15-441 Computer Networking

Lecture 6 – Web Optimizations

Outline

- Persistent HTTP
- HTTP Caching
- Server Selection & Content Distribution Networks

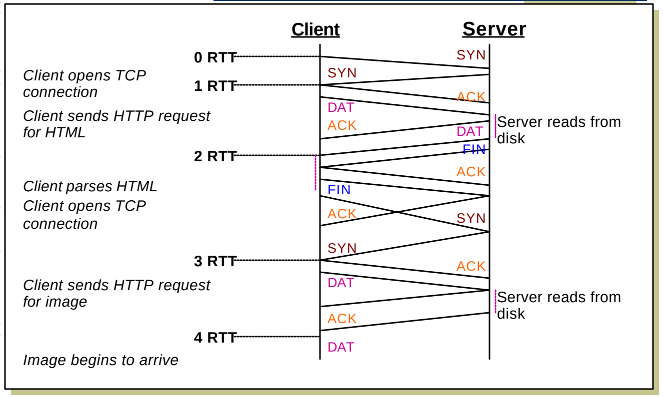
Typical Workload (Web Pages)

- Multiple (typically small) objects per page
- File sizes
  - Heavy-tailed
    - Pareto distribution for tail
    - Lognormal for body of distribution
- Embedded references
  - Number of embedded objects = pareto – $p(x) = ak^a x^{-(a+1)}$

HTTP 0.9/1.0

- One request/response per TCP connection
  - Simple to implement
  - Uses connection close to delimit objects
- Disadvantages
  - Multiple connection setups → three-way handshake each time
    - Several extra round trips added to transfer
  - Multiple slow starts

Single Transfer Example



More Problems

- Short transfers are hard on TCP
  - Stuck in slow start
  - Loss recovery is poor when windows are small
- Lots of extra connections
  - Increases server state/processing
- Server also forced to keep TIME_WAIT connection state
  - Why must server keep these?
  - Tends to be an order of magnitude greater than # of active connections, why?

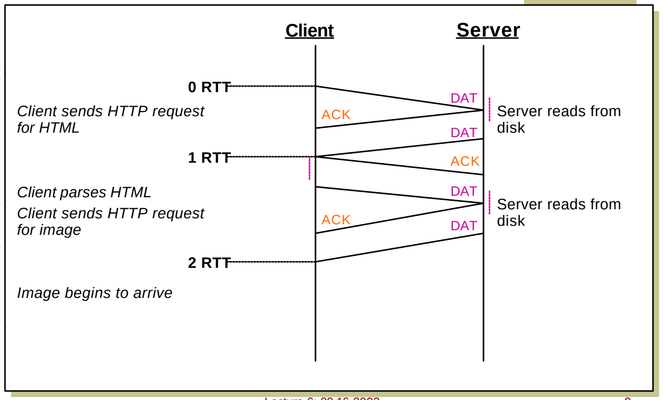
Netscape Solution

- Mosaic (original popular Web browser) fetched one object at a time!
- Netscape uses multiple concurrent connections to improve response time
  - Different parts of Web page arrive independently
  - Can grab more of the network bandwidth than other users
- Doesn’t necessarily improve response time
  - TCP loss recovery ends up being timeout dominated because windows are small

Persistent Connection Solution

- Multiplex multiple transfers onto one TCP connection
- How to identify requests/responses
  - Delimiter → Server must examine response for delimiter string
  - Content-length and delimiter → Must know size of transfer in advance
  - Block-based transmission → send in multiple length delimited blocks
  - Store-and-forward → wait for entire response and then use content-length
  - Solution → use existing methods and close connection otherwise

Persistent Connection Example



Persistent HTTP

Nonpersistent HTTP issues:

- Requires 2 RTTs per object
- OS must work and allocate host resources for each TCP connection
- But browsers often open parallel TCP connections to fetch referenced objects

Persistent HTTP

- Server leaves connection open after sending response
- Subsequent HTTP messages between same client/server are sent over connection

Persistent without pipelining:

- Client issues new request only when previous response has been received
- One RTT for each referenced object

Persistent with pipelining:

- Default in HTTP/1.1
- Client sends requests as soon as it encounters a referenced object
- As little as one RTT for all the referenced objects

