Evaluating the Benefits: Quantifying the Effects of TCP Options, QUIC, and CDNs on Throughput

Simon Bauer, Patrick Sattler, Johannes Zirngibl
Christoph Schwarzenberg, Georg Carle

Monday 24th July, 2023
Introduction

Motivation

- Assessing and understanding connection and network performance is crucial
- Provider perspective: performance impacts user satisfaction
- Research perspective: assess the effectiveness of arising or widely deployed measures

Which impact have ...

- ... TCP options ...
- ... QUIC ...
- ... CDN hosting ...

... on the performance of Internet connections?
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Related Work

- **1992**  
  TCP window scaling (WS) [1]

- **1996**  
  Selected acknowledgments (SACK) [2]

- **2001**  
  Explicit congestion notifications (ECN) [3]

- **2004**  
  7.44% of all SYN/(ACK)s advertise MSS, TS, SACK, and WS [4]

- **2005**  
  Web server: 2.1% ECN capable, 68% SACK capable [5]

- **2013**  
  Alexa Top 1M: 88.22% WS, 89.06% SACK, 29.48% ECN [6]

- **2019**  
  ECN deployed by the majority of Alexa Top 1M domains (74.62% IPv4, 94.12% IPv6) [7]

- **2021**  
  Ongoing growth of infrastructure by hypergiants [8]

- **2021**  
  QUIC [9]–[11]

- **2022**  
  W3Techs: QUIC accounted for 8% of the global Internet traffic [12]
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Measurement Approach

1. Determining measurement targets
2. Conducting Measurements
3. Traffic analysis

Crawling

Downlaoding

PCAP analysis
Measurement Approach

1. Determining measurement targets
   - Public web servers as crawling targets
   - Recursively crawl all links of a website
   - Minimum file size of 1 MB
   - Consider different CDN providers
     - Domain-Org. mapping: IP → AS → Org. [13]

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   - ... and with different **QUIC implementations**
     - quiche, aioquic
   - Vantage points: MUC, SFO, SGP

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PCAP analysis
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   - Capture download traffic
   - Extract packet features and performance indicators
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Extension: Warm-up runs
- First download per run: baseline configuration
  - Bias in comparison to following DLs due to edge caching
- This presentation: results with warm-up run

Crawling

- file?
- file.size
- crawled.csv
- domain x org. mapping
- target_set.csv

Downloadig

- GET /file, SACK = 0, ECN = 0, WS = 0
- GET /file, SACK = 1, ECN = 1, WS = 14

PCAP analysis

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Target selection

TCP target set

- Crawl the top 100K Alexa Top 1M entries
- Selected 2000 domains (200 per CDN, 1000 from other ASes)

QUIC target set

- Top 100K entries of Google's CrUX dataset
- Scanned for QUIC support with QScanner [14]
- Crawling & filtering domains for option support

Three measurement runs per target for both target sets

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- For each download run: \( \text{Config}.\text{MeanTP} \geq x \times \text{Baseline}.\text{MeanTP} \) & \( \text{Config}.\text{MeanTP} < y \times \text{Baseline}.\text{MeanTP} \)
- Results merged for all VPs
  - SACK and ECN results comparable to baseline, only small shares of samples show speed-ups \( \geq 30\% \)
  - WS implies increased throughput for over 90% of samples
  - WS doubles mean TP for nearly 40% of samples, over 60% show a speed up larger 50%

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TCP vs. QUIC

- 70% of quiche downloads show increased throughput compared to aioquic
- quiche vs. aioquic: over 45% of samples show a speed-up ≥ 50%
- > 55% of TCP All downloads faster than aioquic
- But: over 30% of aioquic samples show a speed-up ≥ 100% compared to TCP All
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- Over 70% of *quiche* downloads outperform TCP All, doubled mean throughput for \( \geq 40\% \) of samples

