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On the Interplay between TLS Certificates and QUIC Performance

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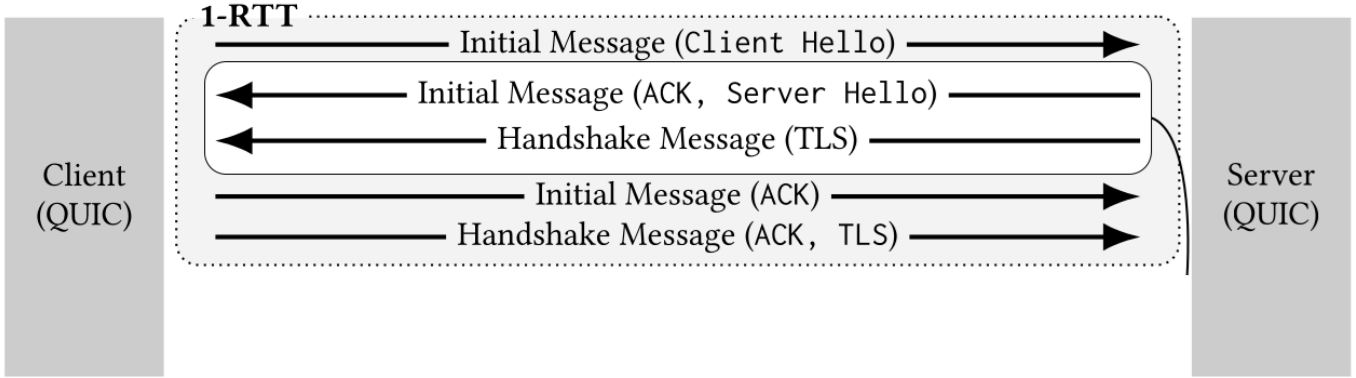
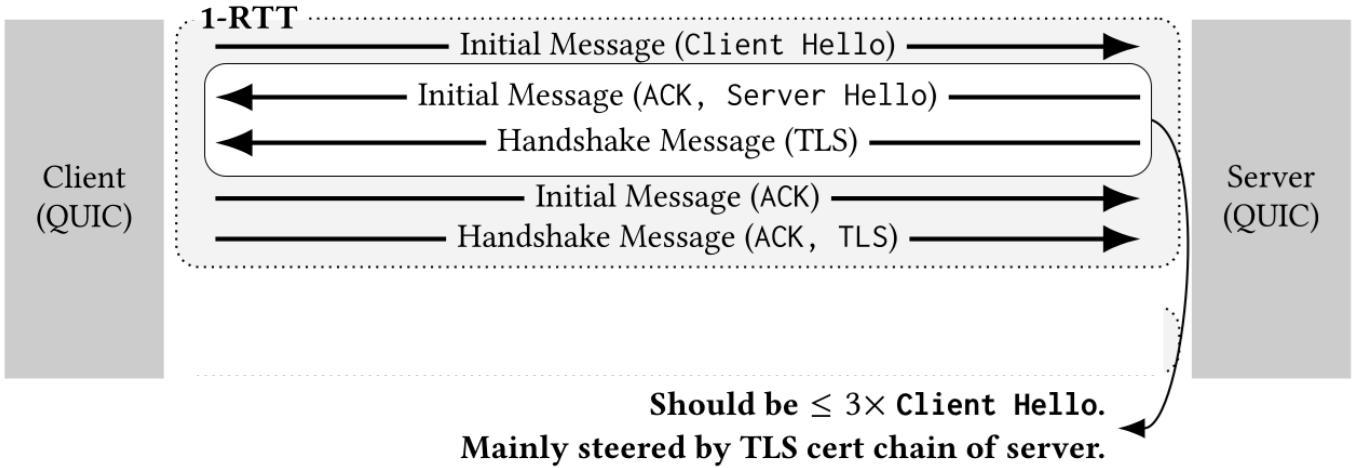
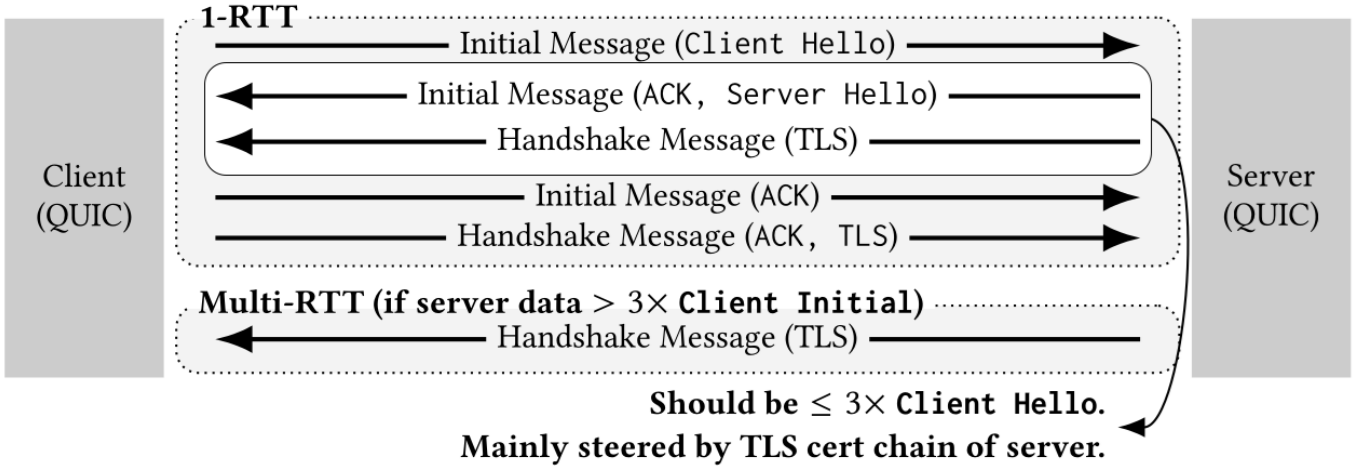
QUIC handshake design goal 1: Reduced round-trips.



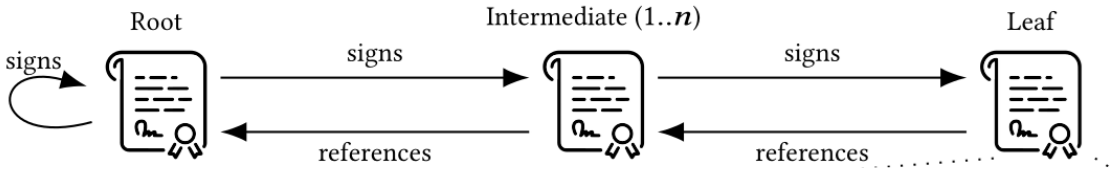
QUIC handshake design goal 2: Reduced amplification.



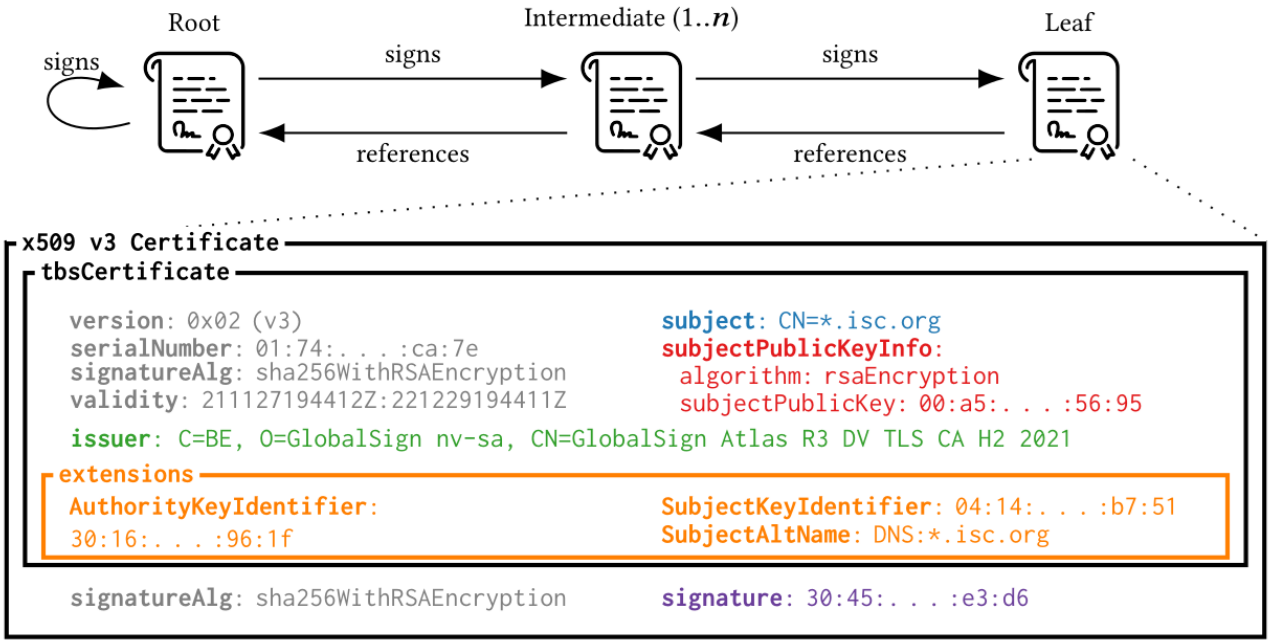
Multi-RTT handshakes validate clients but are inefficient.



A lot of TLS data? Certificates are delivered as a chain.



A lot of TLS data? Large keys, alternative names, *etc.*



Agenda

Hypergiants purposefully ignore the anti-amplification.

This enables clients to estimate a precise RTT.

