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

Detecting and Evaluating QUIC Deployments as Part of the Internet Ecosystem

Johannes Zirngibl

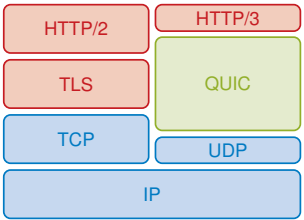
Ph. D. Defense, 20.02.2025

Chairman:	Prof. Dr.-Ing. Jörg Ott
Examiners:	Prof. Dr.-Ing. Georg Carle
	Prof. Kimberly C. Claffy, Ph. D.
	Prof. Anja Feldmann, Ph. D.

Motivation

QUIC is a new fundamental network protocol:

- Standardized in 2021
- Combines functionality of different protocols
  - Reduces handshake latency
  - Reduces head of line blocking
- By design implemented in user space
  - >20 implementations exist
- Widely used already in 2020
  - QUIC carries a third of Google traffic
  - 75 % of Facebook's traffic is HTTP/3



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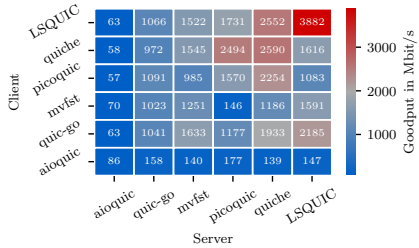

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How Facebook is bringing QUIC to billions

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QUIC is only part of the Internet and relies on, e.g.,

- IPv6:
  - Covers steady increase of network devices
  - ↯ Prevents full enumeration
- DNS:
  - User friendly identifier
  - Often required to select service and certificate
  - ↯ A name does not indicate existence of a service

Knowledge about deployments, supported protocols, extensions but also libraries is required to evaluate the network and quality of experience.

Why is the connection slow?
Is it the network or QUIC?
Is it QUIC or the library?

Existing Work (Not Exhaustive)

	QUIC				IPv6		DNS
	Rüth[1]	Marx[2]	Trevisan[3]	Nawrocki[4]	Gasser[5]	Rye[6]	Dong[7]
QUIC	○	✓	✓	✓	○	×	×
↪ Library differences	×	✓	○	✓	×	×	×
DNS	✓	×	○	✓	✓	×	✓
↪ Alt. Service Discovery	✓	×	✓	×	×	×	✓
Internet measurements	✓	×	✓	✓	✓	✓	✓
↪ IPv6 measurements	×	×	○	×	✓	✓	○

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How can we use Internet-wide measurements
to identify and analyze QUIC deployments
as part of the Internet ecosystem?

Research Questions & Thesis Structure

RQ 1: How can the IPv6 ecosystem be scanned?

- Maintain a valuable list of IPv6 addresses — Chapter 4, IMC'22[1], CONEXT'23[2]
- Identify new responsive IPv6 targets — Chapter 5, IMC'22[1], TMA'23[3]

RQ 2: What is the impact of DNS?

- Identify valid server names — Chapter 6, WTMC'23[4]
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- Differentiate libraries — Chapter 9, PAM'24[7]

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How can we identify IPv6 deployments? (Thesis: Part I)

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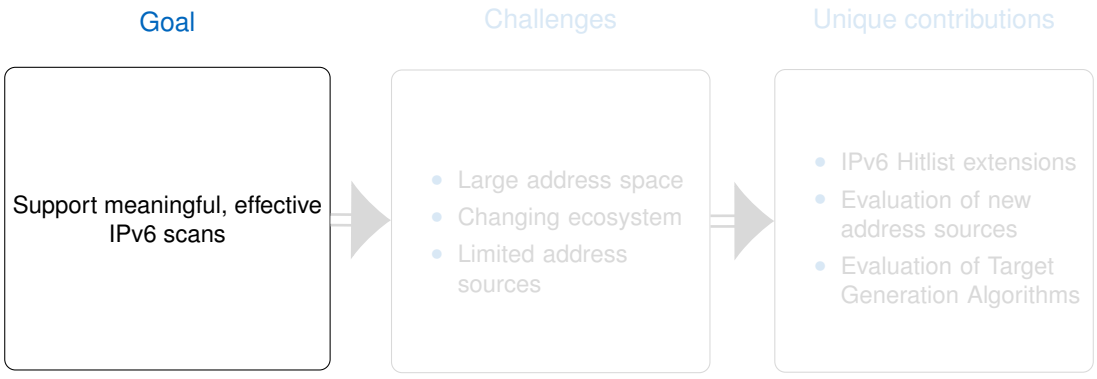

