Content Distribution

To do ...

- Today: Challenges of content delivery
- Content distribution networks
- CDN through an example
Trends and application need

• Some clear trends
  – Growing number of networks
  – Faster networks
  – Growing availability and demand for content

• For applications, higher demand on performance and reliability
  – Small degradation are expensive in lost revenue
    • $2.8m/hour in 2009
  – … damage reputation
  – … reduced productivity
“Flash crowd” that follow the “flash crash”

May 6, 2010

DOW loss 600 points in 5’

It recovered them 20’ later

Users flooded websites for all online brokers

https://blogs.akamai.com/2014/05/the-flash-crash-4-years-later-ready-for-the-next-one.html
Rick Bolstrigde, Akamai, May 5 2010
“Without Akamai, we would have gone down”
Content delivery

• The common answer
  – Replicate content around the world, closer to users
  – Bring users to nearby content, “nearby” in a network sense

• A few ways to do this
  – Content distribution networks
    • “deep into ISPs” or
    • “bring ISPs to home”
  – Peer-to-peer
  – Hybrid peer-assisted CDNs
Distributing content through CDNs

- Content provider determines which objects it wants the CDN to distribute
- ... tags and pushes content to CDN
- CDN replicates and pushes the content to its servers
- ... and provides a mechanism for
  - Replicating content on multiple servers in the Internet
  - Letting clients pick the “best” servers to get the content from
    - Mapping – network proximity != geographic proximity
CDNs’ potential benefits

- An example with Akamai, a “deep into ISPs” CDN
  - Placing replica servers at ISP’s POPS
- Closeness to end users for performance and reliability
  - Good scalability
  - Avoid congestion and long latencies
  - Redundancy for reliability and some resilience to DoS attacks
- Economies of scale – Costly to maintain that many servers, control, replicate content, etc
Internet delivery challenges

- Peering point congestion
- Inefficient routing protocols
- Unreliable networks
- Inefficient communication protocols
  - TCP can be a serious bottleneck to video delivery
- Scalability – under and overprovisioning costs
- Application limitation and slow rate of change adoption
  - IE6 still in use (<6%)

<table>
<thead>
<tr>
<th>Distance (server/user)</th>
<th>RTT</th>
<th>Typical packet loss</th>
<th>Throughput</th>
<th>4GB DVD download time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local &lt;100mi</td>
<td>1.6ms</td>
<td>0.6%</td>
<td>44 Mbps (high quality HDTV)</td>
<td>12min</td>
</tr>
<tr>
<td>Regional 500-1,000mi</td>
<td>16ms</td>
<td>0.7%</td>
<td>4 Mbps (basic HDTV)</td>
<td>2.2hrs</td>
</tr>
<tr>
<td>Cross-continent</td>
<td>48ms</td>
<td>1.0%</td>
<td>1 Mbps (SD TV)</td>
<td>8.2hrs</td>
</tr>
<tr>
<td>Multi-continent~6,000mi</td>
<td>96ms</td>
<td>1.4%</td>
<td>0.4 Mbps (poor)</td>
<td>20hrs</td>
</tr>
</tbody>
</table>
Components of a delivery network:

- End users
- Edge servers/replicas
- Transport system
- Origin
- Customers
- Mapping
- Communication and control system
- Data collection and analysis
- Management portal
When a browser is asked to get www.cnn.com, how does it know it should go to the CDN or get it from CNN?

- Users get an html document from www.cnn.com; this could be index.html
- index.html uses a modified URL for replicated content
- Example: If the jpeg files are what has been replicated then
  - `<img src="http://cnn.com/af/foo.jpg">`
  may be modified as follows:
  - `<img src=http://a73.g.akamai.net/7/23/cnn.com/af/foo.jpg>`
CDN through an example

- What does this mean?

```html
<img src=http://a73.g.akamai.net/7/23/cnn.com/af/foo.jpg>
```

- host part: a73.g.akamai.net
- Akamai control part: /7/23
- Content URL: /af/foo.jpg
CDN redirection

- The browser needs to resolve `a73.g.akamai.net` hostname for replicated content.
- All DNS queries for `g.akamai.net` are sent to an authoritative DNS server for `g.akamai.net`.
- Based on the IP address and information that it has about the Internet (called a map), the IP address of an Akamai regional server is returned to the requesting browser based on policy.
Client requests translation for cnn.com

End user

Client gets CNAME entry with domain name in Akamai

Multiple redirecions to find nearby edge servers

Client is given 2 web replica servers (fault tolerance)

CDN through an example

Hierarchy of CDN DNS servers

Customer DNS servers

Local DNS

Web replica servers

(1) End user

(2) Customer DNS servers

(3) Local DNS

(4) Web replica servers

(5) (6) Multiple redirecions to find nearby edge servers
CDN redirection

- Akamai IPs are cached at local DNS server
  - Not always necessary to go to the root DNS server
  - TTL associated with the IP address of an Akamai edge server is relatively small
- If content is not there
  - Edge server gets it from others
  - Or eventually from origin
- One tricky part, selecting the right edge server
  - Want to spread load evenly
  - Want minimal impact if server is added or removed
Mapping or server selection

- Picking a server
  - Lowest load ➔ To balance customer load
  - Best performance ➔ To improve client’s experience
    - Best on geography? RTT? Throughput? Load?
  - Any server that is up ➔ For reliability

- How to direct clients to the selected server
  - As part of routing ➔ Anycast …
  - As part of application ➔ HTTP redirect
    - 30X responses (301: moved permanently, 307: temporary redirect, …)
  - As part of naming ➔ DNS
Back in 5 minutes
Ubiquity of CDNs

Visit cnn.com...