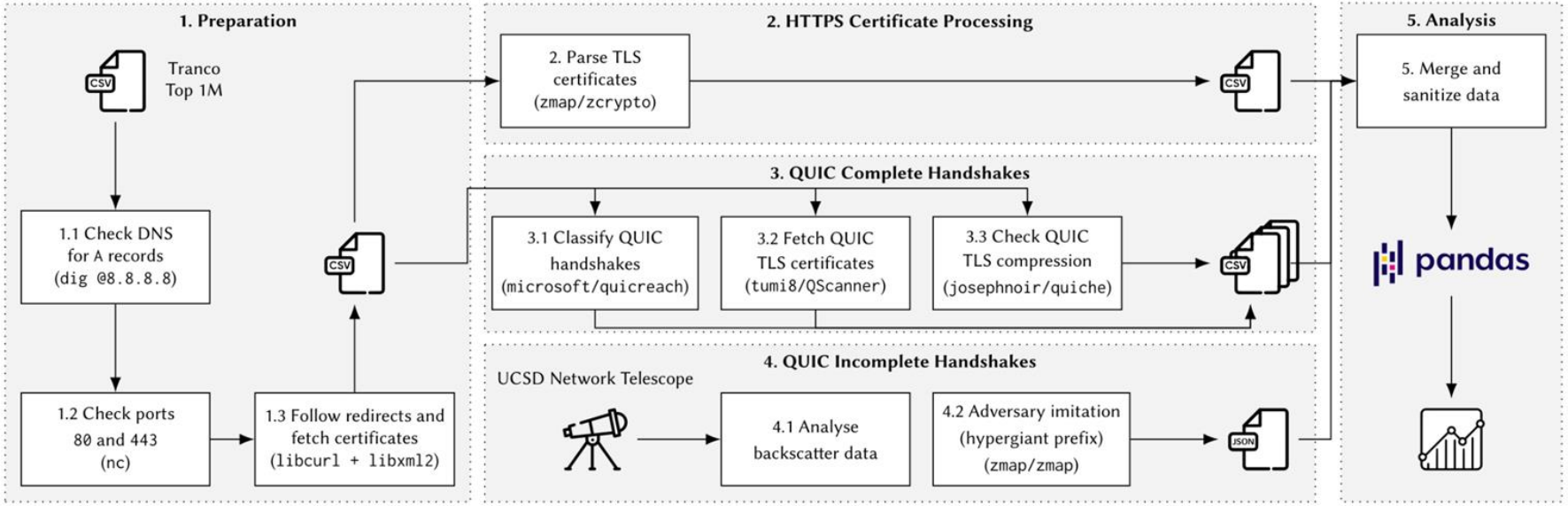
TLS data still interferes with QUIC performance.

Improvements such as compression hard to integrate.

Incomplete QUIC handshakes amplify up to 45x.

Server retransmissions can lead to adverse effects.

Methodology: Active scans with open-source tools.



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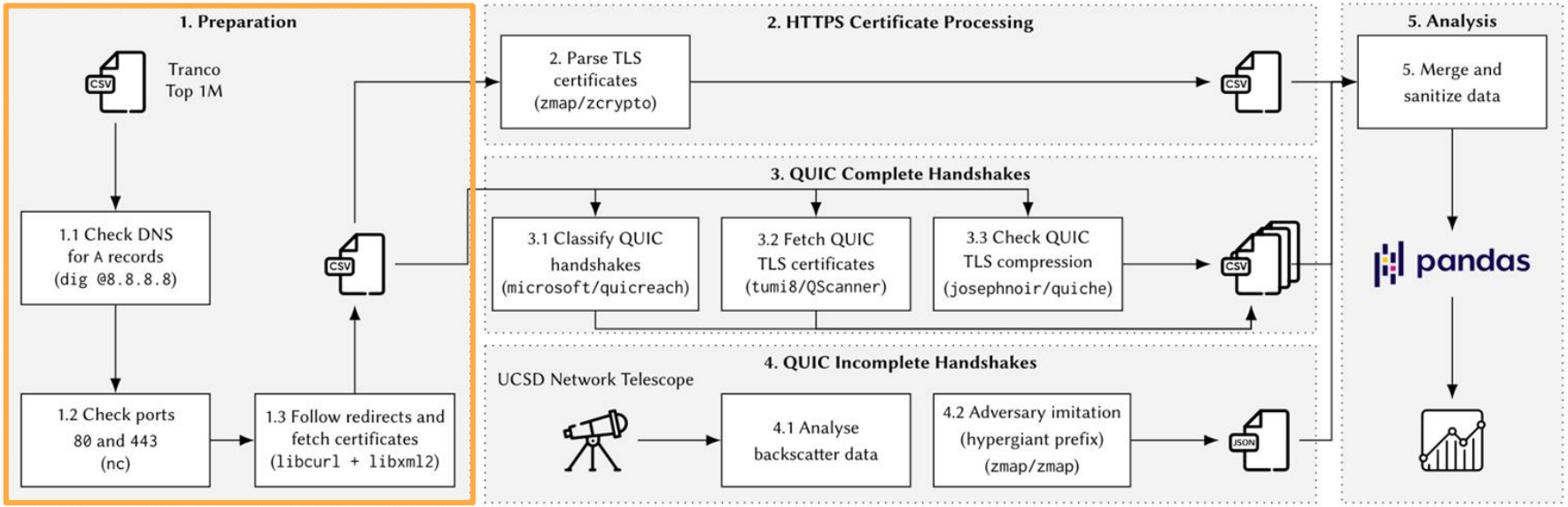

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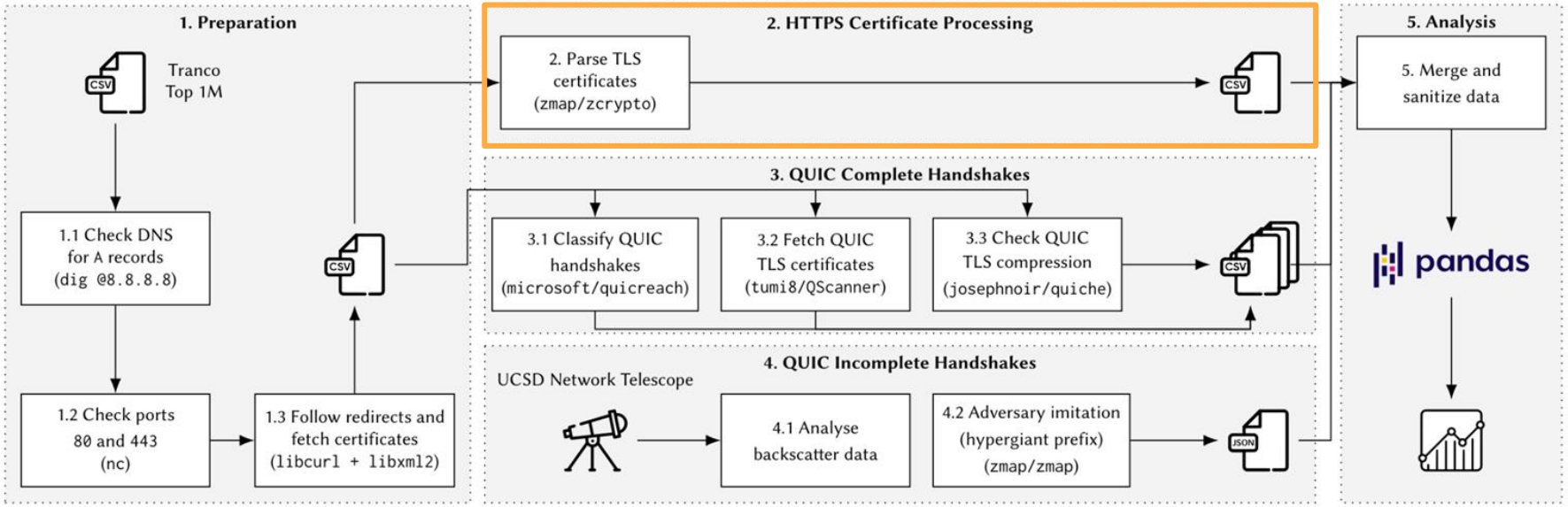

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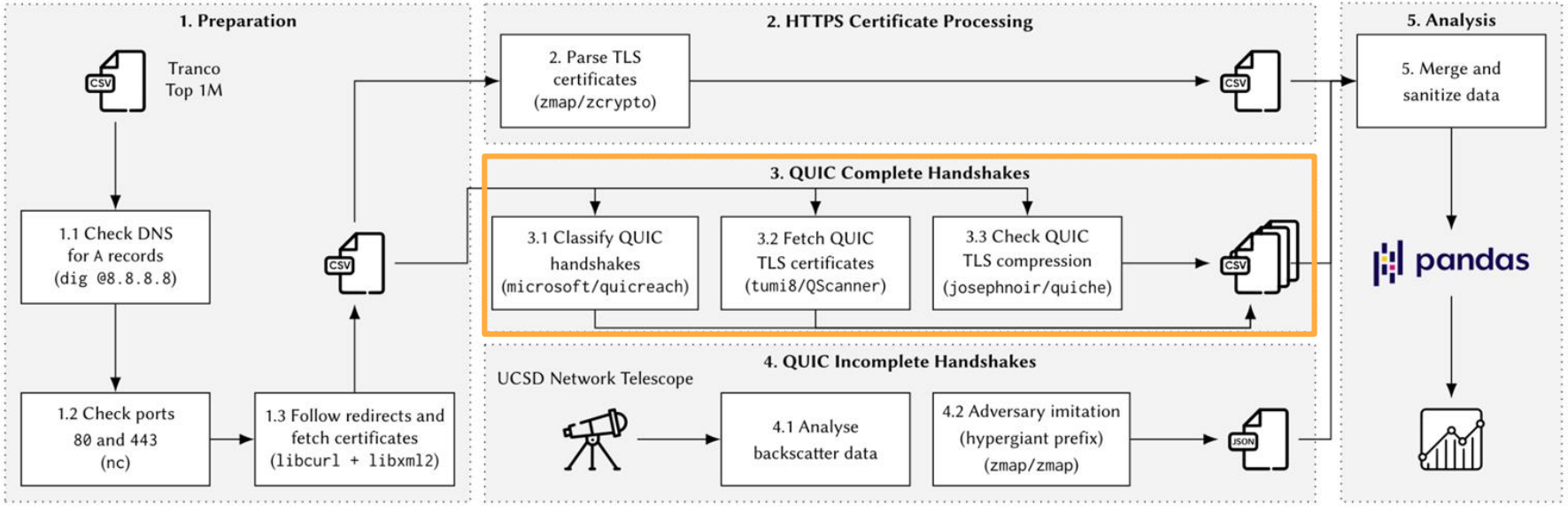
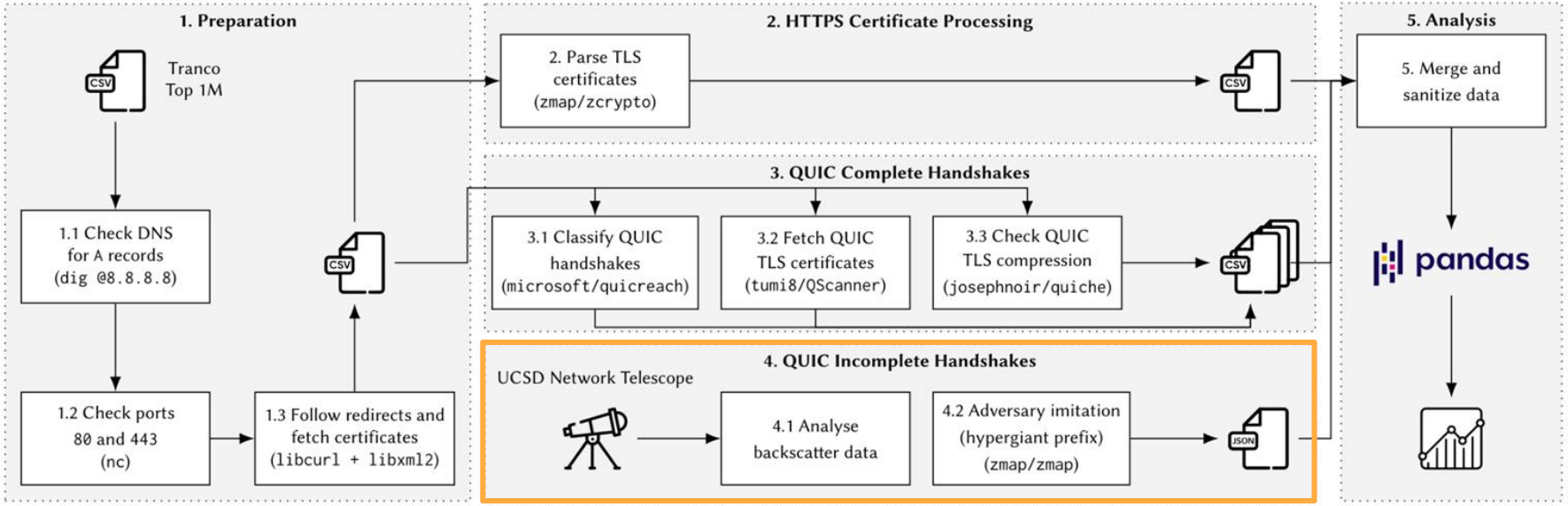


Complete handshakes enable the assessment of real-world performance.