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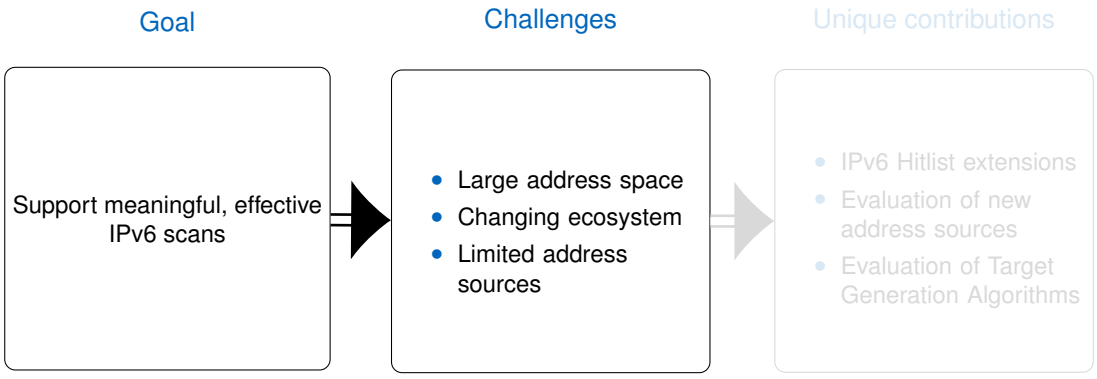

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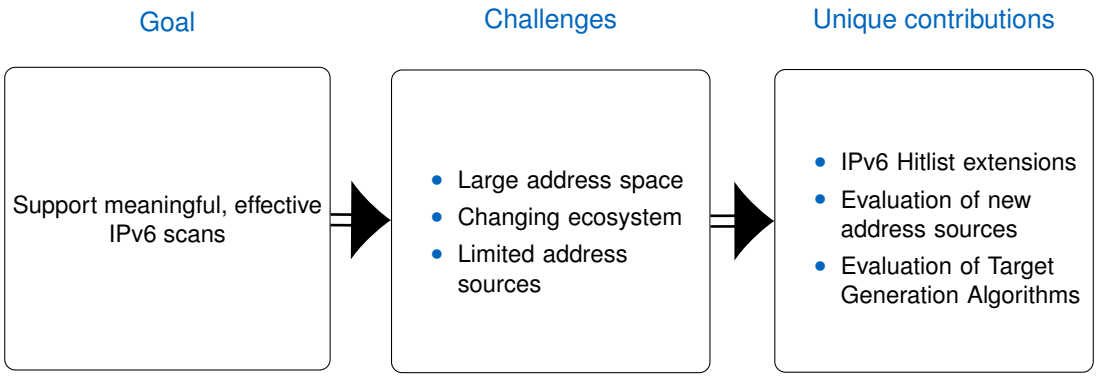

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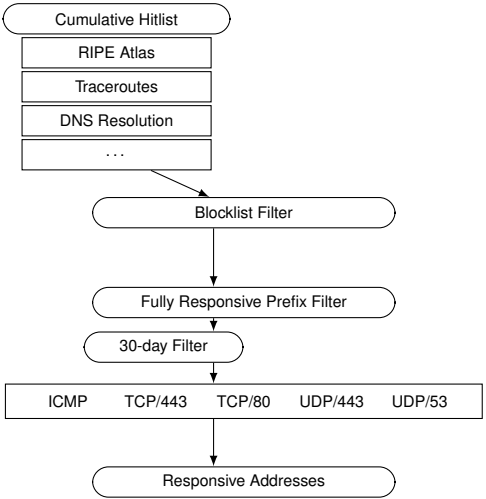

