Chair of Network Architectures and Services
TUM School of Computation, Information and Technology
Technical University of Munich

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

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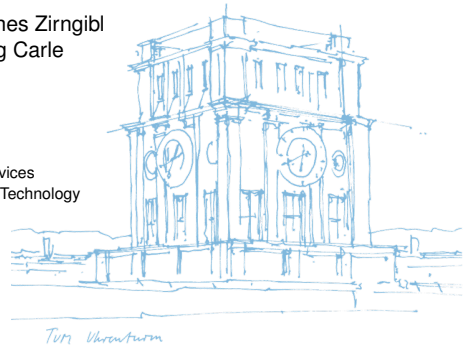

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- Assessing and understanding connection and network performance is crucial
- Provider perspective: performance impacts user satisfaction
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- ... QUIC ...
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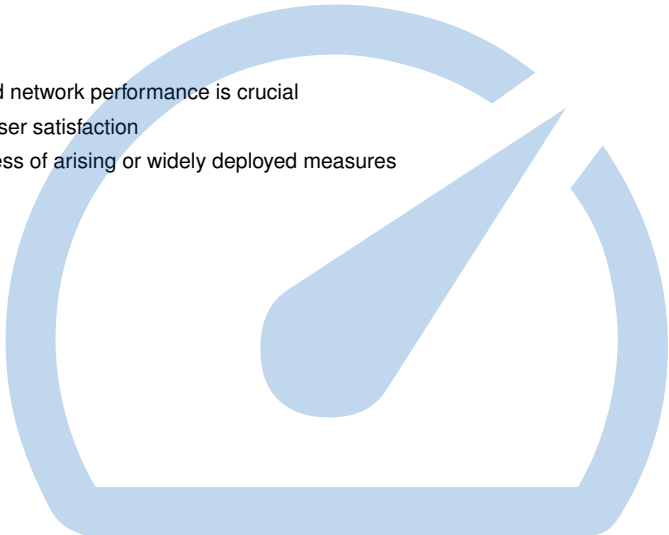

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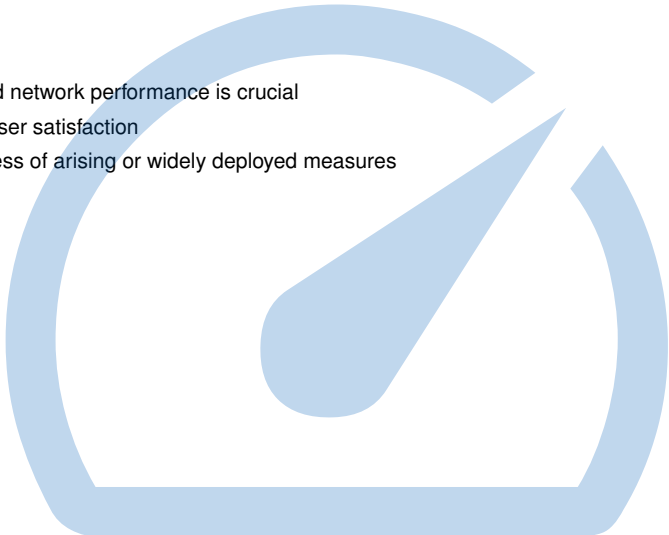

Related Work

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**

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]

2. Conducting Measurements

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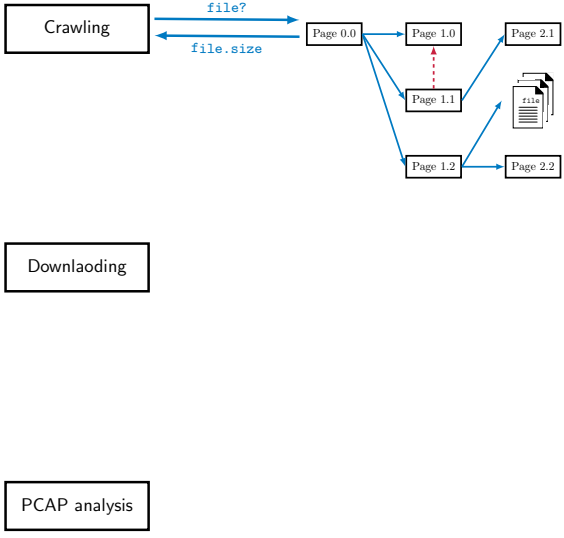