Methodology: Active scans with open-source tools.

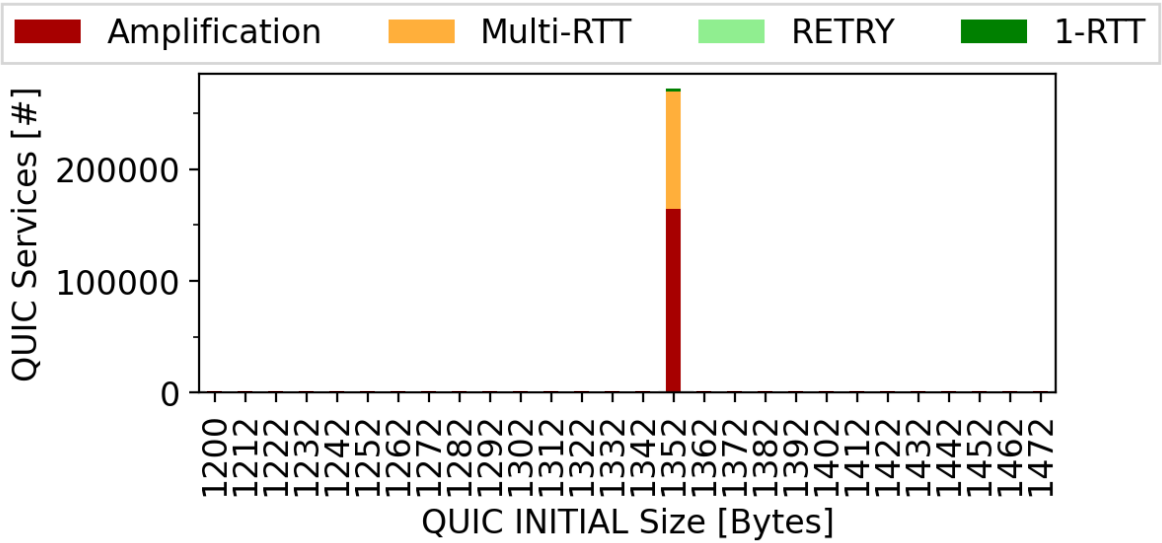


Incomplete handshakes unveil total susceptibility to reflective DDoS attacks.

Classifying QUIC complete handshakes.

(1) **1-RTT (optimal):** Handshakes that complete within 1-RTT and comply with the anti-amplification limit.
(2) **RETRY (less efficient):** Handshakes that require multiple RTTs because the `Retry` option is used [23, §8.1.].
(3) **Multi-RTT (unnecessary):** Handshakes that do not use `Retry` but require multiple RTTs because of large certificates.
(4) **Amplification (not RFC-compliant):** Handshakes that complete within 1-RTT but exceed the anti-amplification limit.

RFC-compliant 1-RTT handshakes are rare!



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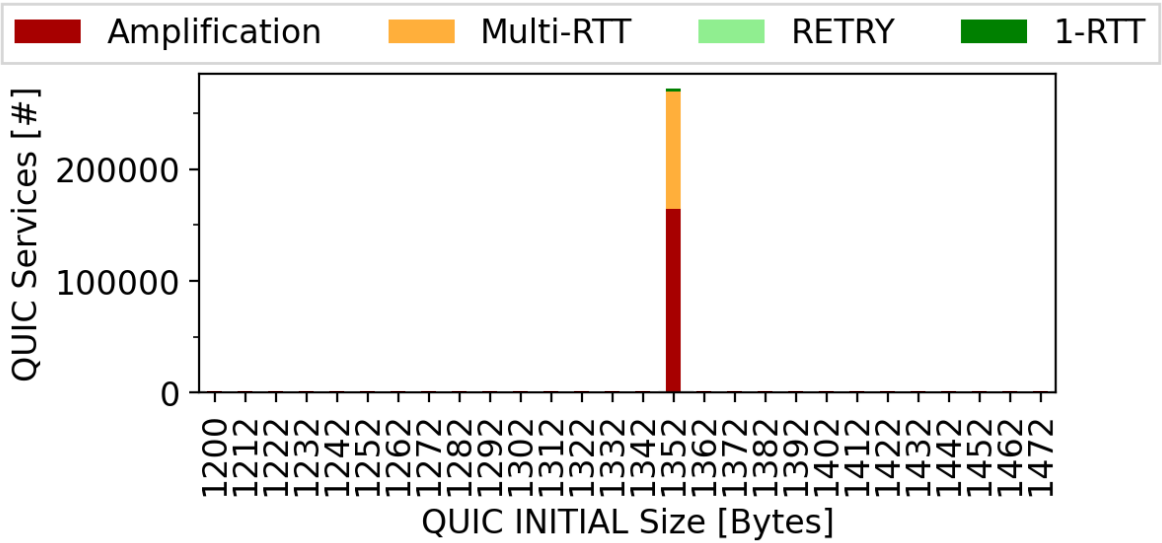
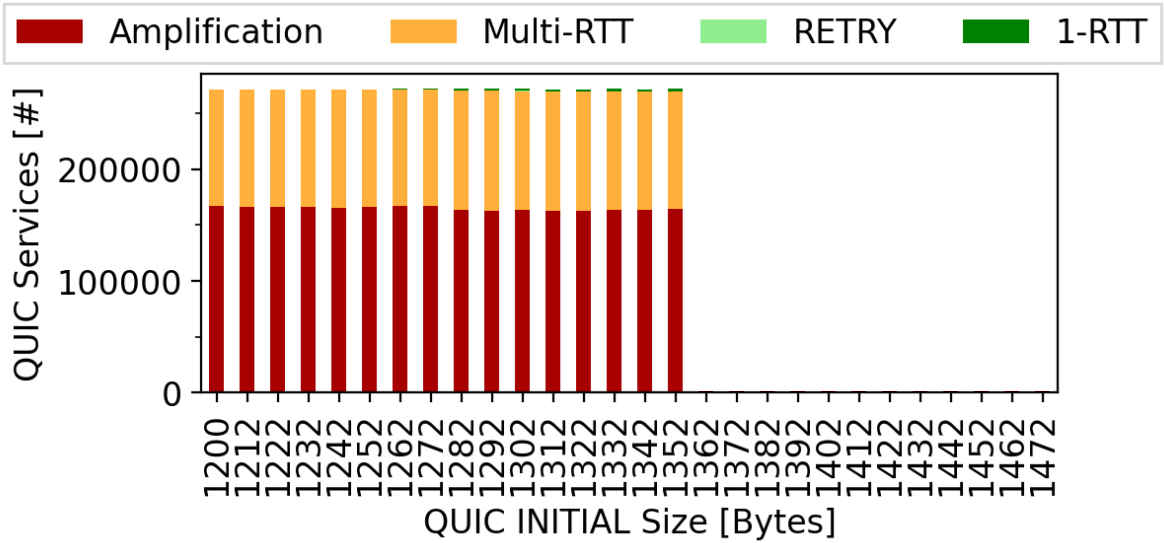


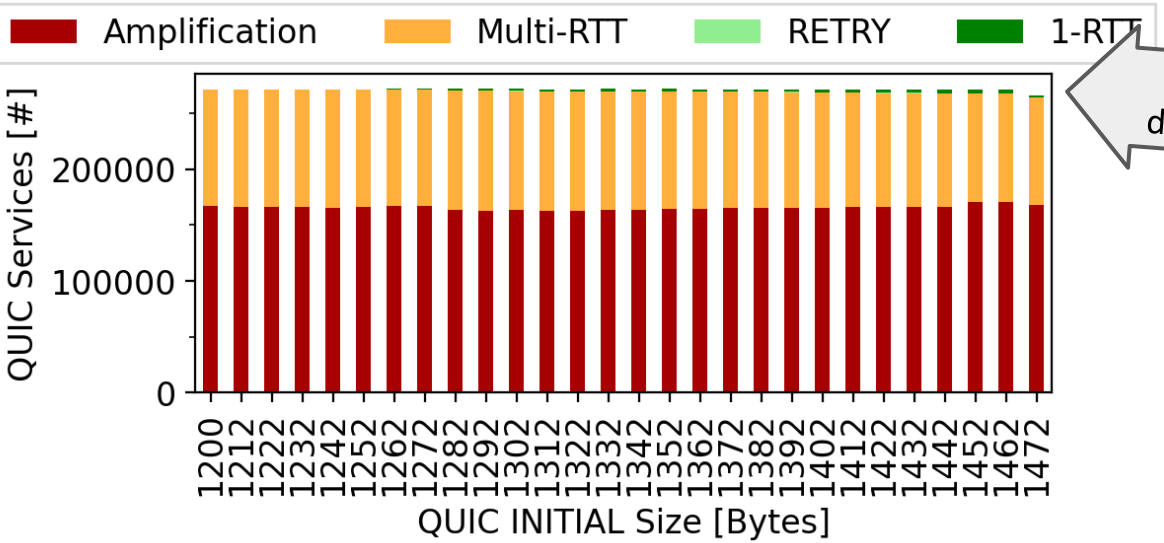
Browser Defaults

Smaller client INITIALs lead to multiple RTTs.



Browser Defaults

Very large client INITIALs reduce reachability.



25% of the top 1k domains unreachable!

Browser Defaults

Agenda

Hypergiants willingly ignore the anti-amplification.

This enables clients to estimate a precise RTT.