Gasser et al.[1] established an ongoing IPv6 Hitlist in 2018:

- Collects candidates from multiple sources
- Applies different filters
- Tests addresses for their responsiveness

[1] O. Gasser, Q. Scheitle, P. Foremski, Q. Lone, M. Korczynski, S. D. Strowes, L. Hendriks, and G. Carle, "Clusters in the Expanse: Understanding and Unbiasing IPv6 Hitlists," IMC'18

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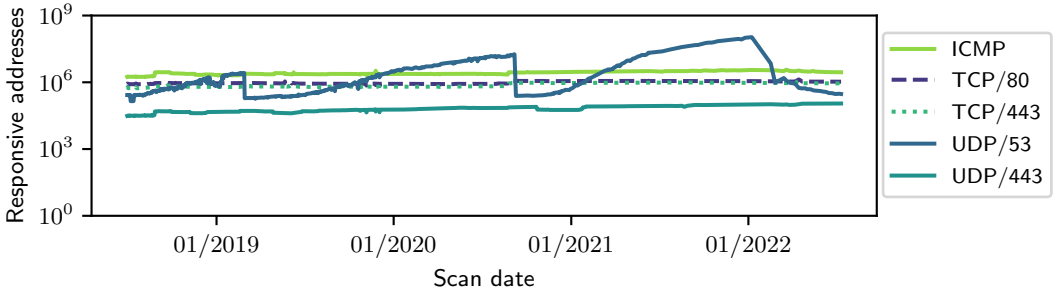

- The IPv6 Hitlist service was running for four years
- Up to 100 M addresses are responsive to at least one protocol
  - Spikes in addresses responsive to UDP/53 are visible
  - Majority are injected DNS responses by Chinese censorship mechanisms

J. Zirngibl, L. Steger, P. Sattler, O. Gasser, and G. Carle, "Rusty Clusters? Dusting an IPv6 Research Foundation," IMC'22

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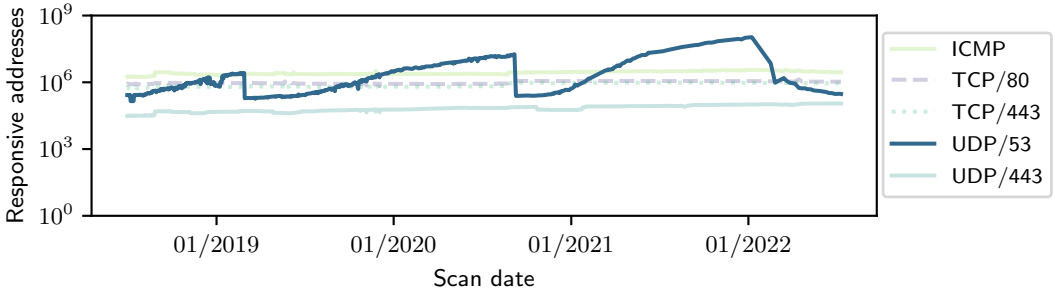

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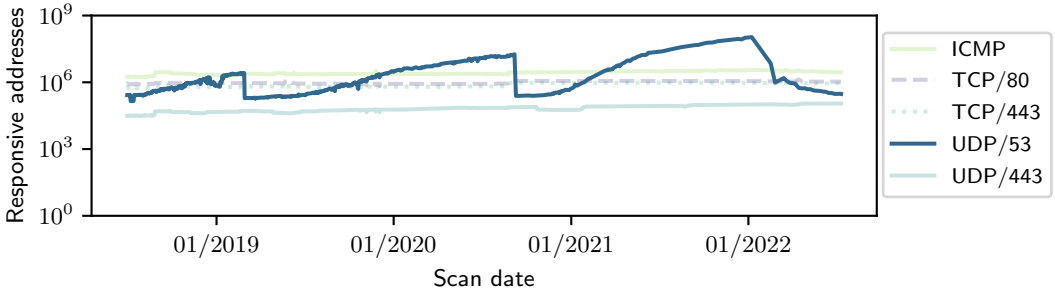