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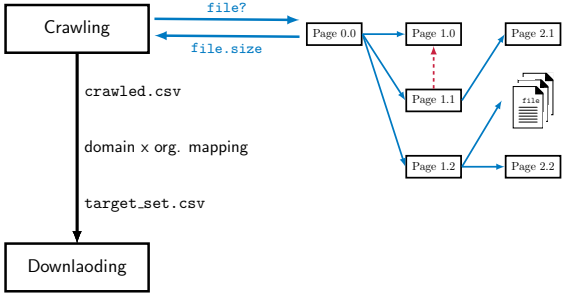

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PCAP analysis

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   - Run downloads with different **TCP options**
     - SACK, ECN, WS
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   - **Vantage points**: MUC, SFO, SGP

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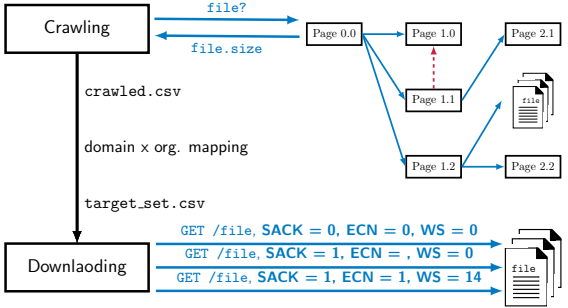

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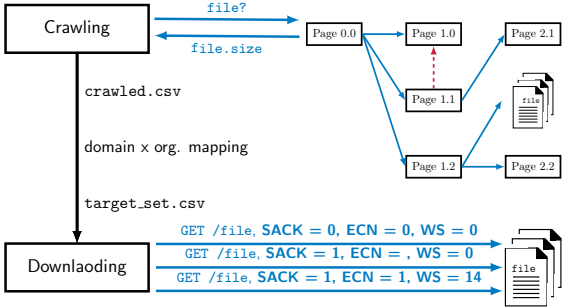

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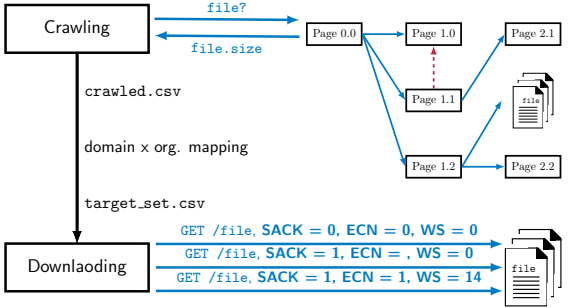

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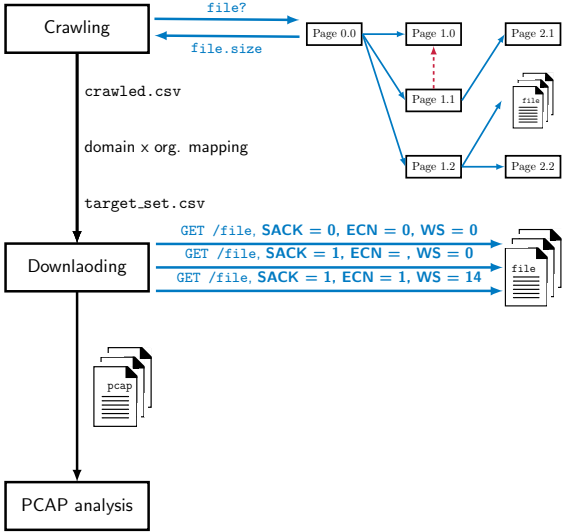
   - Capture download traffic
   - Extract packet features and performance indicators