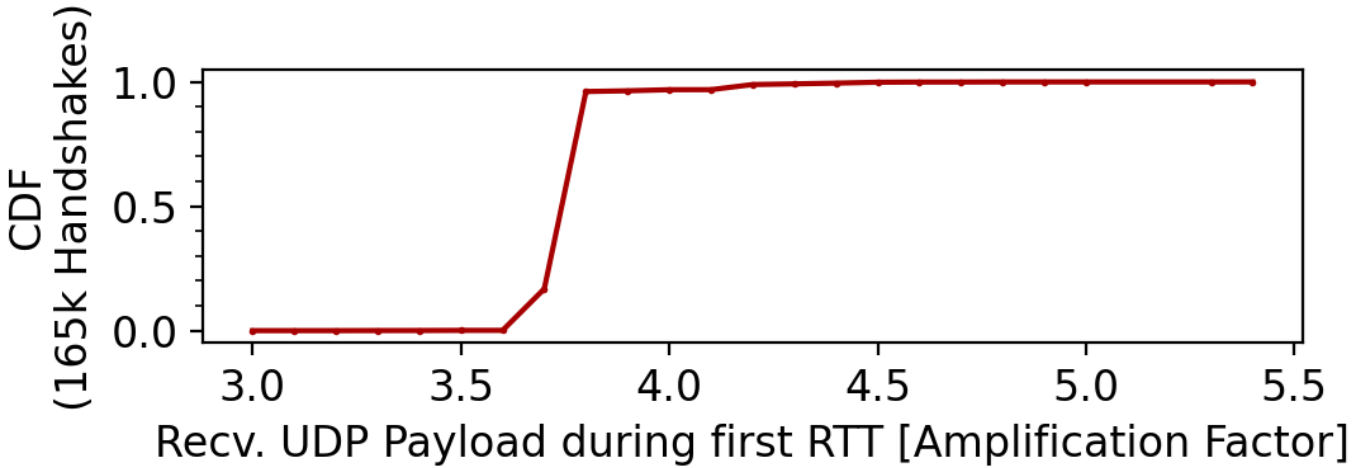
TLS data still interferes with QUIC performance.

Improvements such as compression hard to integrate.

Incomplete QUIC handshakes amplify up to 45x.

Server retransmissions can lead to adverse effects.

How bad are the amplifying handshakes? Not bad.



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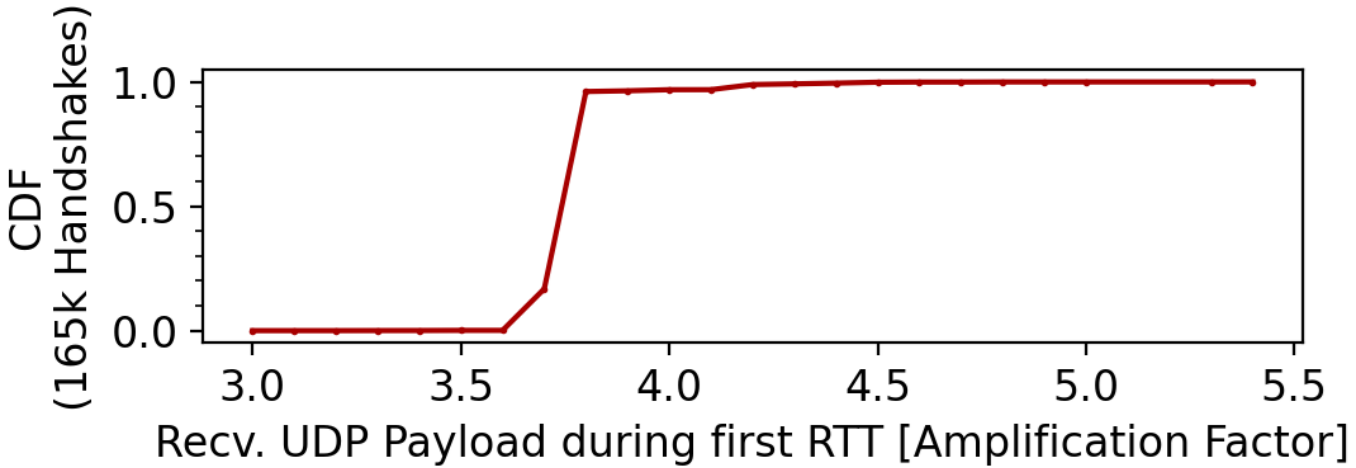
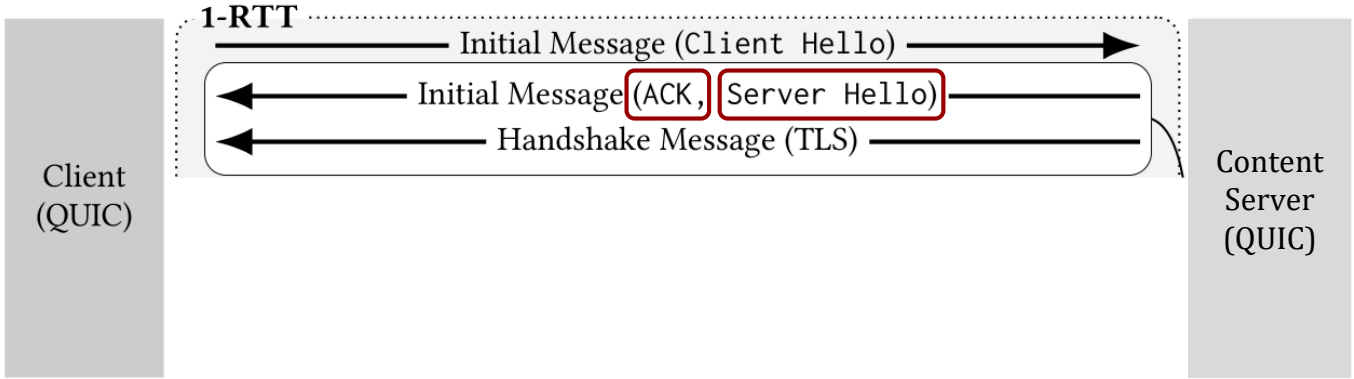


96% of the amplifying handshakes are completed with Cloudflare servers.

Hypergiants split server Initials! Fast responses enable correct minimum RTT estimates.



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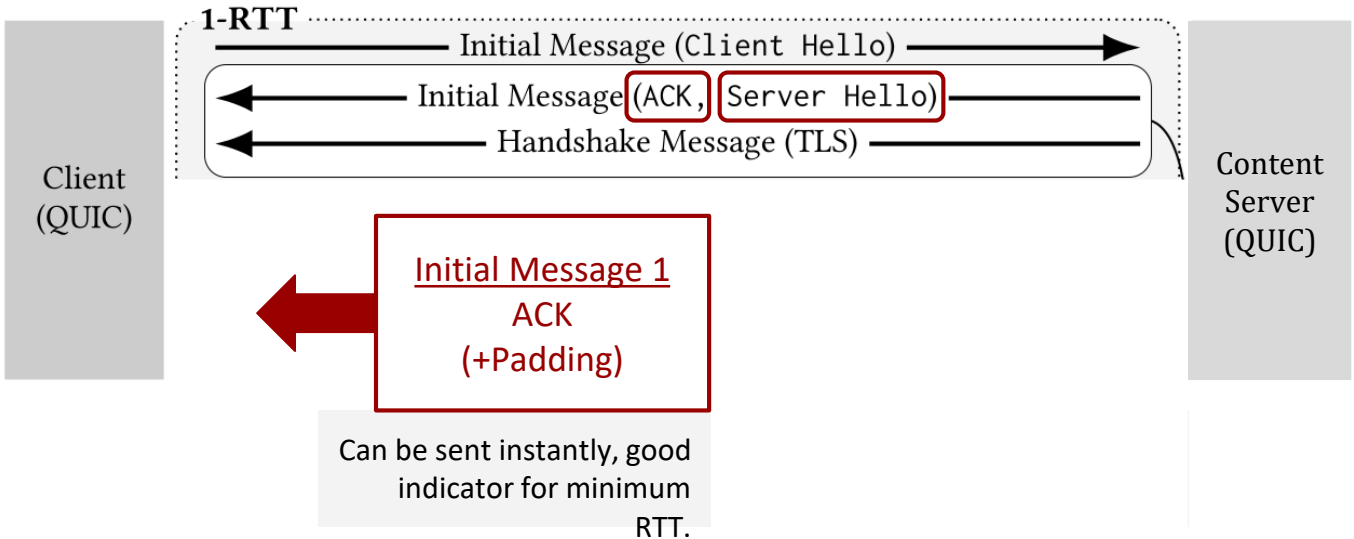

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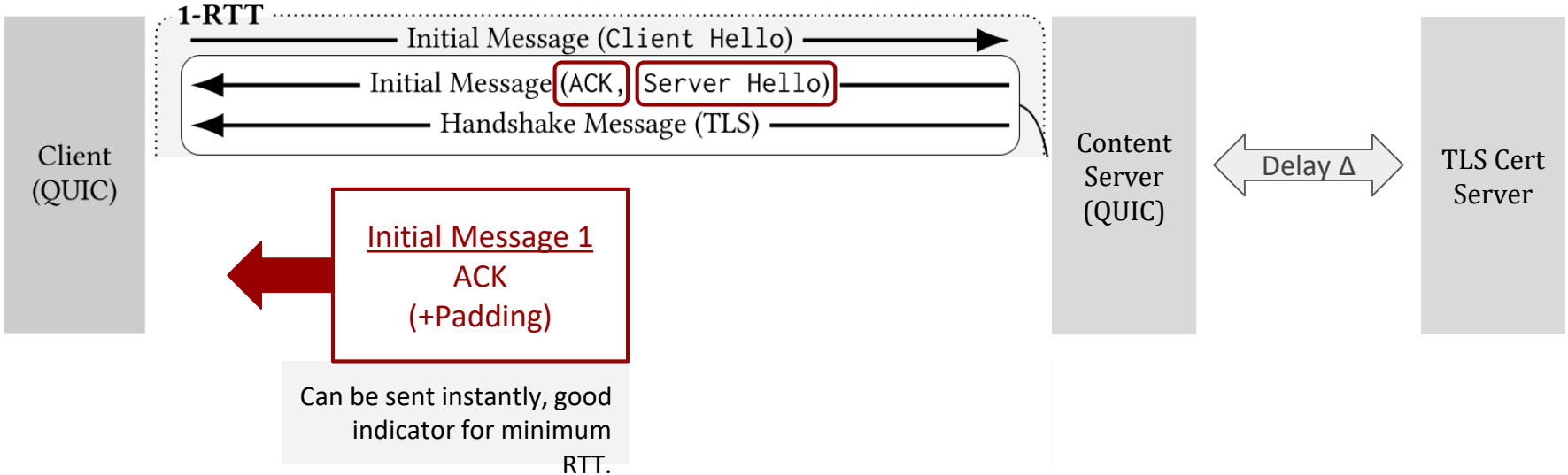

