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QUIC Measurements on Ark

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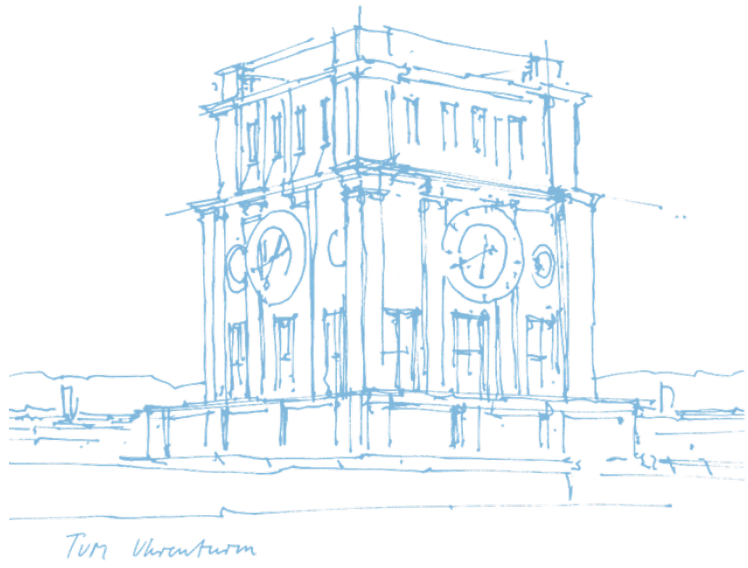
Tuesday 24th February, 2026

AIMS-19



QUIC Scanning and Its Challenges

- QUIC [1] is a transport protocol with growing adoption
  - Major web services (Google, Meta, etc.) are using QUIC
  - HTTP/3 [2] is built on QUIC
  - Compelling target for in-depth measurements

- Encrypted-by-default challenges
  - **Limited passive measurement opportunities**
  - Active measurements are essential to study QUIC behavior and its global deployment

- QScanner [3] is a feature-rich tool for large-scale QUIC scans
  - However, measurements are **limited to a single vantage point (VP)**
  - Restricts visibility in scenarios like geo-distributed CDN deployments or geo-blocking
  - Need globally distributed infrastructure $\rightarrow$ **Archipelago (Ark)** [4]

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[1] Jana Iyengar and Martin Thomson. QUIC: A UDP-Based Multiplexed and Secure Transport. RFC 9000. 2021
[2] Mike Bishop. HTTP/3. RFC 9114. 2022
[3] TUM Chair of Network Architectures and Services. QScanner. https://github.com/tumi8/QScanner. 2022
[4] Archipelago (Ark) Measurement Infrastructure. https://www.caida.org/projects/ark/. Accessed: 2026-02-03

Bringing QUIC Measurements to Ark

- Goal: Deploy **QUIC scanning in the field-tested Ark infrastructure**
  - Transferring our proven approach and insights from QScanner
  - Unlock new opportunities to study QUIC's behavior
  - In **diverse geographic and network conditions**

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Choosing a QUIC Stack: Design Trade-offs

- QUIC runs **entirely in user space**
  - No kernel implementation is currently available, but work is in progress[1]
  - A QUIC library must be chosen and integrated
- Avoid integrating a **full QUIC stack**
  - QUIC is complex: Flow & congestion control, loss recovery, ...
  - Rapidly evolving ecosystem
- Design choice: **Minimal integration overhead**
  - **OpenSSL $\geq$ 3.2** provides native QUIC client support (since Nov. 2023)
  - Interoperable with all major QUIC implementations[2]
  - Commonly available on most systems
  - Scamper already depends on OpenSSL
  - ➔ **No new external dependencies**

[1] https://lwn.net/Articles/1029851

[2] https://github.com/openssl/openssl/actions/workflows/run_quic_interop.yml

QUIC Integration in Scamper

- New Scamper command `quic`
  - Inspired by Scamper's `http` command
  - Similar structure and handling of connections and library calls