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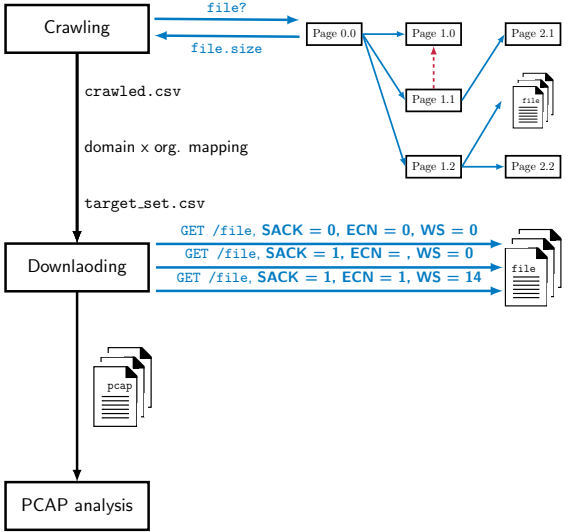
Extension: Warm-up runs

- First download per run: baseline configuration
- → Bias in comparison to following DLs due to edge caching
- **This presentation: results with warm-up run**



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

Run	Total	Akamai	Amazon	Cloudflare	Google	Microsoft	Others
TCP							
MUC	1679	167	150	170	147	172	873
SFO	1678	165	147	168	152	173	873
SGP	1640	162	147	163	143	166	859
QUIC							
MUC_Q	511	3	15	289	2	0	202
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Measurements: July 2023

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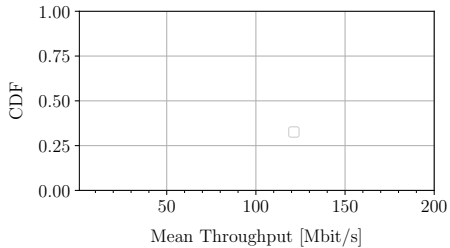
How does TCP option usage impact performance?

VP in MUC



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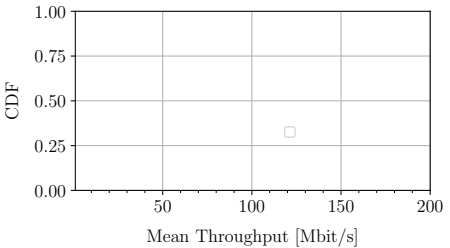

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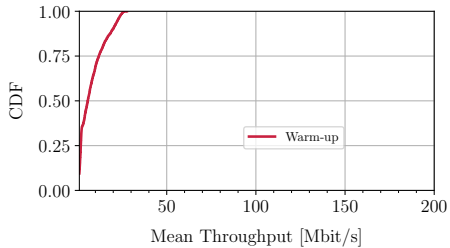

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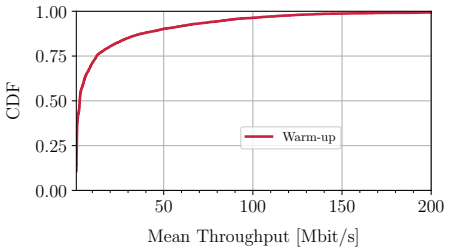

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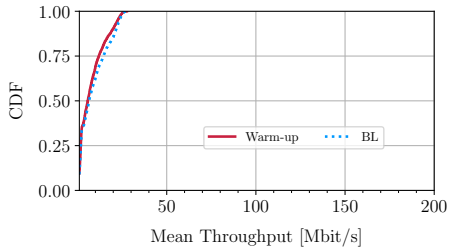

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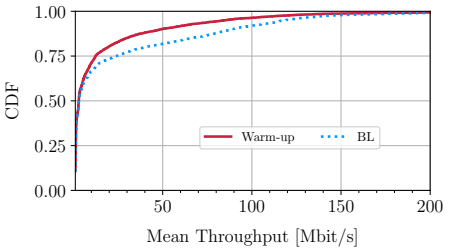