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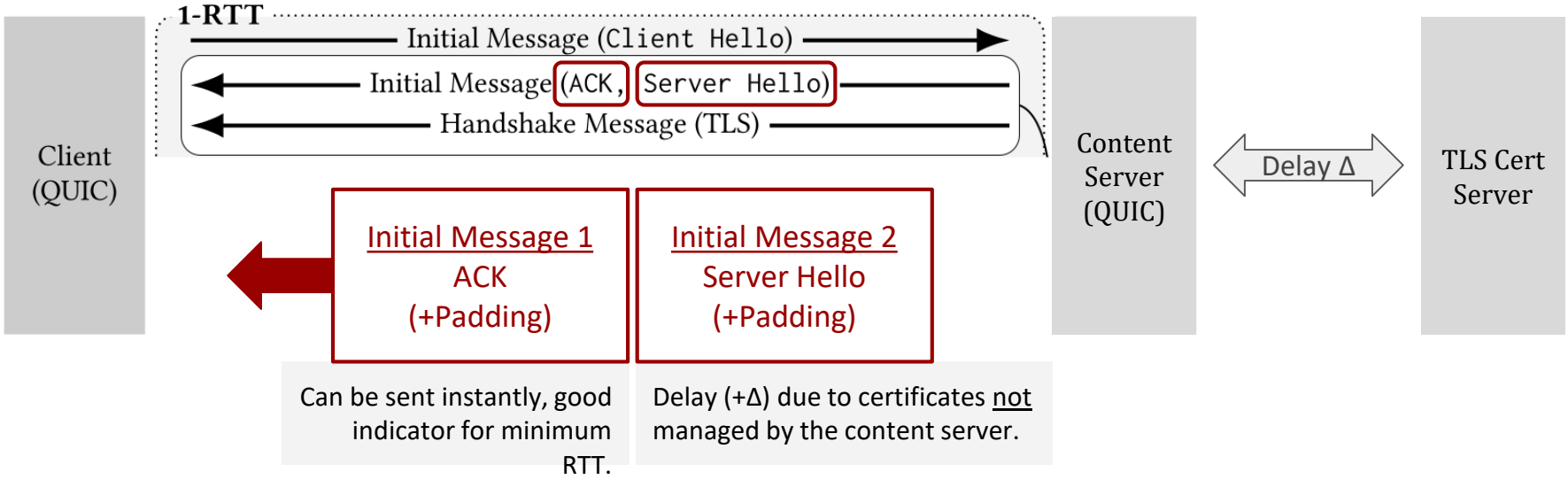

Hypergiants split server Initials! Fast responses enable correct minimum RTT estimates.

Instant ACK prevents inflated RTT estimates, which keeps Probe Timeouts low.
Padded ACK confirms that reverse path supports large packets.

With two padded Initials, this leads to amplification (≈4x).
Cloudflare tolerates this non-standard behavior for the sake of 1-RTT.

RTT.

server.

Agenda

Hypergiants willingly ignore the anti-amplification.

This enables clients to estimate a precise RTT.

TLS data still interferes with QUIC performance.

Improvements such as compression hard to integrate.

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What causes **multiple RTTs**?

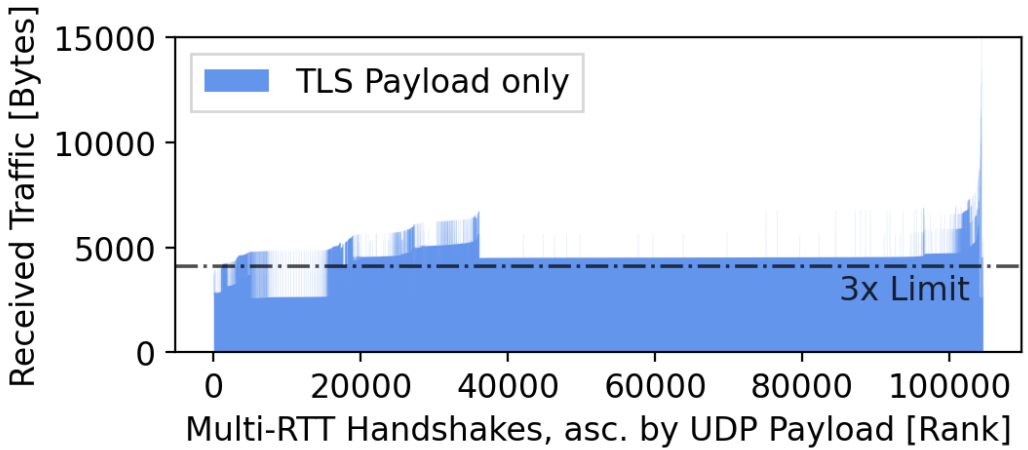
DDoS prevention
(RETRY tokens)

< 200 domains.

Large TLS certificates
(that challenge the 3x limit)

The majority!

For multi-RTT handshakes, TLS bytes almost always (87%) exceed the limit but padding also has a significant impact.



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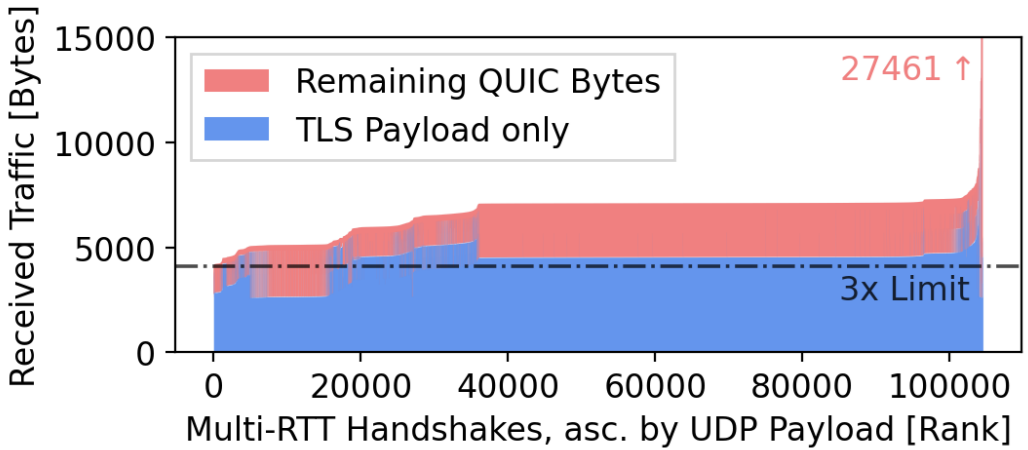
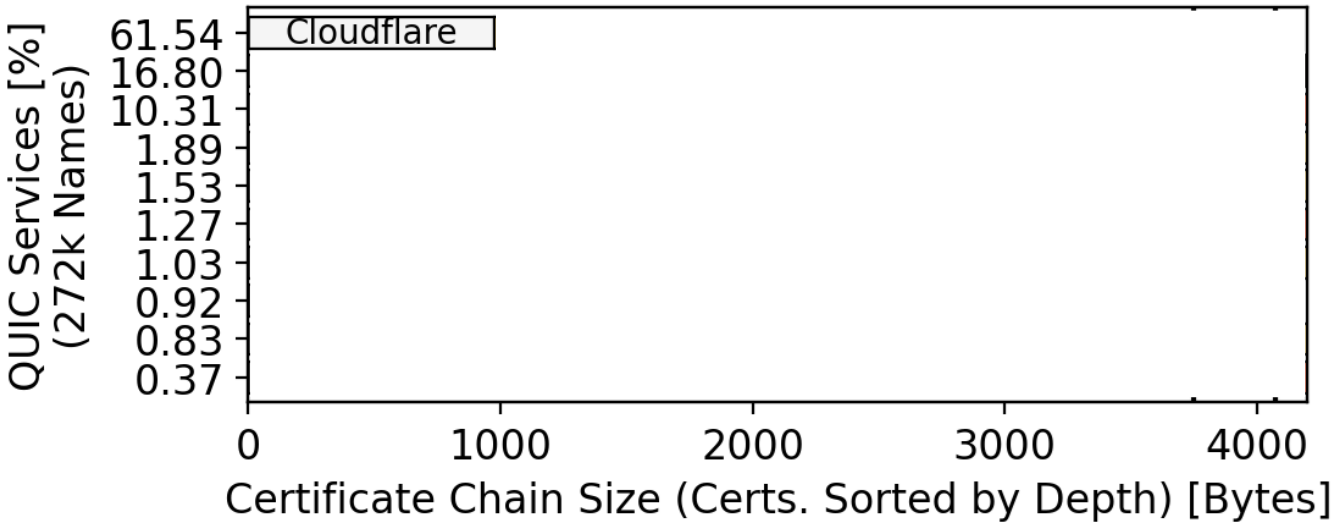
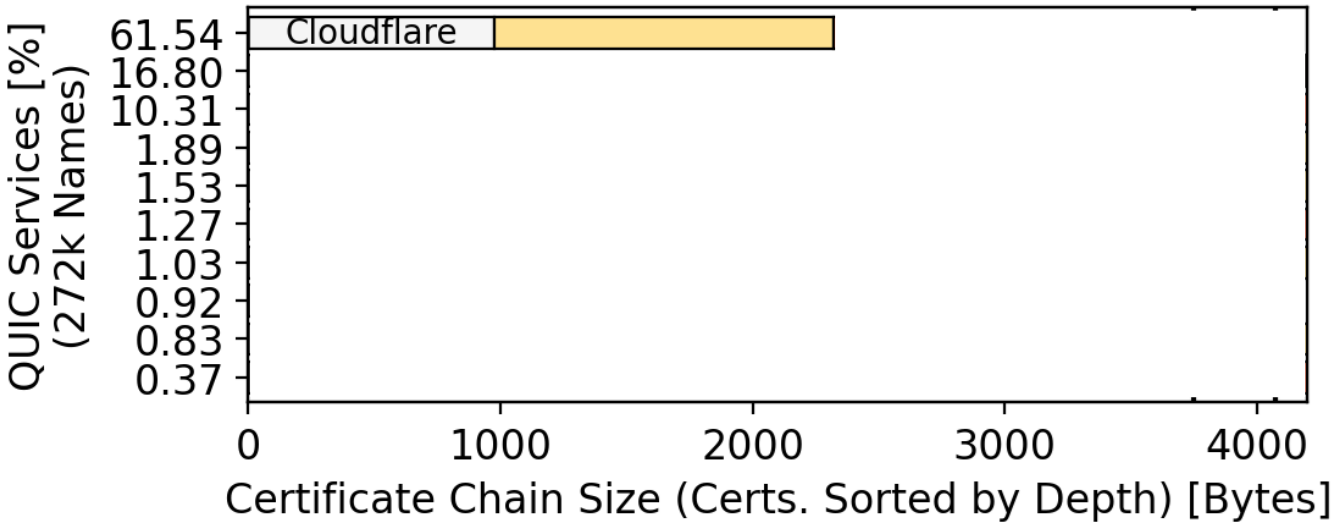


