Performance comparison of distributed architectures for content adaptation and delivery of Web resources

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Current Web scenario

- Heterogeneity:
  - Client devices range from smartphones to high-end workstations

- Critical Web-based services
  - Web is a critical communication channel
  - Need for system to enable ubiquitous Web access.

Web content adaptation *on-the-fly*
Functions in a distributed Web content adaptation system

- Content adaptation
  - Computationally expensive (on-the-fly adaptation)
- Client capability/User preferences identification
- Caching
  - Multi-version caching
- Location of (possibly adapted) resources
  - Multi-version lookup process: Exact hit, Useful hit and Miss
- Interaction with Origin server

On which nodes to place these functions?
Providing Web content adaptation

Different approaches for mapping content adaptation functions on the nodes:

- “Keep every function in the origin server area”

- “Move most functions towards the network edge nodes”
  - Non cooperative edge server-side architecture
  - “Exploit potential of distributed architectures by allowing cooperation among edge nodes”
Origin server-side architecture

- “Keep every function in the origin server area”
- Potential advantages
  - Simplify interaction with origin server (security / privacy / sophisticated services)
  - Can exploit clusters
- Possible drawbacks
  - Sensitive to network parameters
  - High latency
**Edge server-side architecture**

- “Move most functions towards the network edge nodes”
- Potential advantages
  - Caching is more effective
  - Reduce bandwidth usage
- Possible drawbacks
  - Higher complexity than origin server-side approach

What is the performance gain from pushing services on the network edge?
Cooperative Edge server-side architecture

- “Exploit potential of distributed architectures by allowing cooperation among edge nodes”
- We focus on the best performing algorithm for cooperative lookup (query-based)
- Potential advantages
  - Increased efficiency
- Potential drawbacks
  - Higher complexity

What is the advantage from cooperation?
Main goals:

• Comparison of **leading solutions** for content adaptation
  
  • **What is the gain** from pushing content adaptation on the **network edge?** **Under which circumstances** this performance gain is more evident?
  
  • **What is the advantage** achieved through cooperation?

• Performance evaluation with **real prototypes** in a **controlled environment**
  
  • Different workloads
  
  • **WAN emulation** with multiple network scenarios
Performance evaluation

- Experimental setup
  - 16 nodes with content adaptation capabilities (adaptation servers)
  - 1 Web server (Origin server) + 1 client emulator
  - WAN emulation (*NetEm* network scheduler: delay, packet loss, bandwidth limitation)
Performance evaluation

- Two workload models (prevalent static resources)
  - IRcache (from IRcache logs)
  - Photo album (heavy content adaptation tasks)
- Multiple WAN setups, we report the most significant results (sensitivity to bandwidth)

<table>
<thead>
<tr>
<th>Architecture</th>
<th>WAN-emulated links</th>
<th>Bandwidth [Mbit/s]</th>
<th>Delay [ms]</th>
<th>Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin server-side</td>
<td>Client-Adapt. server</td>
<td>8, 16, 32</td>
<td>100</td>
<td>1,00%</td>
</tr>
<tr>
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<td>Adapt.-Origin server</td>
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<td>100</td>
<td>1,00%</td>
</tr>
<tr>
<td></td>
<td>Adapt.-Adapt. server</td>
<td>8, 16, 32</td>
<td>25</td>
<td>1,00%</td>
</tr>
</tbody>
</table>
Architectures comparison: Origin server vs. Edge server-side

- Edge server-side always outperforms Origin server-side
- Performance gain is more significant in the case of light workload (IRcache)
Architecture comparison: Impact of cooperation

- Performance improvement on median response time (cooperation can improve cache hit rate)
- Less advantage for the 90-percentile (a miss is more expensive in the case of cooperation)
Summary (architecture comparison)

- Pushing content adaptation on the network edge has a significant performance gain in the case of “light” services
  - Network-related time is dominant
  - In the case of a cache hit we save a connection to the origin server
- Performance gain from cooperation is related to the effectiveness of cooperative caching.
  - Limited global performance gain
    - Cooperation increases the hit rate
    - No gain in the case of cache miss
Sensitivity to network parameters: Origin vs. Edge server-side

- Edge server-side provides better performance
  - Lower response time
  - Reduced sensitivity to bandwidth
  - Reduced number of open sockets (less parallel requests)

Median response time

Photo album workload
Sensitivity to network parameters: impact of cooperation

- In the case of poor network bandwidth cooperation increases dramatically performance
- The cooperation reduces sensitivity to network effects

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<th>Bandwidth [Mbit/s]</th>
<th>Edge server-side architecture</th>
<th>Cooperative edge server-side architecture</th>
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<tr>
<td></td>
<td>Adapt.-Origin server</td>
<td>Adapt.-Adapt. server</td>
</tr>
<tr>
<td></td>
<td>Response time</td>
<td>Response time</td>
</tr>
<tr>
<td></td>
<td>median</td>
<td>90-perc.</td>
</tr>
<tr>
<td>8</td>
<td>470</td>
<td>54680</td>
</tr>
<tr>
<td>16</td>
<td>180</td>
<td>1848</td>
</tr>
<tr>
<td>32</td>
<td>170</td>
<td>1630</td>
</tr>
</tbody>
</table>
Summary (sensitivity to network)

- Edge server-side architecture reduces network utilization with respect to the Origin server-side approach
  - Reduction in the sensitivity to network parameters
- Cooperation further reduces the load on the network links
- The real advantage from cooperation lies in the limited sensitivity to network parameters
Conclusions

- Gain from pushing content adaptation on the network edge
  - Edge server-side approach is always best
  - The performance gain is more evident in the case of services with lower computational complexity

  \[ \text{We should move “light” services towards the edge} \]

- Advantages achieved through cooperation

  - Reduction in sensitivity to network parameters

  \[ \text{We should exploit cooperation in the case of poor network conditions (e.g., low bandwidth and/or network congestions)} \]
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For more information:

http://weblab.ing.unimo.it/research/trans_caching.shtml
Conclusions

- Edge server-side architecture outperforms Origin server-side approach
  - Performance gain is more evident when content adaptation time is reduced
  - Performance gain increases dramatically in the case of low bandwidth links
- Cooperation in edge server-side architecture provides better performance
  - Performance gain less evident then in the case of origin-server side architecture
  - Cooperation reduces sensitivity to network parameters
Critical Issue

- Content adaptation is **computationally expensive**
  - Can take advantage from caching
  - We can reduce computational load by exploiting already-adapted resources
- Caching in a content adaptation system is more complex than traditional Web caching
  - Multiple versions of the same resource
  - We need **multi-version lookup**
  - We have a rich caching semantics: a lookup can result in **Exact hit, Useful hit and Miss**
Providing Web content adaptation

- Three base approaches
  - Client-side
  - Origin server-side
  - Edge-side (possibly cooperative)

- Drawbacks of the client-side approach
  - Limited computation power on edge nodes *(not efficient)*
  - Requires client-specific implementation *(not general)*
  - Does not save bandwidth *(not effective)*