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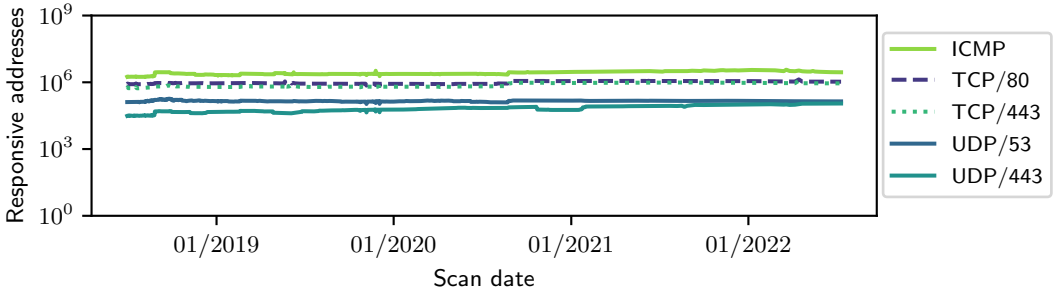

- We cleaned the IPv6 Hitlist and published data
- The result is more stable for all protocols
  - 3.2 M addresses are responsive (1 M TCP/80), covering 15.7 k ASes
  - Significantly less compared to IPv4 (80 M TCP/80)

J. Zirngibl, L. Steger, P. Sattler, O. Gasser, and G. Carle, "Rusty Clusters? Dusting an IPv6 Research Foundation," IMC'22

How can we identify IPv6 deployments?

- Re-tested all filtered addresses
- Evaluated and added new data sources
- First exhaustive comparison of target generation algorithms
  - Fair comparison: Same time, same inputs
  - Algorithms convince for different goals

Method	Addr	Responsive Addr. ↓	ASes
6Graph	125.8 M	3.8 M	10.7 k
6Tree	37.6 M	2.2 M	11.5 k
DC	5.3 M	651.9 k	5.5 k
6GAN	3.3 M	4.3 k	39
6VecLM	70.3 k	1.0 k	105

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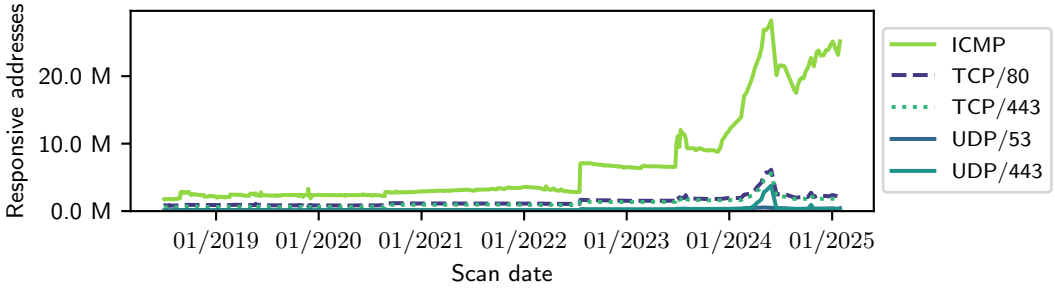

→ We identified 5.6 M new responsive IPv6 addresses from 14.6 k ASes[1]

→ We identified 13.9 M new responsive IPv6 addresses from 18.1 k ASes[2]

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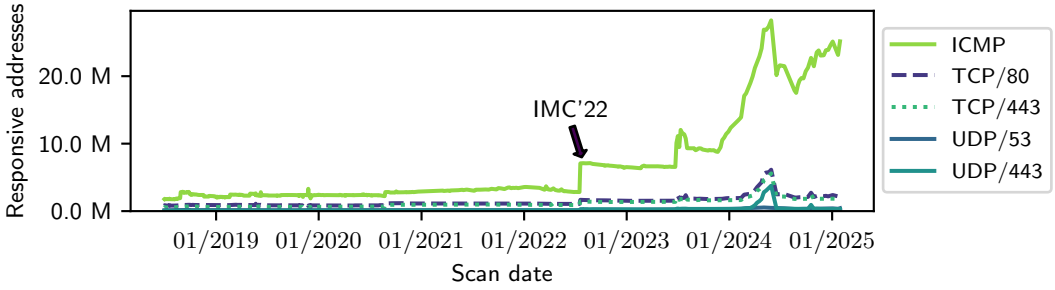

