15-441 Computer Networking

Lecture 25 – The Web

Outline

- HTTP review and details (more in notes)
- Persistent HTTP review
- HTTP caching
- Content distribution networks

HTTP Basics (Review)

- HTTP layered over bidirectional byte stream
  - Almost always TCP
- Interaction
  - Client sends request to server, followed by response from server to client
  - Requests/responses are encoded in text
- Stateless
  - Server maintains no information about past client requests

How to Mark End of Message? (Review)

- Size of message → Content-Length
  - Must know size of transfer in advance
- Delimiter → MIME-style Content-Type
  - Server must "escape" delimiter in content
- Close connection
  - Only server can do this

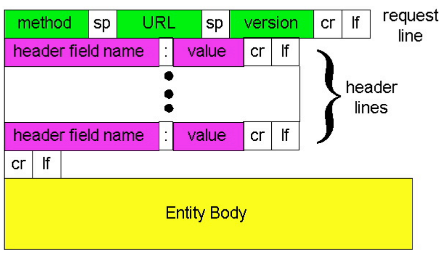
HTTP Request (review)

- Request line
  - Method
    - GET – return URI
    - HEAD – return headers only of GET response
    - POST – send data to the server (forms, etc.)
  - URL (relative)
    - E.g., /index.html
  - HTTP version

HTTP Request (cont.) (review)

- Request headers
  - Authorization – authentication info
  - Acceptable document types/encodings
  - From – user email
  - If-Modified-Since
  - Referrer – what caused this page to be requested
  - User-Agent – client software
- Blank-line
- Body

HTTP Request (review)



HTTP Request Example (review)

GET / HTTP/1.1
Accept: */*
Accept-Language: en-us
Accept-Encoding: gzip, deflate
User-Agent: Mozilla/4.0 (compatible; MSIE 5.5; Windows NT 5.0)
Host: www.intel-iris.net
Connection: Keep-Alive

HTTP Response (review)

- Status-line
  - HTTP version
  - 3 digit response code
    - 1XX – informational
    - 2XX – success
      - 200 OK
    - 3XX – redirection
      - 301 Moved Permanently
      - 303 Moved Temporarily
      - 304 Not Modified
    - 4XX – client error
      - 404 Not Found
    - 5XX – server error
      - 505 HTTP Version Not Supported
  - Reason phrase

HTTP Response (cont.) (review)

- Headers
  - Location – for redirection
  - Server – server software
  - WWW-Authenticate – request for authentication
  - Allow – list of methods supported (get, head, etc)
  - Content-Encoding – E.g x-gzip
  - Content-Length
  - Content-Type
  - Expires
  - Last-Modified
- Blank-line
- Body

HTTP Response Example (review)

HTTP/1.1 200 OK
Date: Tue, 27 Mar 2001 03:49:38 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
Last-Modified: Mon, 29 Jan 2001 17:54:18 GMT
ETag: "7a11f-10ed-3a75ae4a"
Accept-Ranges: bytes
Content-Length: 4333
Keep-Alive: timeout=15, max=100
Connection: Keep-Alive
Content-Type: text/html
…..

Outline

- HTTP intro and details
- Persistent HTTP
- HTTP caching
- 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

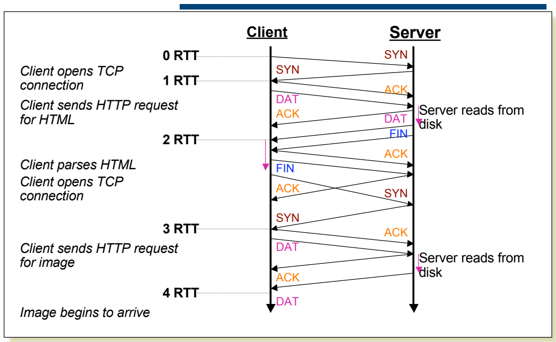
-- For reference/interest only --

- Embedded references
  - Number of embedded objects = pareto – $p(x) = ak^a x^{-(a+1)}$

HTTP 0.9/1.0 (mostly review)

- One request/response per TCP connection
  - Simple to implement
- 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

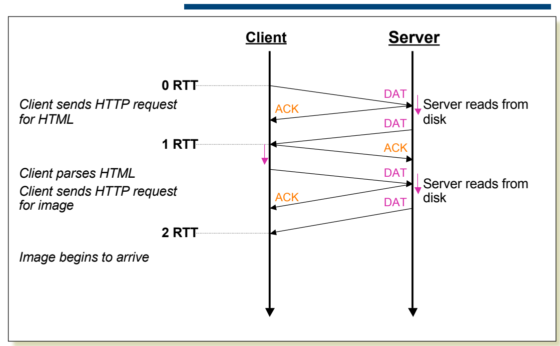
-- Things to think about --

  - Why must server keep these?
  - Tends to be an order of magnitude greater than # of active connections, why?