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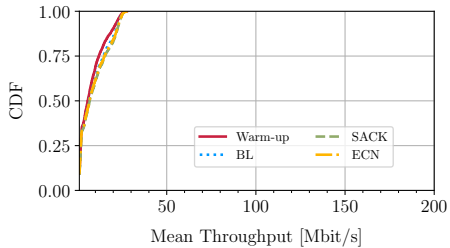

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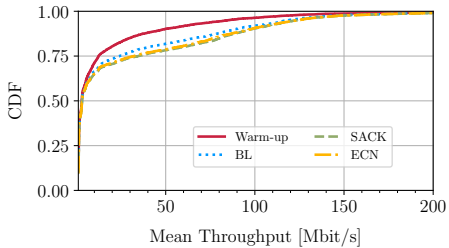

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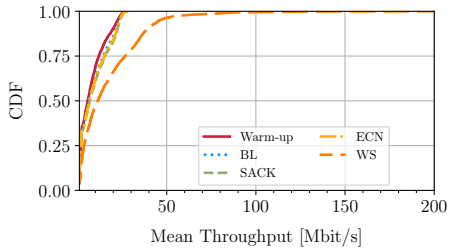

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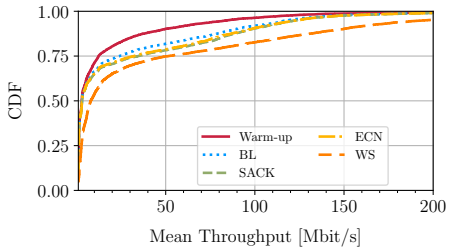

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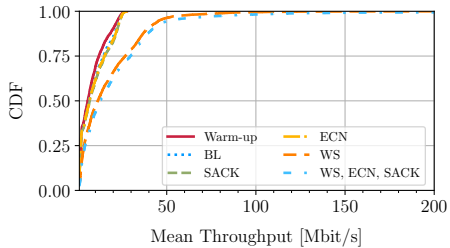

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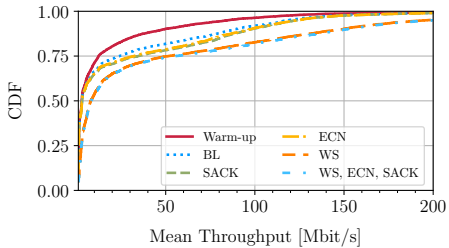

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- Results merged for all VPs
- SACK and ECN results comparable to baseline, only small shares of samples show speed-ups $\geq 30\%$
- WS implies increased throughput for over 90% of samples
- WS doubles mean TP for nearly 40% of samples, over 60% show a speed up larger 50%

				TCP options						
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Warm-up	BL	35.4%	64.6%	12.1%	37.1%	25.9%	5.3%	1.6%	1.2%	1.5%
ECN	BL	53.3%	46.7%	7.4%	34.0%	35.0%	8.4%	2.6%	2.2%	5.1%
SACK	BL	54.2%	45.8%	7.4%	33.2%	34.7%	9.1%	2.6%	2.4%	5.5%
WS	BL	90.3%	9.7%	2.5%	3.5%	5.7%	12.9%	10.8%	22.9%	38.0%
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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 $\geq$ 50%
- $>$ 55% of TCP All downloads faster than *aioquic*
- But: over 30% of *aioquic* samples show a speed-up $\geq$ 100% compared to TCP All
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QUIC and TCP

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aioquic	ALL	44.5%	55.5%	12.2%	4.7%	3.3%	2.7%	1.6%	4.6%	32.4%
quiche	ALL	71.9%	28.1%	8.6%	5.5%	9.1%	11.8%	4.3%	5.9%	40.7%

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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]

Conclusion

Measurement results

- TCP WS is crucial to achieve higher throughput rates
- Significant difference between downloads with *quiche* and *aioquic*
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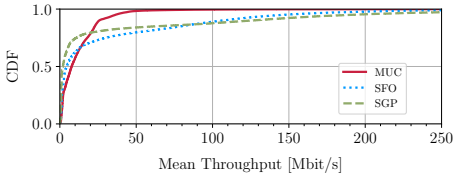
Back-up - How does observed performance differ between vantage points?