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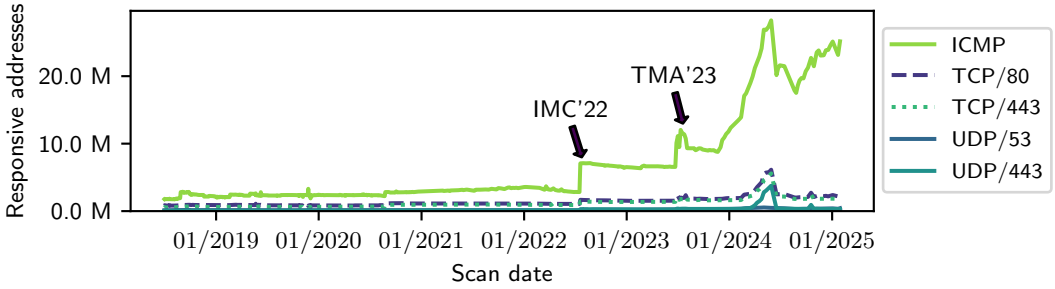

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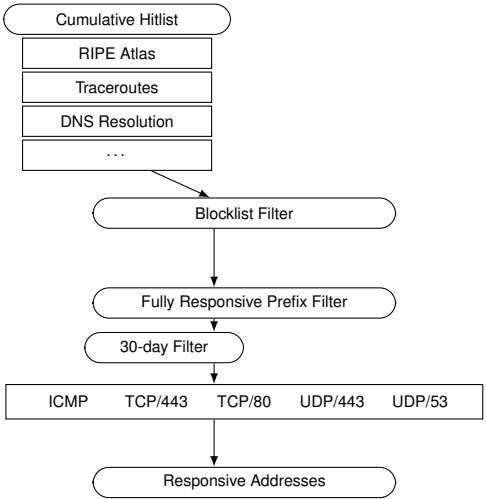

The IPv6 Hitlist

- Is in an improved state
- With new sources and significantly more addresses
- Unbiased from censorship mechanisms
- Running regularly

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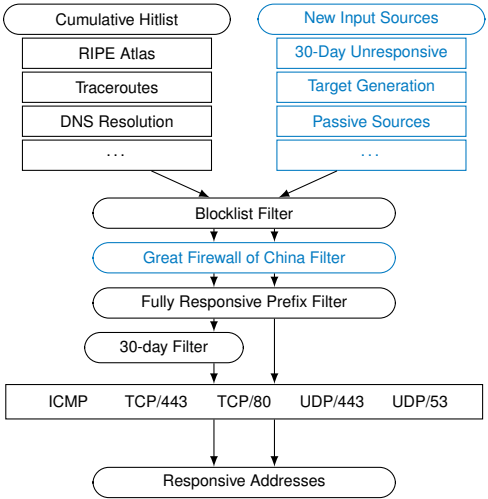

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How can we identify QUIC deployments and libraries?
(Thesis Part III)

How can we identify the library of QUIC deployments?

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Goal

Effectively identifying QUIC libraries on large scale

Challenges

- Transport and TLS handshake combined
- Libraries implement standards differently
- Behavior might be configuration specific

Unique contributions

- Development of a QUIC scanners
- Evaluation of scan and library identification methodologies
- Internet-wide evaluation

