Factors Affecting Performance of Web Flows in Cellular Networks

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Introduction
Introduction — Motivation

• ∼ 99% of the Internet traffic flows are short (<100 KB).

  [Brownlee and claffy SIGMETRICS'02, Ramachandran Google'10]

• > 95% traffic generated by smartphones consists short-lived TCP flows.

  [Huang et al. SIGCOMM'13]

Performance of short web flows driven by latency than network throughput:

• DNS lookup time
• TCP connect time
Few studies that quantify the factors that are responsible for DNS lookup & TCP connect times in cellular network. [Xu et al. SIGMETRICS’11, Rula and Bustamante, SIGCOMM’14]

We want to know:

- What are factors affecting DNS lookup and TCP connect time?
- How much DNS cached entries and TCP proxies improve latency?
- Distribution of packet loss and DNS look up failure.
Introduction — Contribution

1. DNS lookup failure & packet loss
   - ~ 2% DNS lookup test experience failures
   - ~ 14.98% of have lost at least one packet

2. Radio technology & device model:
   - TCP connect times to popular websites are reduced by ~80% on LTE compared to legacy networks.
   - Device model has an impact on DNS lookup time.

3. ISP caches & DNS server’s proximity:
   - ISP caches improve TCP connect times towards some websites.
   - DNS server’s proximity to the subscriber has an impact on DNS lookup time.
Methodology
DNS lookup and TCP Connect time towards 4 websites:

- www.google.fi
- www.youtube.com
- www.facebook.com
- www.elisa.net

Ping Test towards:

- www.google.fi
**Measurement — DNS Lookup Time — TCP Connect Time — Ping Test**

**DNS Lookup Time:**
- DNS lookup time (in milliseconds)
- IPv4 address of DNS server
- Radio technology, device model
- Response error code

**TCP Connect Time**
- Starting time of the test
- FQDN of the destination host
- Radio technology, device model

**Ping Test:**
- ICMP echo request towards `www.google.fi`
- RTT and packet loss
- five to nine ICMP Echo requests
- payload size of request is 16 bytes

**DNS lookup test**
- Measures the time it takes to look up a FQDN from a DNS server

**TCP connect time**
- Measures the time to connect to a target website (IPv4, 80) from the client
Measurements tests are executed inside sessions.

A session starts when a network interface becomes available or best interface changes.

It is not periodic, but they are repeated when network conditions changes.
Data Set and Measurement Trials

The geographical distribution of \(\sim 25\)K subscribers in Finland.

<table>
<thead>
<tr>
<th>Website</th>
<th>DNS (#)</th>
<th>TCP (#)</th>
<th>ping (#)</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="http://www.facebook.com">www.facebook.com</a></td>
<td>3.4M</td>
<td>4.6M</td>
<td>-</td>
</tr>
<tr>
<td><a href="http://www.google.fi">www.google.fi</a></td>
<td>6.9M</td>
<td>4.9M</td>
<td>2.1M</td>
</tr>
<tr>
<td><a href="http://www.youtube.com">www.youtube.com</a></td>
<td>1.6M</td>
<td>4.1M</td>
<td>-</td>
</tr>
<tr>
<td><a href="http://www.elisa.net">www.elisa.net</a></td>
<td>1.8M</td>
<td>5.3M</td>
<td>-</td>
</tr>
</tbody>
</table>

DNS, TCP and ping measurements by website.

A month-long dataset collected through a mobile operator in Finland (Elisa)
Data Analysis & Results
DNS Lookup Failures

~ 2% of the total DNS lookup show failure

- ~ 86% of the DNS failures indicating that a responder does not implement the version level of the request
- LTE (1.9%), UMTS (3.4%), HSPA (3.9%) and HSPA+ (2.7%)
Latency — Using Ping Test

Min, Avg & Max RTT values split by radio technology for a ping towards www.google.fi

- ~90% of the average ping test towards www.google.fi using LTE have a RTT < 100 ms.
- Legacy 3G technologies are quite slow with more than 200 ms RTT.
Ping Test — packet loss by radio technology

Distribution of packet loss as the fraction total ping by radio technology type.

- Of all ping tests over LTE, 2.4% of them lost at least a single packet.
- ping test over UMTS network experience highest packet loss (∼65%).
Ping Test — packet loss by # packets sent at every ping test instance

Percentage of packets loss across the number of packets sent.

- \(~14.98\%\) of tests in ping measurement have at least one packet loss.
- Packet loss happens, if the number of packets sent at every ping test instance > 5 Echo Requests.
**DNS lookup time — by radio technology**

LTE exhibits significantly lower latency.

- 75% www.youtube.com < 200ms [LTE]
- 25% www.youtube.com < 200ms [3G]
TCP connect time — by radio technology

TCP Connect time towards www.youtube.com (L) & www.google.fi (R)

TCP Connect time towards www.youtube.com

- 92% of TCP test using LTE finished < 100ms
- 28% of 3G based TCP test finished < 100ms

DNS response time of www.google.fi (L) and www.facebook.com (R) across device models as measured over LTE — order by device models’ release year.

No clear pattern between DNS lookup time & device models year of release

- Variation in DNS resolution time among device models is very high
- Google has faster resolution time in most devices than Facebook (median case)
TCP connect time — Device models

TCP connect time for www.google.fi (L) and www.facebook.com (R) across device models as measured over LTE — order by device models’ release year.

Device type has smaller impact to TCP connect time

- Both Google and Facebook have similar TCP Connect time for most of device models
DNS lookup time — Websites

DNS response time towards websites using LTE — towards different DNS resolvers.

DNS server's proximity to the subscriber has an impact on DNS lookup time.

- www.youtube.com and www.facebook.com are slower than www.google.fi (likely cached by DNS resolvers) & www.elisa.net (ISP's website).
TCP connect time — Websites

TCP connect time towards websites under LTE.

- ~90% of the time, www.facebook.com and www.youtube.com can be reached in less than 100 ms from a client’s device.
- For www.google.fi and www.elisa.net, only 80% and 76% of the TCP connection test are below 100 ms, respectively.
TCP Connect time — by destination ASN from LTE networks

- Requests towards www.youtube.com served by the ISPs cache are faster than those served by Google CDN.
- www.facebook.com does not hit any caches in the ISP network —
  - slower TCP connect time than www.youtube.com and www.google.fi

Caching can improves the fetch time of small files
TCP Connect time—by destination ASN from LTE networks

TCP connect time towards www.google.fi showing the latency difference between ISP cache - Elisa (AS719) and CDN - Google (AS15169) using LTE.

Values on the negative scale indicate that ISP cache is faster

- ~ 70% of TCP connect time towards www.google.fi achieve lower latency when they hit ISP cache.
Conclusion
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1. DNS lookup & TCP connect times varies for different websites, even when the same radio technology is accessed.

2. ISP caches & DNS server proximity: Caches entries closer to the ISP could significantly improve TCP connect time. The proximity of DNS server to the subscriber has a higher impact on DNS lookup time performance.

3. Network radio technology: LTE offers considerably low latency compared to legacy radio technologies.

4. Packet loss using ping test can be underestimated e.g., if # of packets to be sent per ping test instance < 5. Consider increasing the number of packets per ping test instance for better results.
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Rula, J. P., & Bustamante, F. E. (2014). Behind the Curtain: The Importance of