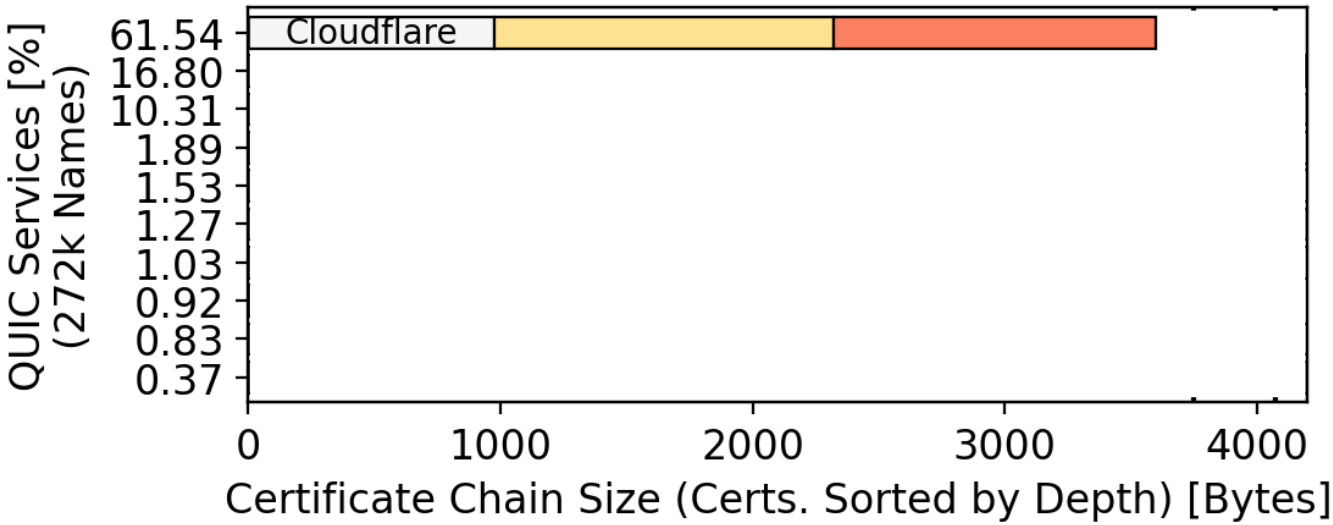
QUIC certificate chains. We look at non-leafs



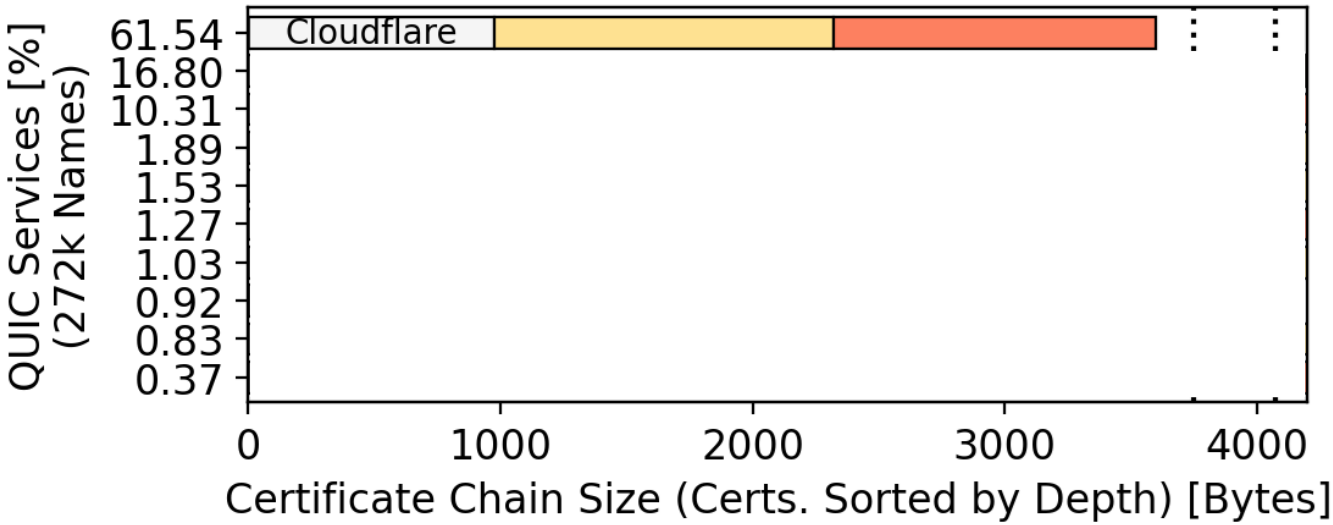
QUIC certificate chains. We look at non-leafs, median leaf sizes



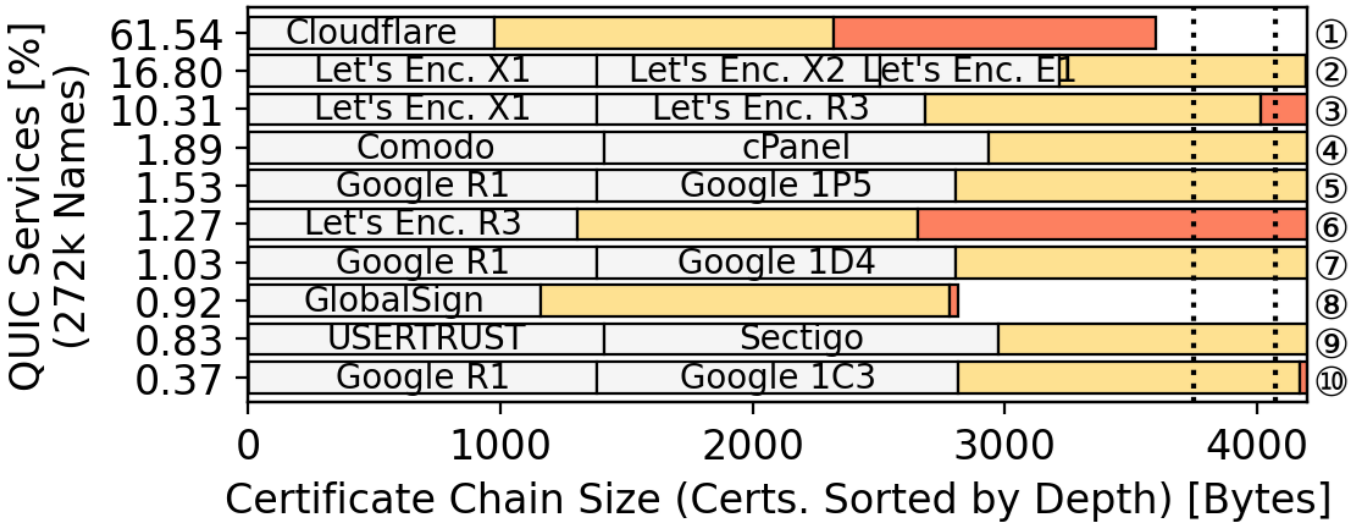
QUIC certificate chains. We look at non-leafs, median leaf sizes, extra bytes for maximum leaf



QUIC certificate chains. We look at non-leafs, median leaf sizes, extra bytes for maximum leaf, and common limits.



QUIC certificate chains. Median chains are likely to exceed common anti-amplification limits.



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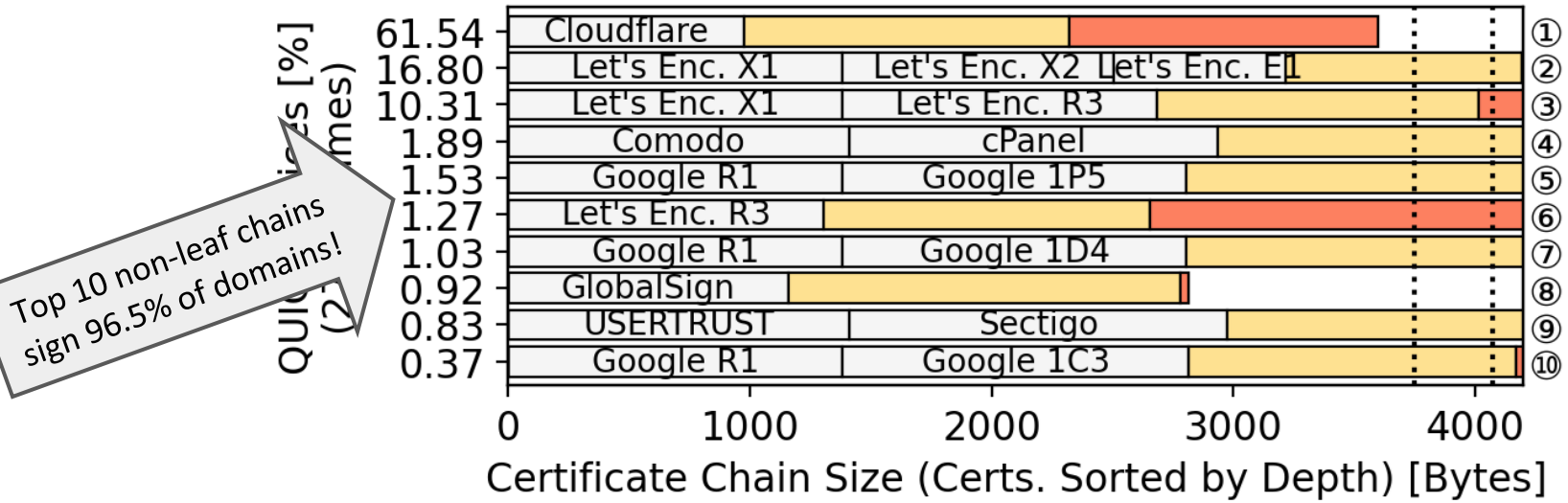
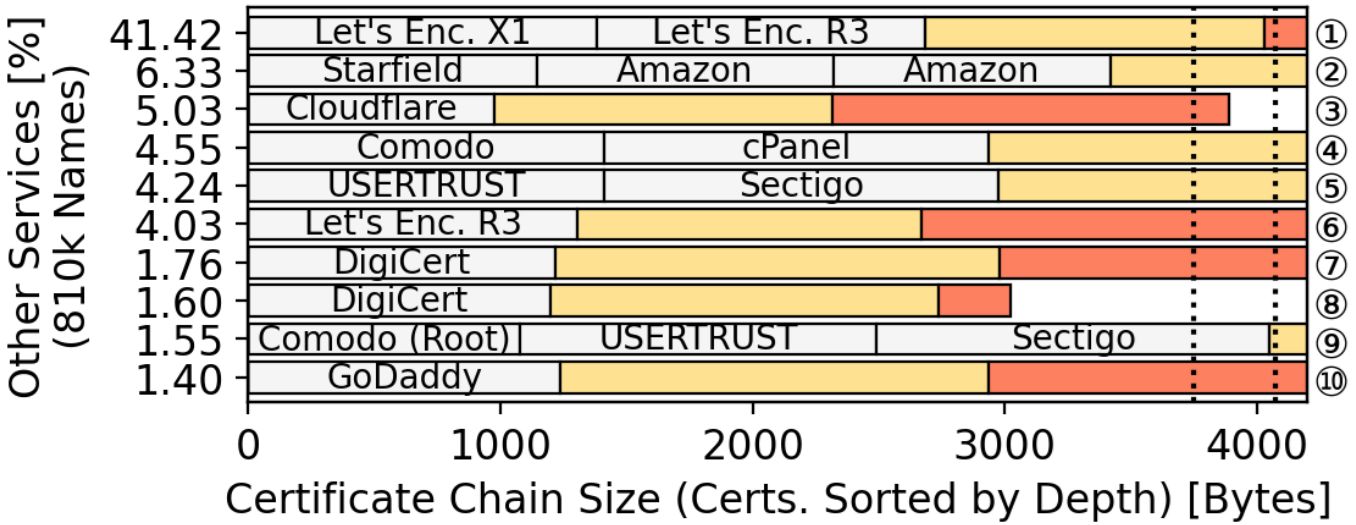


TCP/HTTPS-only services are less consolidated but still exceed the common limits.