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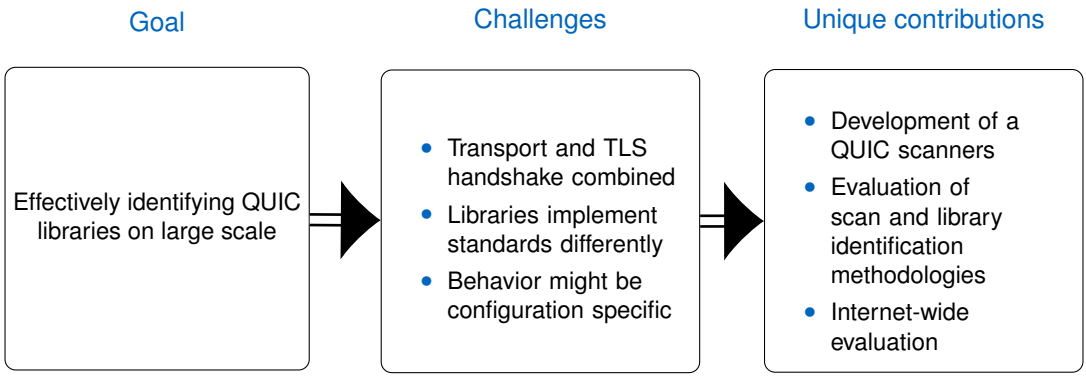
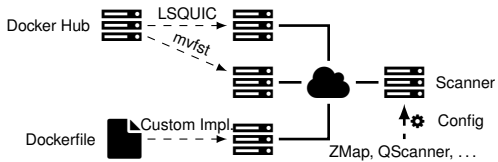


How can we identify the library of QUIC deployments?

Test environment:

- Test scanners and configurations



ZMap:

- Large-scale, stateless scans
- Development of a QUIC module
- Evaluation of different probes

QScanner:

- Stateful scans
- Conducts full QUIC handshakes
- Supports HTTP/3
- Extracts QUIC, TLS, HTTP features

Library identification:

- Extract library features
- Not configurable by user

Impl.	Error Message
Quinn	peer doesn't support any known
aioquic	No common ALPN protocols

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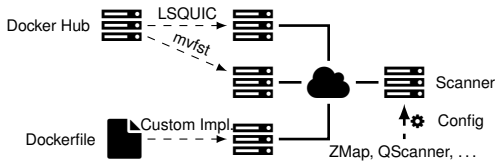

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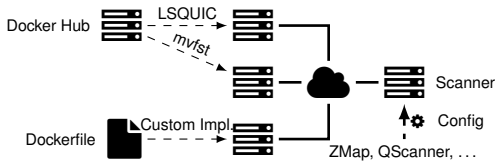

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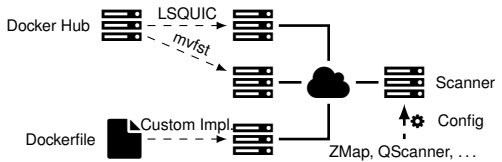

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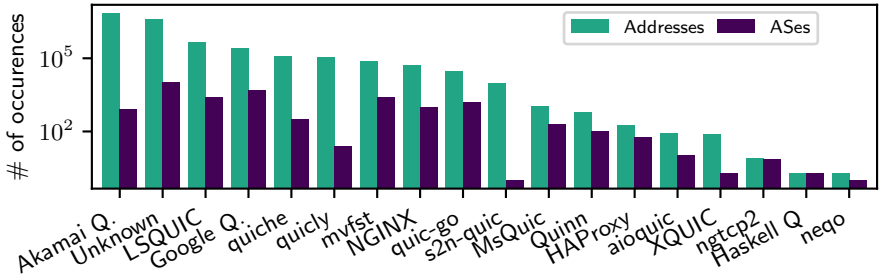

- At least one deployment for 18 libraries
- Most common libraries are from:
  - Hyper Giants: Akamai, Google, Cloudflare, Facebook
  - Web servers with early QUIC adoption: LiteSpeed, NGINX and Caddy
- Unknown deployments:
  - Addresses: Amazon (56.7 %) and Cloudflare (17.2 %)
  - ASes: Timeouts (4.7 k) or Google Edge Caches (4.4 k)

J. Zirngibl, F. Gebauer, P. Sattler, M. Sosnowski, and G. Carle, "QUIC Hunter: Finding QUIC Deployments and Identifying Server Libraries Across the Internet," PAM'24