Mean Throughput

- *MUC* shows higher throughput for the majority of samples
- *SFO & SGP:* share of samples significantly exceeding throughput observed by *MUC*



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- *SFO & SGP:*
  - DLs with significantly increased throughput correlate to very small RTTs
  - Small RTTs associate with DLs from Akamai, Cloudflare, and Amazon domains

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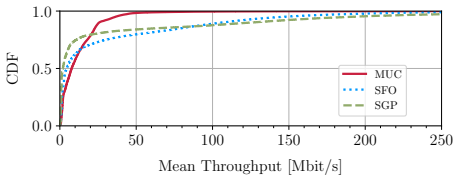

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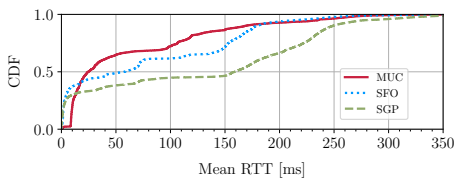
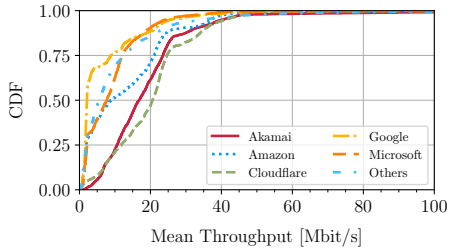
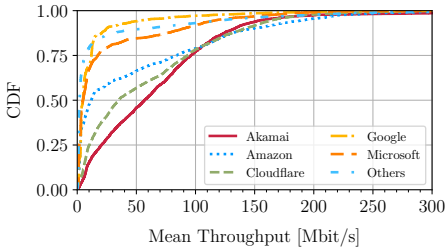
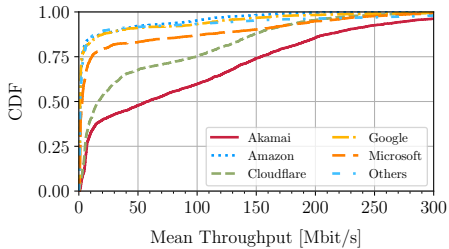


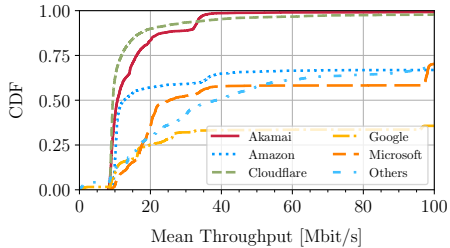
Back-up - CDN Throughput (MUC, SFO, SGP)

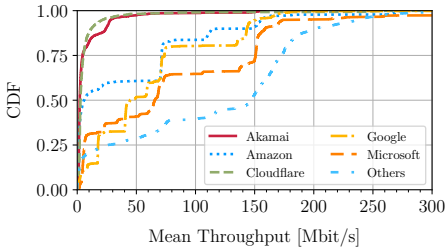


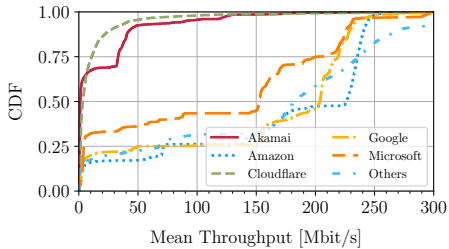




Back-up - CDN RTT (MUC, SFO, SGP)