How to compensate for large certificates?

Updating non-leafs (RSA → ECDSA) would have beneficial cascading effects.

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TLS certificate compression keeps 99% of data below anti-amplification limits.
Although we see high server support, clients and libraries struggle.

Agenda

Hypergiants willingly ignore the anti-amplification.

This enables clients to estimate a precise RTT.

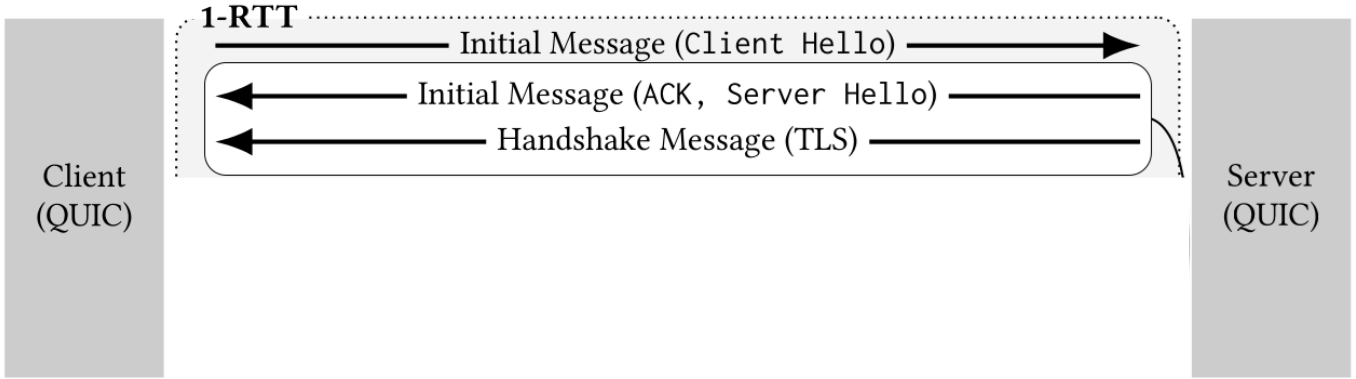
TLS data still interferes with QUIC performance.

Improvements such as compression hard to integrate.

Incomplete QUIC handshakes amplify up to 45x.

Server retransmissions can lead to adverse effects.

Amplification factors increase drastically for incomplete handshakes because of server retransmissions.



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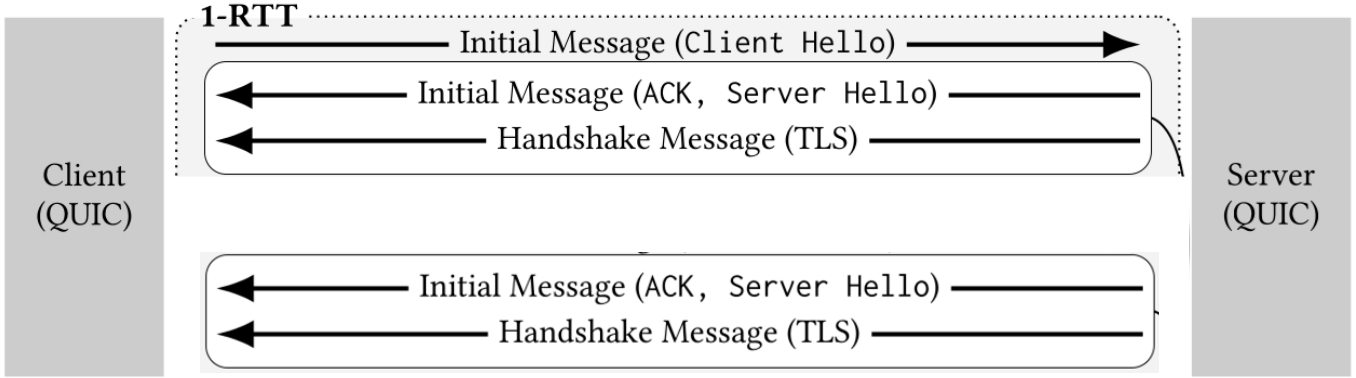

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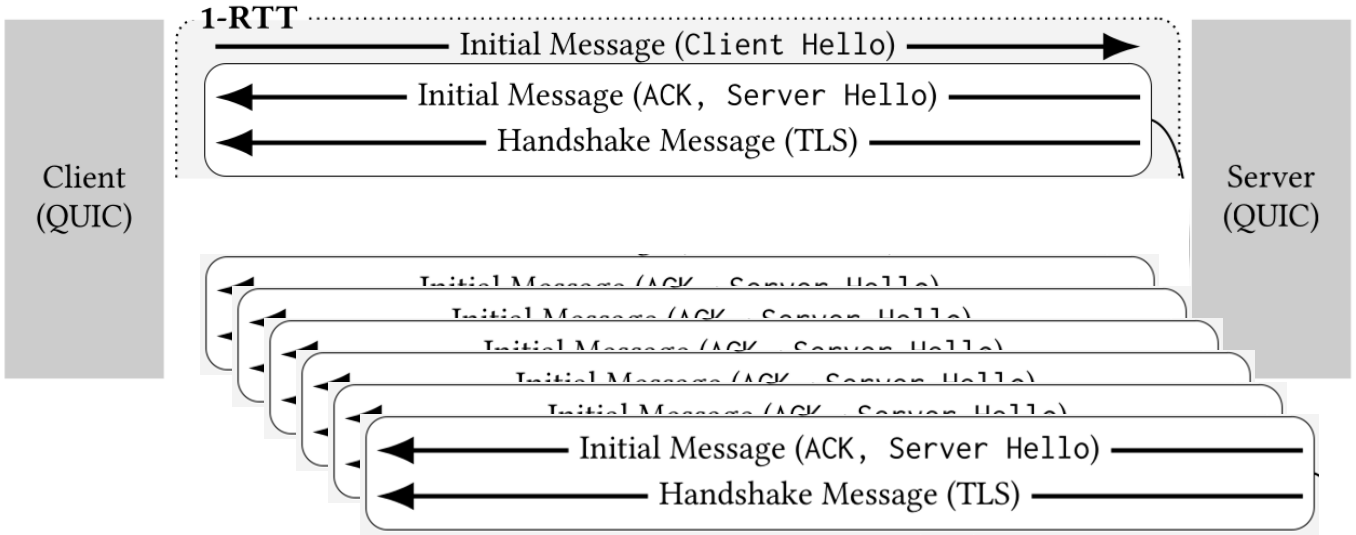

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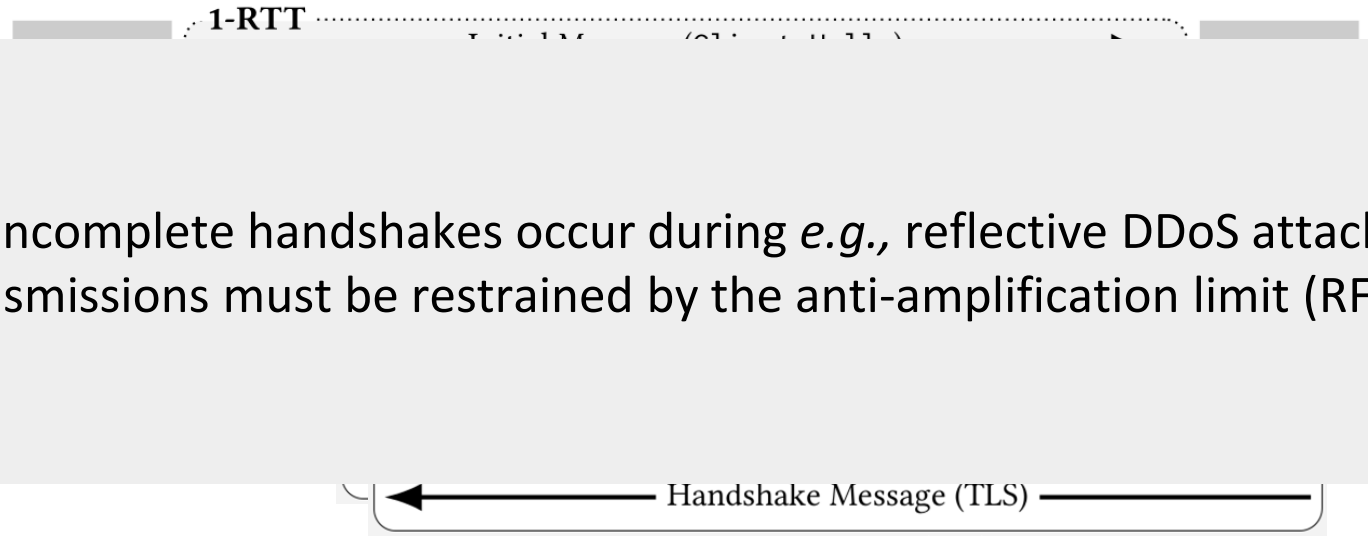
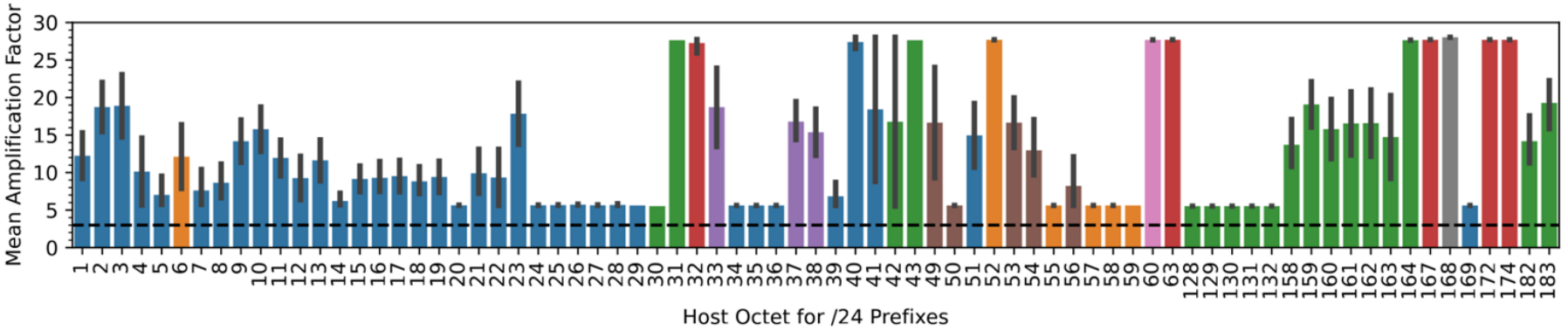
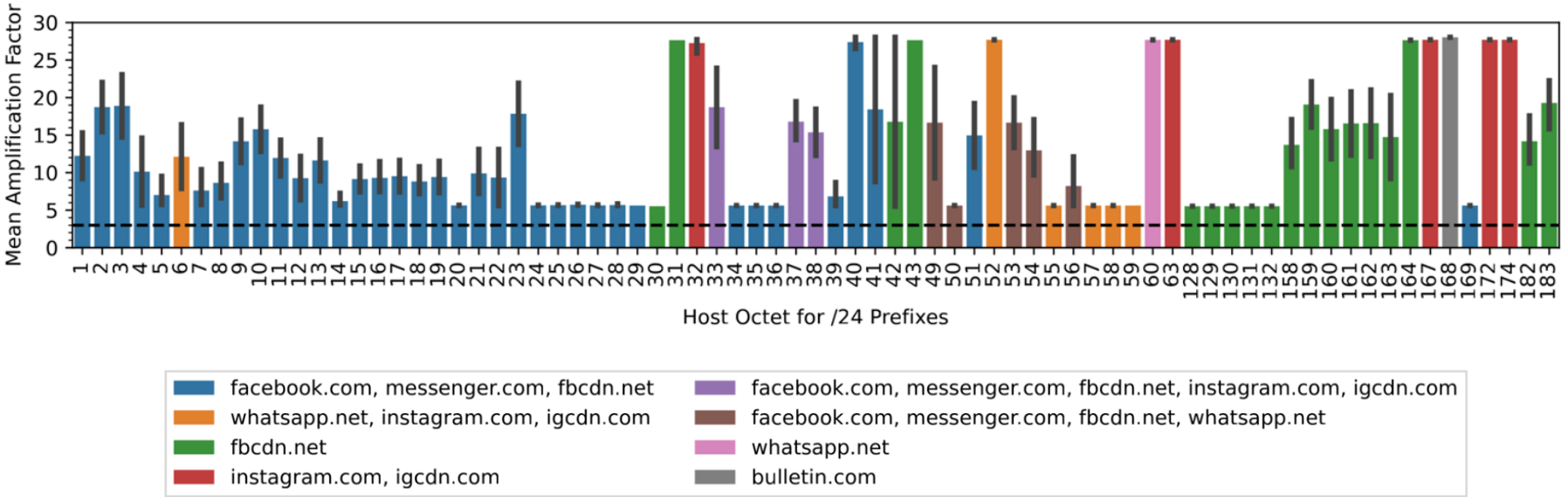


