hot-spots
  - [Semi-]static metrics
    - Geography
    - Route metrics
- Predicted application performance
- How to predict?
  - Only have limited info at name resolution
- Multiple techniques
  - Static metrics to get coarse grain answer
  - Current performance among smaller group
- How does this affect caching?
  - Typically want low TTL to adapt to load changes
  - What do the first and subsequent lookups do?

How Akamai Works

- Content is prepared by rewriting URLs for replicated content
  - `<img src="http://cnn.com/a/ix.gif">` replaced with `<img src="http://a73.g.akamaitech.net/7/23/cnn.com/a/ix.gif`>
- Clients fetch html document from server
  - E.g. fetch index.html from cnn.com
- Client is forced to resolve aXYZ.g.akamaitech.net hostname for replicated content

Akamai Content Servers

- Are really caches
  - Modified name contains file name
  - If content server doesn’t have that object then it is requested from primary server and cached
- Tricky issue is selecting which local content server to use for a particular request
  - Want to spread load evenly
  - But want minimal impact if server is added or removed

Naïve approach: Content hashing

- Basic idea: hash pages according to their associated keys
- Straightforward solution
  - Assume \( m \) caches (servers), \( 1, 2, \ldots, m \)
  - Store page with key \( x \) on cache \( (ax + b) \mod m \)
- Advantages:
  - Load balancing: each cache stores roughly the same number of pages
  - Page location: a client can easily locate the cache storing a particular page
But...

- What happens when the number of caches change?
  - Virtually every page will change its location!
  - \((ax + b) \mod m \rightarrow (ax + b) \mod (m+1)\)
- What happens when a user knows only a subset of caches (i.e., users have different views)?
  - Each user will look on a different cache for the same page

Solution: Consistent Hashing

- Assume
  - Each cache (server) is identified by an \(id\) uniformly distributed in range \([0, 1]\)
  - The key of each page is uniformly distributed within the same range \([0, 1]\)
  - A page is stored to the cache (server) which is the closest in the identifier space

Consistent Hash – Advantages

- Monotone \(\rightarrow\) addition of bucket does not cause movement between existing buckets
- Spread & Load \(\rightarrow\) small set of buckets that lie near object
- Balance \(\rightarrow\) no bucket is responsible for large portion of unit interval

Akamai Example

- cnn.com (content provider)
- DNS root server
- Akamai server

Akamai – Subsequent Requests

- cnn.com (content provider)
- DNS root server
- Akamai server

Caveats

- Approach only applies to static objects
  - Amazon Web page is different for everyone
- Assumes IP address of DNS request is correct
- Need good metric to capture “closeness” in network to get best performance
- Based on “pull”-model… what about suddenly popular content?
- However, in practice, is very effective
Summary

- Content distribution
  - Replicate content to improve response time/overhead

- Issues
  - How to replicate content
  - How to select best replica
  - How to direct client to replica

Next time...

- Peer-to-peer networks
  - Napster, Gnutella, KaZaA, Chord/CFS, etc.