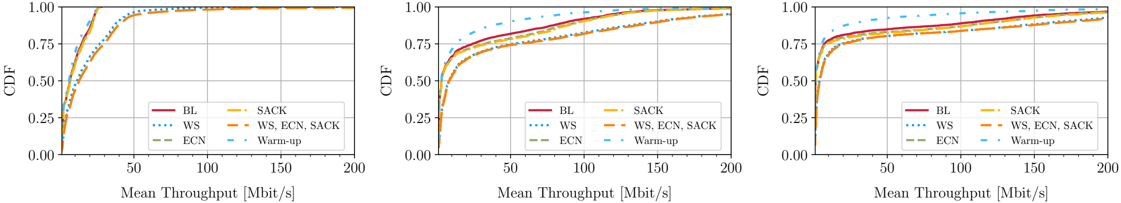


Back-up - Option Deployment in the Alexa Top 1M

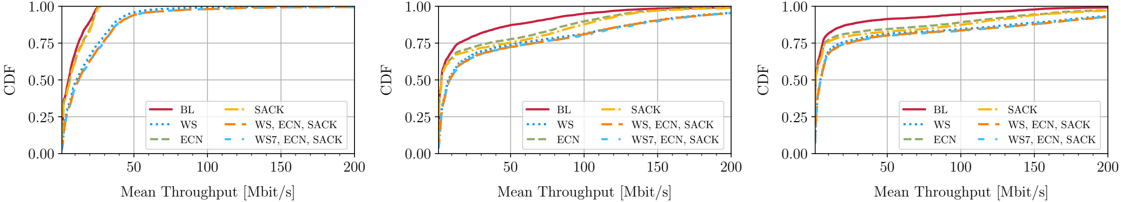
5,3 % of domains do not support a single option while 81,0 % support all three considered options. ECN is supported by 85,8 %, SACK by 91,4 % and WS by 91,1 % of the domains.

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												
Config.	vs.	+	-	<0.5	0.5 - 0.6	0.6 - 0.7	0.7 - 0.8	0.8 - 0.9	0.9 - 1.0	1.0 - 1.1	1.1 - 1.2	>1.2
ECN	ALL14	9.6%	90.4%	39.3%	15.4%	8.5%	10.7%	9.7%	6.8%	3.2%	1.4%	5.1%
SACK	ALL14	10.3%	89.7%	37.7%	15.0%	8.8%	11.2%	10.2%	6.9%	3.4%	1.1%	5.8%
WS	ALL14	45.9%	54.1%	7.3%	1.7%	2.4%	3.9%	7.1%	31.7%	28.9%	5.3%	11.7%
QUIC and TCP												
Config.	vs.	+	-	0.7 - 0.8	0.8 - 0.9	0.9 - 1.0	1.0 - 1.1	1.1 - 1.2	1.2 - 1.3	1.3 - 1.5	1.5 - 2	>2
quiche	TCP-BL	72.1%	27.9%	2.8%	1.9%	3.1%	11.5%	7.1%	3.7%	6.4%	13.2%	30.2%
quiche	TCP-ALL14	47.6%	52.4%	3.9%	5.9%	5.4%	12.9%	6.5%	3.1%	5.6%	3.9%	15.7%

July'23

TCP options												
Config	vs.	+	-	0.7 - 0.8	0.8 - 0.9	0.9 - 1.0	1.0 - 1.1	1.1 - 1.2	1.2 - 1.3	1.3 - 1.5	1.5 - 2	>2
ECN	BL	53.3%	46.7%	2.1%	5.3%	34.0%	35.0%	6.1%	2.3%	2.6%	2.2%	5.1%
SACK	BL	54.2%	45.8%	2.1%	5.3%	33.2%	34.7%	6.3%	2.8%	2.6%	2.4%	5.5%
All	BL	91.4%	8.6%	1.0%	1.3%	3.2%	5.6%	6.8%	5.7%	10.2%	22.8%	40.2%
quiche	TCP-BL	82.9%	17.1%	2.1%	2.8%	3.9%	5.2%	3.9%	2.9%	4.7%	14.6%	51.5%
quiche	TCP-ALL	71.9%	28.1%	4.3%	4.3%	5.5%	9.1%	7.5%	4.3%	4.3%	5.9%	40.7%