### QUIC and TCP

<table>
<thead>
<tr>
<th>Config. vs.</th>
<th>+</th>
<th>-</th>
<th>0.7 - 0.9</th>
<th>0.9 - 1.0</th>
<th>1.0 - 1.1</th>
<th>1.1 - 1.3</th>
<th>1.3 - 1.5</th>
<th>1.5 - 2</th>
<th>&gt;2</th>
</tr>
</thead>
<tbody>
<tr>
<td>quiche</td>
<td>aioquic</td>
<td>70.0%</td>
<td>30.0%</td>
<td>6.8%</td>
<td>2.9%</td>
<td>4.0%</td>
<td>10.5%</td>
<td>7.7%</td>
<td>8.9%</td>
</tr>
<tr>
<td>aioquic</td>
<td>ALL</td>
<td>44.5%</td>
<td>55.5%</td>
<td>12.2%</td>
<td>4.7%</td>
<td>3.3%</td>
<td>2.7%</td>
<td>1.6%</td>
<td>4.6%</td>
</tr>
<tr>
<td>quiche</td>
<td>ALL</td>
<td>71.9%</td>
<td>28.1%</td>
<td>8.6%</td>
<td>5.5%</td>
<td>9.1%</td>
<td>11.8%</td>
<td>4.3%</td>
<td>5.9%</td>
</tr>
</tbody>
</table>
Conclusion

Measurement results

- TCP WS is crucial to achieve higher throughput rates
- Significant difference between downloads with *quiche* and *aioquic*
- *quiche* mostly exceeds TCP with all options (diff. between measurement series observed)
- Observed different impacts by vantage point location and edge caching

Future Work

- Extension of pipeline with further QUIC implementations
- Conducting root cause analysis of throughput limitations
- Running long-term measurements

Pipeline published on Github [15]
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Back-up - How does observed performance differ between vantage points?

**Mean Throughput**
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Back-up - CDN Throughput (MUC, SFO, SGP)
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5.3% of domains do not support a single option while 81.0% support all three considered options. ECN is supported by 85.8%, SACK by 91.4% and WS by 91.1% of the domains.
Back-up - With vs. Without Warm-up (July’23 vs. June’23)

With Warm-up

Without Warm-up
# Back-up - Speed-ups June’23 vs July’23

## June’23

### TCP options

<table>
<thead>
<tr>
<th>Config. vs.</th>
<th>+</th>
<th>-</th>
<th>&lt;0.5</th>
<th>0.5 - 0.6</th>
<th>0.6 - 0.7</th>
<th>0.7 - 0.8</th>
<th>0.8 - 0.9</th>
<th>0.9 - 1.0</th>
<th>1.0 - 1.1</th>
<th>1.1 - 1.2</th>
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</thead>
<tbody>
<tr>
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<td>9.6%</td>
<td>90.4%</td>
<td>39.3%</td>
<td>15.4%</td>
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<td>9.7%</td>
<td>6.8%</td>
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<td>1.4%</td>
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<tr>
<td>SACK</td>
<td>ALL14</td>
<td>10.3%</td>
<td>89.7%</td>
<td>37.7%</td>
<td>15.0%</td>
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<td>10.2%</td>
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<td>3.4%</td>
<td>1.1%</td>
</tr>
<tr>
<td>WS</td>
<td>ALL14</td>
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<td>1.7%</td>
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<td>3.9%</td>
<td>7.1%</td>
<td>31.7%</td>
<td>28.9%</td>
<td>5.3%</td>
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### QUIC and TCP

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<th>0.9 - 1.0</th>
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<th>1.2 - 1.3</th>
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<th>1.5 - 2</th>
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<td>6.5%</td>
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</table>

## July’23

### TCP options

<table>
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<th>Config</th>
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<th>0.7 - 0.8</th>
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<th>0.9 - 1.0</th>
<th>1.0 - 1.1</th>
<th>1.1 - 1.2</th>
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<tr>
<td>SACK</td>
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<td>33.2%</td>
<td>34.7%</td>
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<td>2.4%</td>
<td>5.5%</td>
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<tr>
<td>All</td>
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<td>1.0%</td>
<td>1.3%</td>
<td>3.2%</td>
<td>5.6%</td>
<td>6.8%</td>
<td>5.7%</td>
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