- 34 DNS lookups
- 204 HTTP requests
- 520 KB of data downloaded
Ubiquity of Content Delivery Networks

56% of domains resolve to a CDN
Ubiquity of CDNs

- And it’s not just cnn.com…

74% of the top 1000 web sites use CDNs

J. Otto et al., Content delivery and the natural evolution of DNS - Remote DNS Trends, Performance Issues and Alternative Solutions, IMC 2012
Impact of CDN growth

- Flattening of the Internet
  - More content served from the edge
  - Increase in peering
  - Growth of IXPs
  - More traffic at the edge, less in the core

- Changing economics
  - Clients are happier with closer content
  - So are CDNs
  - And perhaps ISPs (reducing traffic from providers)
Some interesting trends

- Content providers have CDNs
  - If you are big enough it could be cheaper
  - Tune caching to your particular service
  - Can still rely on CDN services

- ISPs have CDNs
  - Not just putting up pipes
  - Reduce cross-ISP traffic
  - Hard to develop relationships with content providers

- Users have CDNs
  - CoralCDN, BitTorrent, …

- Hybrid solutions
  - CDNs and ISPs
  - Content providers and CDNs
  - Peers and CDNs
CDNs – models and markets

Much more than Akamai

- Tons of commercial CDNs: Amazon CloudFront, BitGravity, CacheFly, CDNetworks, ChinaCache, CloudFare, Cotendo, Distil Networks, EdgeCast, Limelight, MaxCDN, Speedera, …

- A few non-commercial ones: BootstrapCDN, CloudFare, Coral, Incapsula

- Some from telcos: AT&T, Bell, DT, Telecom, Telefonica, Level 3, …
CDNs or P2P?

- **P2P systems**
  - Cheap, easy to scale
  - Security issues, potential low-quality, hard to find unpopular content, difficult accounting

- **Infrastructure-based systems**
  - Expensive to setup and scale
  - Akamai 137,000 servers in 87 countries (*probably out of date*)
  - Can provide predictable QoS and *reliable accounting*
CDNs or P2P? Both

- Hybrid? Peer-assisted CDNs
  - Deliver content by peers, with operation coordinated (and backstopped) by dedicated infrastructure
  - Akamai’s NetSession – Operating commercially since 2010
  - True global coverage – 239 countries in 2013

- Risks/Issues
  - Need for revenue, unlike P2P
  - No transparency – users are aware of them
  - Heterogeneity
  - NATs and firewalls
  - Impact to ISP – change of traffic patterns
NetSession’s approach and some answers

- Download starts from edge servers
  - Standard HTTPS
- Ask control plane for nearby peers
- If anyone’s around, download from them
  - ~Swarm – small pieces exchanged
  - No need for tit-for-tat
  - Edge servers generate unique secure IDs for content and hashes for validation
  - HTTPS connection is used for configuration and reporting
Some interesting trends

- Electricity costs of datacenters are high
  - Estimated cost of Google in 2009 ~ over $38M/year
- And growing
  - Systems growth outpacing energy efficiency gains
- Relative cost of electricity is growing
  - Compared to hardware or bandwidth
- What’s being done
  - Energy efficient hardware, virtualization and consolidation, power off servers when possible, cheaper cooling
- Key observation: electricity prices vary on an hourly basis across markets
Price volatility across markets

Locational pricing
- not well correlated
- CA-VA correlation ≈ 0.2

Hourly variation
- peaks ~ $350/MWh
- negative prices

From A. Qureshi et al, SIGCOMM09
Price volatility across markets

From A. Qureshi et al, SIGCOMM09
Some interesting trends

- Can you use request routing and replication to route away from high energy costs? [A. Qureshi et al, SIGCOMM09]
  - 2% without increasing bw costs or worsening client performance
  - Depends on the energy elasticity of clusters – with full elasticity (an no bw constraints) – over 30%

- Environmental impact, rather than energy? [P. Gao et al., SIGCOMM12]
  - CO₂ emission of datacenters ~ Netherlands in 2008, reaching 2.6% of global total in 2020, > Germany
  - Source (i.e., emission) changes per hour (termal generators on peak)
  - Can you redirect traffic to a cleaner location?

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### Washington

- Hydro: 67%
- Gas: 10%
- Nuclear: 9%
- Coal: 8%
- Other: 6%

### Texas

- Gas: 45%
- Nuclear: 10%
- Coal: 37%
- Other: 8%

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Generator fuel type*
Summary

- Demand for content drives CDNs
- CDNs are interesting distributed systems
  - Conceptually a virtual network
  - Higher performance, reliability, security ...
  - Works on the existing Internet as-is
- Alternatively, a clean slate re-design of the Internet could address the challenges
  - Slow change due to sunk investment and entrenched adoption