Persistent Connection Performance

- Benefits greatest for small objects
  - Up to 2x improvement in response time
- Server resource utilization reduced due to fewer connection establishments and fewer active connections
- TCP behavior improved
  - Longer connections help adaptation to available bandwidth
  - Larger congestion window improves loss recovery

Remaining Problems

- Serialized transmission
  - Stall in transfer of one object prevents delivery of others
  - Much of the useful information in first few bytes
  - Can “packetize” transfer over TCP
    - Could use range requests
- Application specific solution to transport protocol problems
  - Solve the problem at the transport layer
  - Could fix TCP so it works well with multiple simultaneous connections
    - More difficult to deploy

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Typical Workload (Server)

- Popularity
  - Zipf distribution ($P = kr^{-1}$) → surprisingly common
  - Obvious optimization → caching
- Request sizes
  - In one measurement paper → median 1946 bytes, mean 13767 bytes
  - Why such a difference? Heavy-tailed distribution
    - Pareto – $p(x) = ak^a x^{-(a+1)}$
- Temporal locality
  - Modeled as distance into push-down stack
  - Lognormal distribution of stack distances
- Request interarrival
  - Bursty request patterns

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 file signature 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

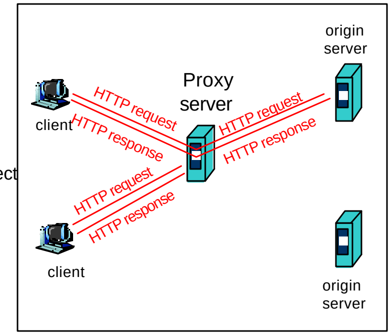
Connection: Keep-Alive

Keep-Alive: timeout=15, max=100

ETag: "7a11f-10ed-3a75ae4a"

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



Proxy Caching

- Goal: Satisfy client request without involving origin server
  - Reduce client response time
  - Reduce network bandwidth usage
    - Wide area vs. local area use
  - These two objectives are often in conflict
    - May do exhaustive local search to avoid using wide area bandwidth
    - Prefetching uses extra bandwidth to reduce client response time

Caching Example (1)

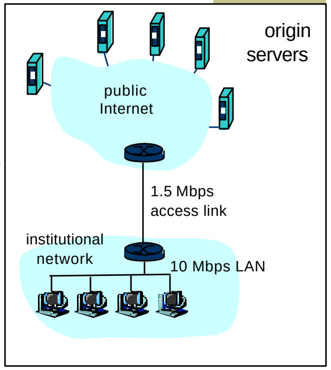
Assumptions

- 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



Caching Example (2)

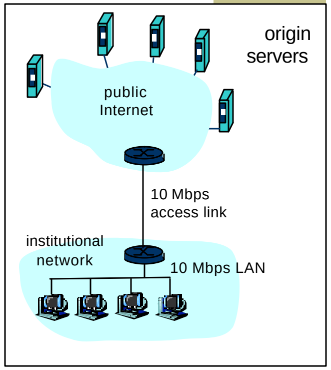
<u>Possible solution</u>

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

<u>Consequences</u>

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

= 2 sec + msecs + msecs



Caching Example (3)

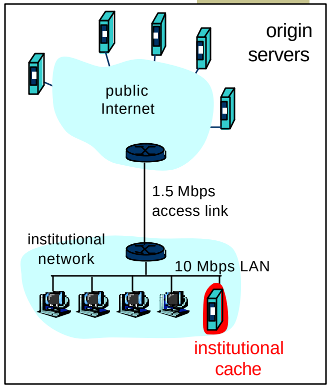
<u>Install cache</u>

- Suppose hit rate is .4

<u>Consequence</u>

- 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



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.
- What will be the end result?