Incomplete handshakes occur during *e.g.,* reflective DDoS attacks.
Retransmissions must be restrained by the anti-amplification limit (RFC 9002).

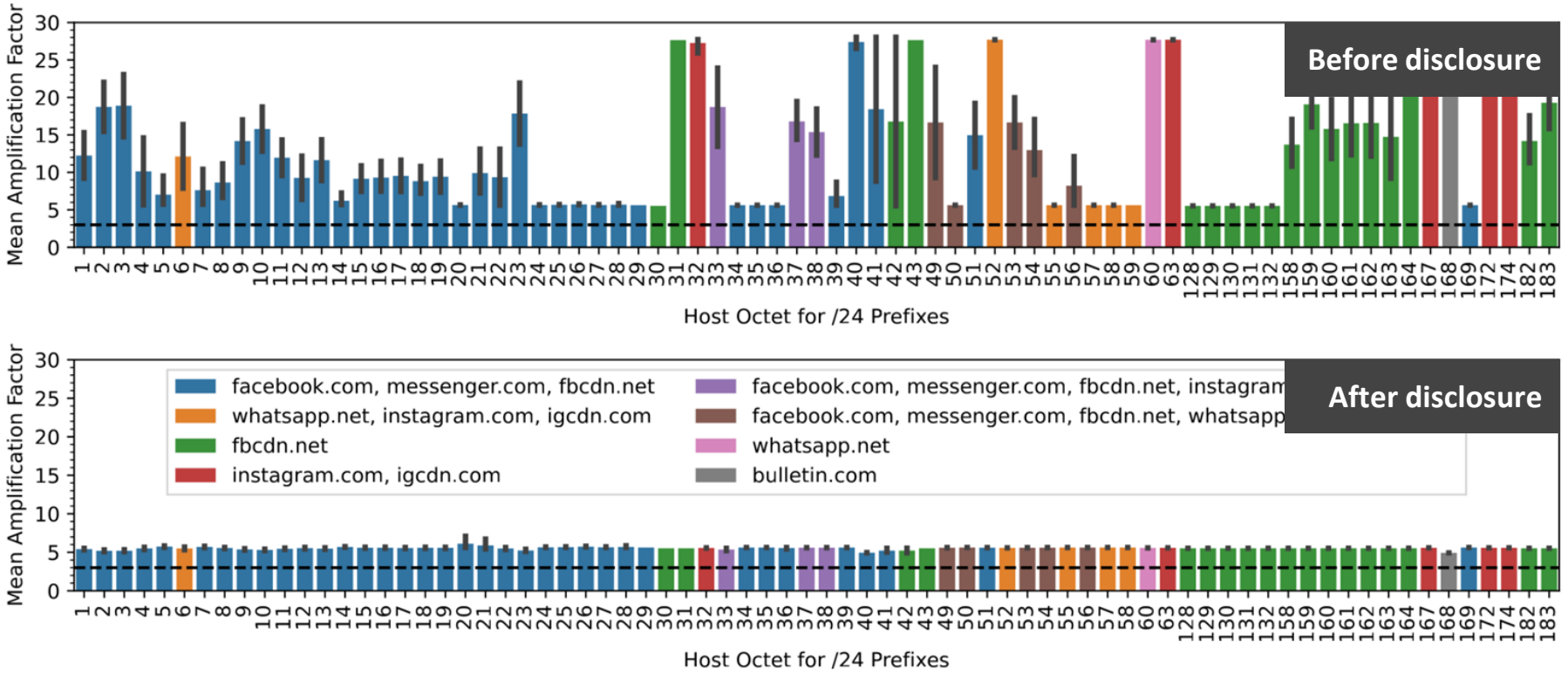
Amplification for incomplete handshakes with Meta PoPs



Amplification factors vary across different services.



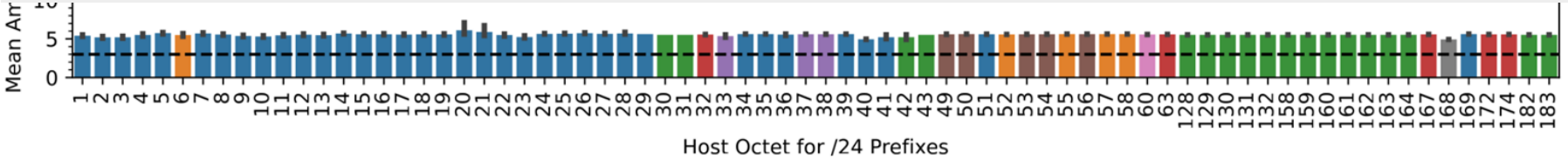
Scans after (responsible) disclosure show improvement.



Scans after (responsible) disclosure show improvement.

Large TLS data leads to large retransmits. Respecting the anti-amplification limit decreases the chances of loss correction.

Open challenge: How to deal with packet loss during the QUIC connection setup in a secure but efficient way?



Conclusion

TLS Certificate Ecosystem

TLS configurations have now direct impact on transport layer performance.

ECDSA certificates lead to substantially smaller certificates chains.

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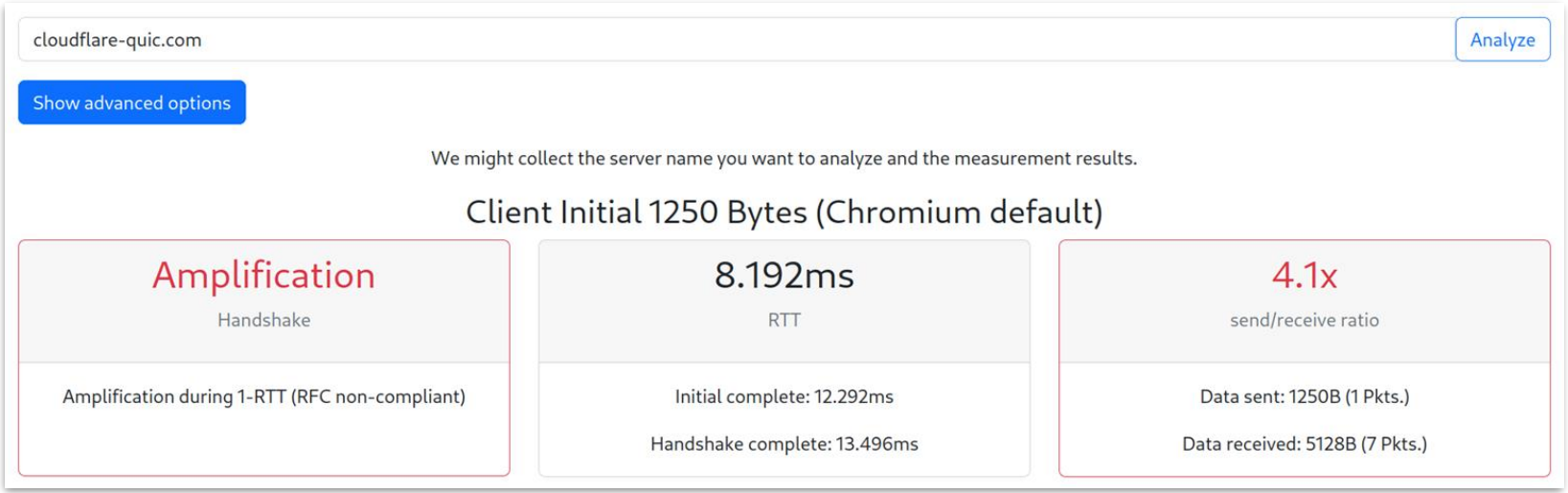
QUIC Deployments

Design goals (1-RTT, 3x anti-amplification limit) have been not met in the wild.

Trade-off during the handshake: Packet coalescence (less padding) vs. delay.

Padding and retransmissions significantly exacerbate the amplification factor.

QUIC Handshake Classification API (IETF 115 Hackathon)



[https://understanding-quic.net]