- Implemented **Python bindings**
  - Like Scamper does for other measurement primitives
  - Enables easy integration into existing Python-based analysis pipelines

- Perform a QUIC handshake with targets and **capture all QUIC packets**
  - Together with TLS keys for decryption
  - Results saved in **warts**[3] files
  - Can be converted to PCAPs using `sc_warts2pcap`
  - Analysis separated from measurement process
  - ➔ **Future compatibility**

[3] https://www.caida.org/catalog/software/scamper/man/warts.5.pdf

Scamper QUIC Command

```
./scamper -c “quic -d 443 -h ’example.com’ -a h3 -O insecure” -i 23.215.0.136
```

Usage string: `quic`

`[-d dport]`

- Destination port

`[-h host]`

- Set as Server Name Indication (SNI) and used for certificate verification

`[-a alpn-protos]`

- Comma-separated list of Application-Layer Protocol Negotiation (ALPN) names
- ALPN must be specified for QUIC handshakes according to RFC 9001 [5]

`[-c ciphersuites]`, `[-g groups]`, `[-s sigalgs]`

- Lists of TLS 1.3 cipher suites, groups, and signature algorithms to offer during the handshake
- Allows testing server behavior with different configurations, e.g., PQC algorithms

`[-O option]`

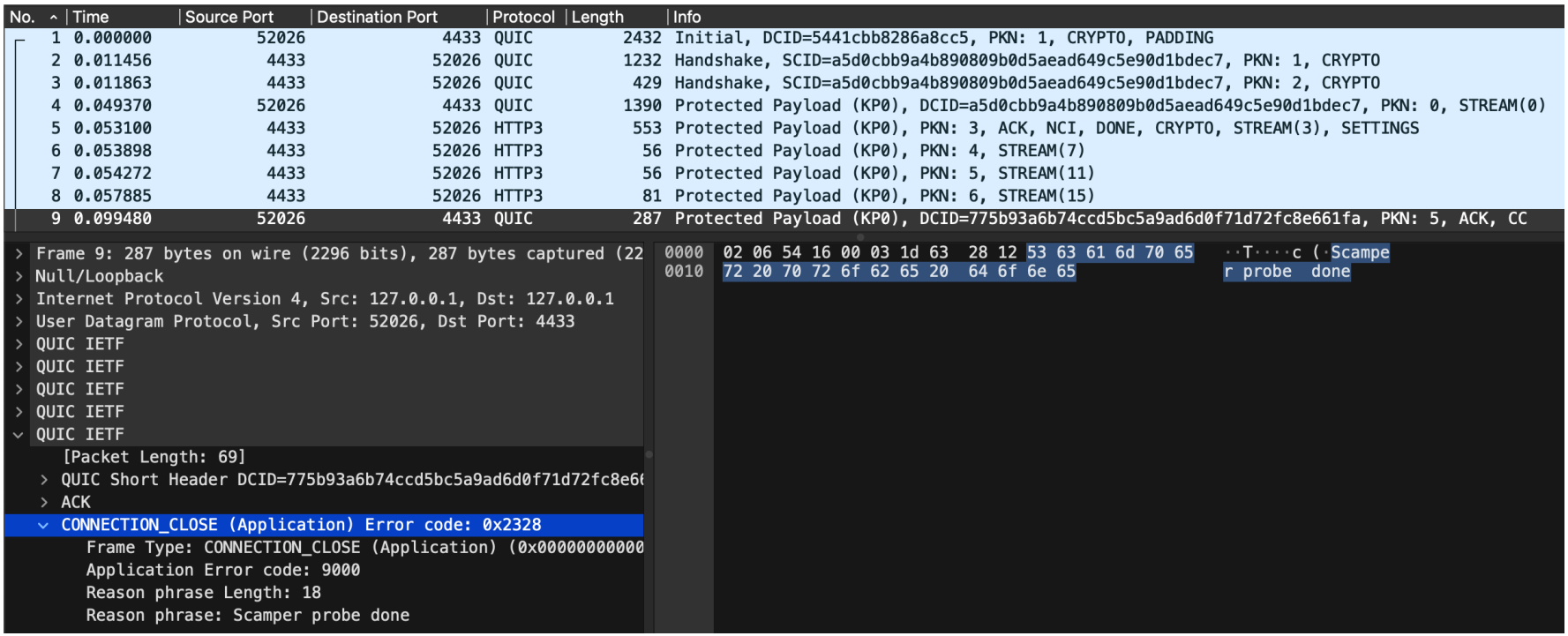
- Currently only `insecure` is implemented: disables certificate verification
- More options can be added in the future, e.g., QUIC transport parameters