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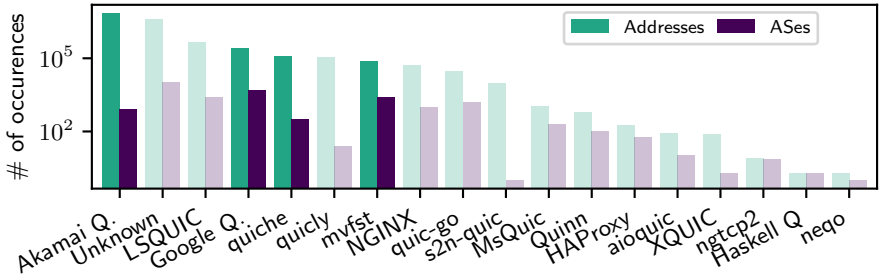

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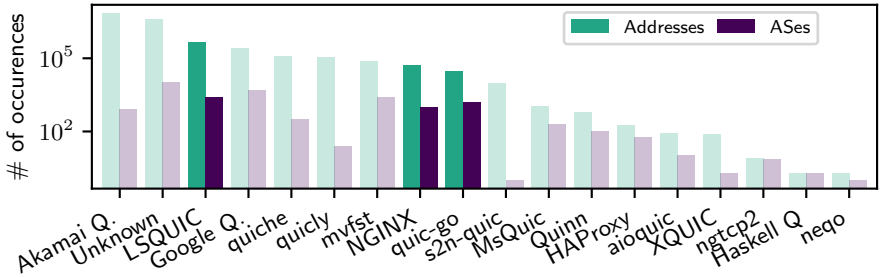

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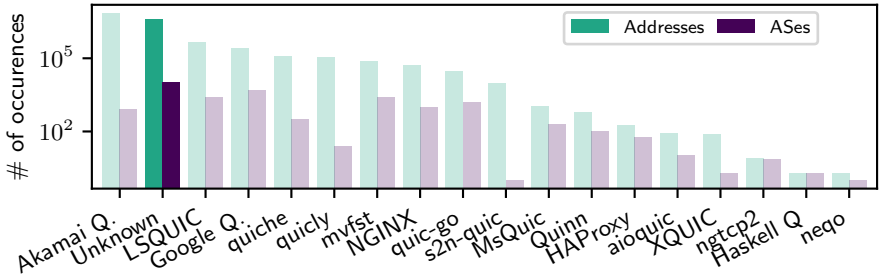

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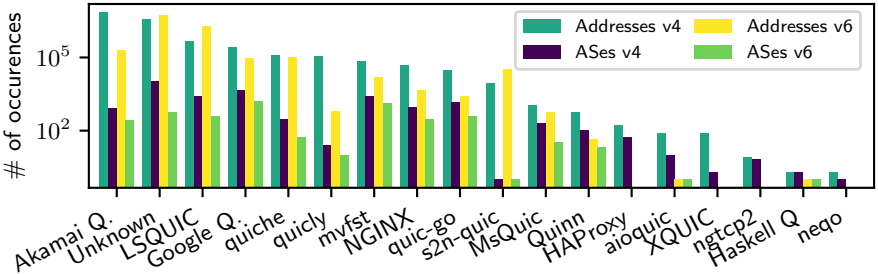

- The IPv6 Hitlist, DNS and alternative service discovery allow IPv6 scans:
  - At least one deployment for 13 libraries
  - Similar distribution across hyper giants and libraries

J. Zirngibl, F. Gebauer, P. Sattler, M. Sosnowski, and G. Carle, "QUIC Hunter: Finding QUIC Deployments and Identifying Server Libraries Across the Internet," PAM'24

Summary

This work provides the methodologies and tools and insights to effectively identify and analyze QUIC deployments as part of the Internet ecosystem

- All developed tools are open source and measurements setup as regular service
- The IPv6 Hitlist is in an improved state, with more addresses and running regularly
- DNS resolutions are important (but not necessarily all domains are interesting)
  - To identify IPv6 targets
  - To identify SNI values for TLS or QUIC scans
- A large variety of QUIC libraries is deployed impacting scans and the Internet
  - Thorough testing and evaluations are required

IMC'21

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TMA'23

CoNEXT'23

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