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
- Conflict
  - No such misses

Proxy Implementation Problems

- Aborted transfers
  - Many proxies transfer entire document even though client has stopped → eliminates saving of bandwidth
- Making objects cacheable
  - Proxy's apply heuristics → cookies don't apply to some objects, guesswork on expiration
  - May not match client behavior/desires
- Client misconfiguration
  - Many clients have either absurdly small caches or no cache
- How much would hit rate drop if clients did the same things as proxies

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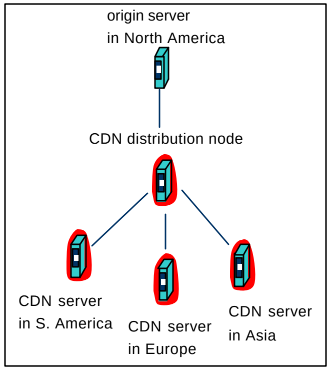
Content Distribution Networks (CDNs)

- 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



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 know 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

Naming Based

- Round-robin
  - Randomly choose replica
  - Avoid hot-spots
- [Semi-]static metrics
  - Geography
  - Route metrics
  - How well would these work?
- Predicted application performance
  - How to predict?
  - Only have limited info at name resolution

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

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

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?

Simple Hashing

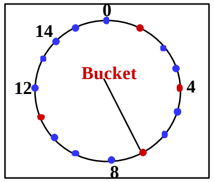
- Given document XYZ, we need to choose a server to use
- Suppose we use modulo
- Number servers from 1…n
  - Place document XYZ on server (XYZ mod n)
  - What happens when a servers fails? n → n-1
    - Same if different people have different measures of n
  - Why might this be bad?

Consistent Hash

- "view" = subset of all hash buckets that are visible
- Desired features
  - Balanced – in any one view, load is equal across buckets
  - 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

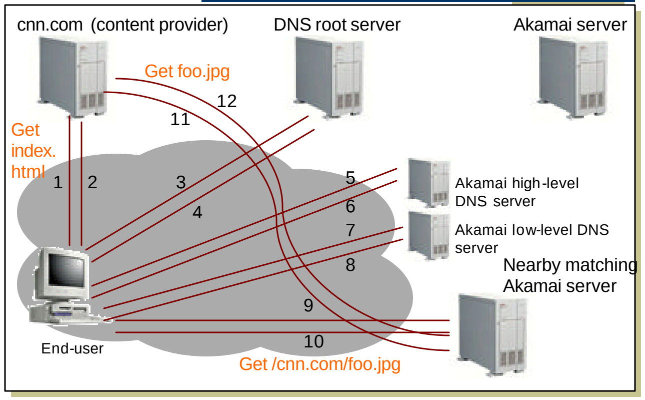
Consistent Hash – Example

- 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 circle
  - Hash of object = closest clockwise bucket

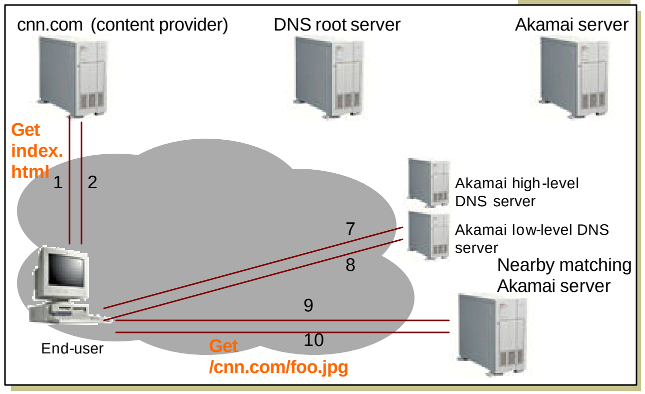


- Smoothness → addition of bucket does not cause movement between existing buckets
- Spread & Load → small set of buckets that lie near object
- Balance → no bucket is responsible for large number of objects

How Akamai Works



Akamai – Subsequent Requests



Impact on DNS Usage

- DNS is used for server selection more and more
  - What are reasonable DNS TTLs for this type of use
  - Typically want to adapt to load changes
  - Low TTL for A-records → what about NS records?
- How does this affect caching?
- What do the first and subsequent lookup do?

HTTP (Summary)

- Simple text-based file exchange protocol
  - Support for status/error responses, authentication, client-side state maintenance, cache maintenance
- Workloads
  - Typical documents structure, popularity
  - Server workload
- Interactions with TCP
  - Connection setup, reliability, state maintenance
  - Persistent connections
- How to improve performance
  - Persistent connections
  - Caching
  - Replication

Next Lecture

- Transport introduction
- Error recovery
- TCP flow control
- TCP connection setup/data transfer