Persistent Connection Solution (review)

- 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 (review)



Persistent HTTP (review)

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

Outline

- HTTP intro and details
- Persistent HTTP

-- new stuff --

- HTTP caching
- Content distribution networks

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

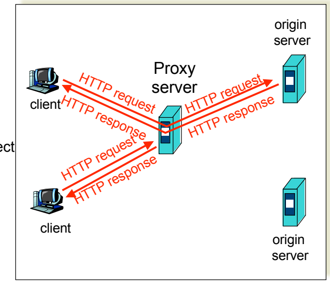
HTTP/1.1 304 Not Modified
Date: Tue, 27 Mar 2001 03:50:51 GMT
Server: Apache/1.3.14 (Unix) (Red-Hat/Linux) mod_ssl/2.7.1 OpenSSL/0.9.5a DAV/1.0.2 PHP/4.0.1pl2 mod_perl/1.24
Connection: Keep-Alive
Keep-Alive: timeout=15, max=100
ETag: "7a11f-10ed-3a75ae4a”

Ways to cache

Client-directed caching: Web Proxies
Server-directed caching: Content Delivery Networks (CDNs)

Web Proxy Caches

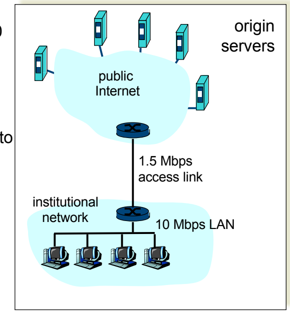
- User configures browser: Web accesses via cache
- Browser sends all HTTP requests to cache
  - Object in cache: cache returns object
  - Else cache requests object from origin server, then returns object to client



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

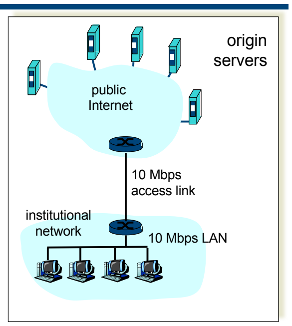
Consequences
- Utilization on LAN = 15%
- Utilization on access link = 100%
- Total delay = Internet delay + access delay + LAN delay
= 2 sec + minutes + milliseconds



Caching Example (2)

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

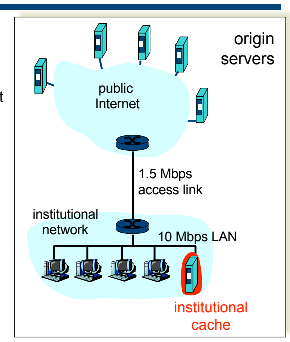
Consequences
- Utilization on LAN = 15%
- Utilization on access link = 15%
- Total delay = Internet delay + access delay + LAN delay
= 2 sec + msecs + msecs



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



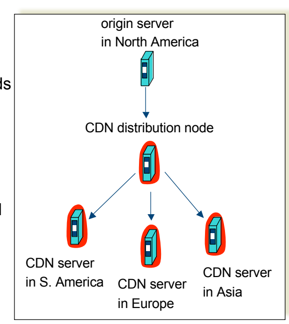
Problems

- 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?

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



Outline

- HTTP intro and details
- Persistent HTTP
- HTTP caching
- Content distribution networks

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.
- OK solution in general, but…
  - HTTP Redirect has some flaws – especially with current browsers
  - Incurs many delays, which operators may really care about

Naming Based

- Client does DNS 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

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?

Simple Hashing

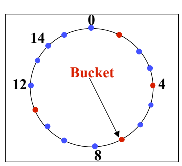
- Given document XYZ, we need to choose a server to use
- Suppose we use modulo
- Number servers from 1…n
  - Place document XYZ on server (XYZ mod n)
  - What happens when a servers fails? n → n-1
    - Same if different people have different measures of n
  - Why might this be bad?

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

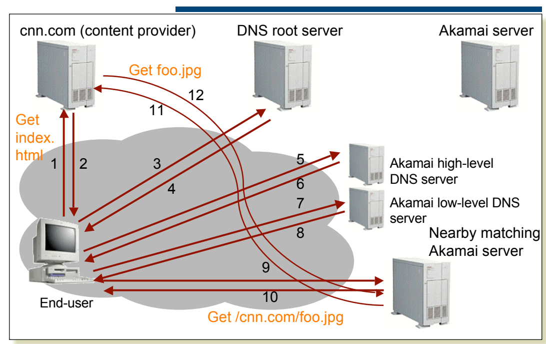
Consistent Hash – Example

- 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

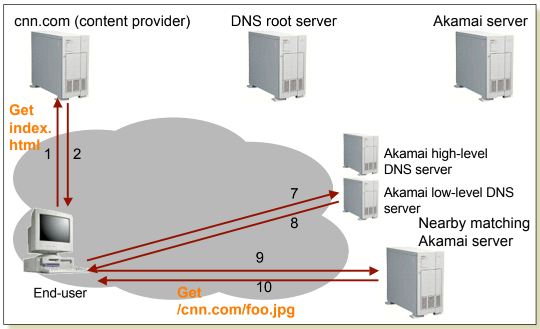


- Smoothness → addition of bucket does not cause movement between existing buckets
- Spread & Load → small set of buckets that lie near object
- Balance → no bucket is responsible for large number of objects

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

EXTRA SLIDES

The rest of the slides are FYI

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

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