[5] Martin Thomson and Sean Turner. Using TLS to Secure QUIC. RFC 9001. 2021

Scamper QUIC Measurement Packet Exchange

PCAP of a Scamper QUIC measurement against Cloudflare quiche on port 4433

- `CONNECTION_CLOSE` frame with reason phrase sent



Challenges Encountered & Lessons Learned

- Many systems have an **old OpenSSL version** installed
  - QUIC support was only added in OpenSSL 3.2 (Nov. 2023)
  - Must ensure that the target system has OpenSSL $\geq$ 3.2 installed
  - Debian Trixie ships with OpenSSL 3.5
  - ➔ **Test across multiple target distributions early** to uncover dependency mismatches

- QUIC transport parameters are currently **not configurable** in OpenSSL's QUIC stack
  - Restricts our ability to evaluate server behavior under varying transport parameter settings
  - A pull request has been submitted to OpenSSL[4]
  - Changes are expected to be merged in the immediate future
  - ➔ **Contribute to open-source projects** to close feature gaps and accelerate development

[4] https://github.com/openssl/openssl/pull/29664

Early Findings: Distributed QUIC Scans

- **Post-Quantum Cryptography**
  - Detection of PQ/hybrid key exchange (KE) groups in TLS 1.3
  - Measurable deployment share: ∼41 % support rate
  - ➔ Consistent across VPs

Library	ASes	PQ KE Support
Akamai	AKAMAI-AS, AKAMAI-ASN1	✗
LSQUIC	mixed	✗
MsQuic	mixed	✗
nginx	mixed	○
quic-go	mixed	○
Cloudflare quiche	CLOUDFLARE	✓
Google QUICHE	GOOGLE, GOOGLE-CLOUD-PLATFORM	✓[5]
mvfst	FACEBOOK	✓[6]
quicly	FASTLY	✓
s2n-quic	AMAZON-02	✓

[5] PQC support mainly in *GOOGLE* AS and not widely deployed in *GOOGLE-CLOUD-PLATFORM* AS

[6] We found 1 off-net deployment without PQC support

Why Did You Listen to This?

- We want to make QUIC measurements **easily accessible** to the research community!
  - QUIC-enabled Scamper currently deployed on test VPs: DE, NZ, US, UK, FR, PL, JP
  - Status: Merge into main Scamper codebase — *work in progress*
  - Available to the public soon!

- Currently working on my Master's thesis: **Analyzing QUIC deployments on the Internet**
  - **TLS features:** Cipher suites, certificates, PQC support
  - **QUIC features:** Deployed QUIC libraries, transport parameters
  - **Network features:** Handshake latency, anycast deployments

Which QUIC measurements would be most useful to you?

Which scanning features would add the most value for the community?

Bibliography

[1] Jana Iyengar and Martin Thomson. QUIC: A UDP-Based Multiplexed and Secure Transport. RFC 9000. 2021.

[2] Mike Bishop. HTTP/3. RFC 9114. 2022.

[3] TUM Chair of Network Architectures and Services. QScanner. https://github.com/tumi8/QScanner. 2022.

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[5] Martin Thomson and Sean Turner. Using TLS to Secure QUIC. RFC 9001. 2021.