Analysis of QUIC Session Establishment and its Implementations

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@pictyeye

Olivier Levillain

- M2 internship on the FORK-256 hash function (2006)
- member of the systems security lab at ANSSI (2007-2012)
- head of the network security lab at ANSSI (2012-2015)
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Research

- low-level security mechanisms in x86 CPUs (ACPI, SMM)
- PhD on SSL/TLS
- studies on the langages
- work on *parsers* and on network protocol implementations

Documents and tools

`https://paperstreet.picty.org`

- my PhD manuscript (if you are into TLS)
- articles and slides for most of my contributions and seminars

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Active software projects

- Parsifal, a parser generator written in OCaml
  - https://github.com/picty/concerto
- Concerto, a tool to analyse TLS campaigns and certificate chains
  - https://github.com/picty/parsifal
- Wombat, one more Bleichenbacher toolkit
  - https://gitlab.com/pictyeye/wombat

The GASP project

a Generic Approach to Secure network Protocols (2019-2022)

- description of protocol messages using simple languages
- network scans at large to better understand real world ecosystems
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- a platform to test and compare parser generators
- experimentations to fuzz existing state machines with $L^\star$
  - reproduction of existing results on TLS
  - extension to the discovery of Bleichenbacher oracles
  - performance improvement
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Most of the material presented here comes from the work from Eva Gagliardi (2019 internship) and was presented at WISTP last December

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The experiments were made against `draft-23` implementations and may not accurately reflect on the current state of the ecosystem (current version is `draft-28`, mostly with minor changes regarding the session establishment)

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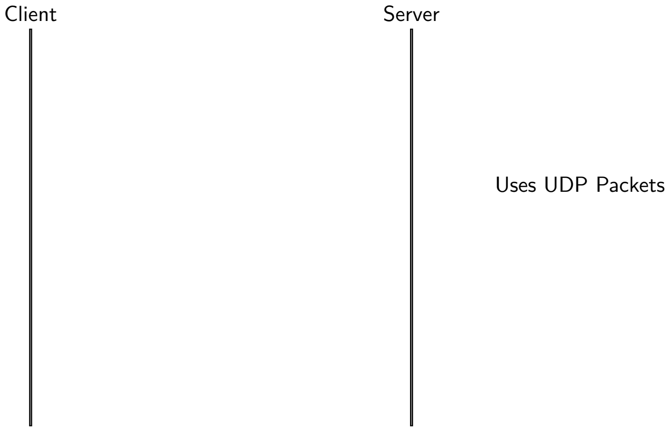
Warning: this presentation is about IETF QUIC only

A Typical QUIC Connection



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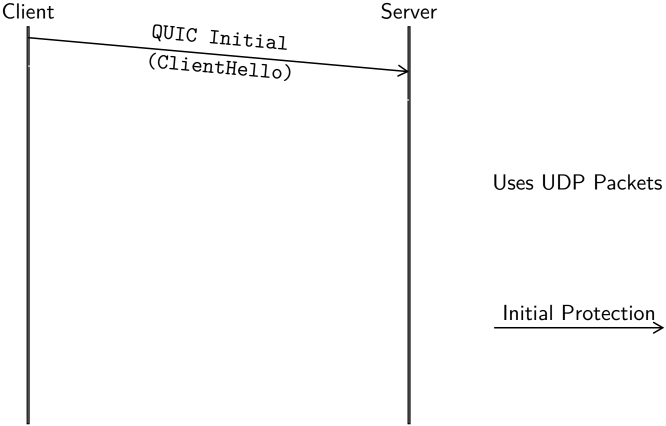

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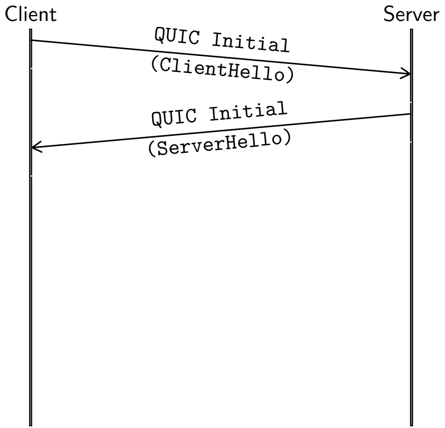

Uses UDP Packets

Initial Protection

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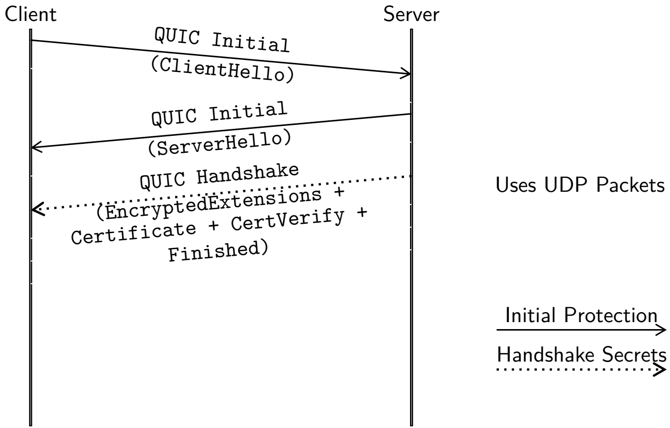

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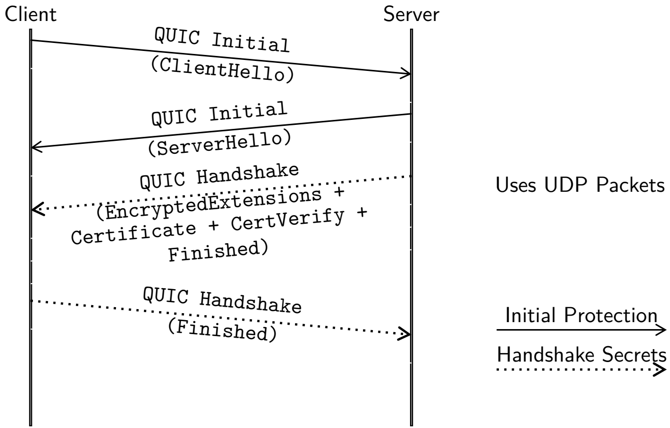

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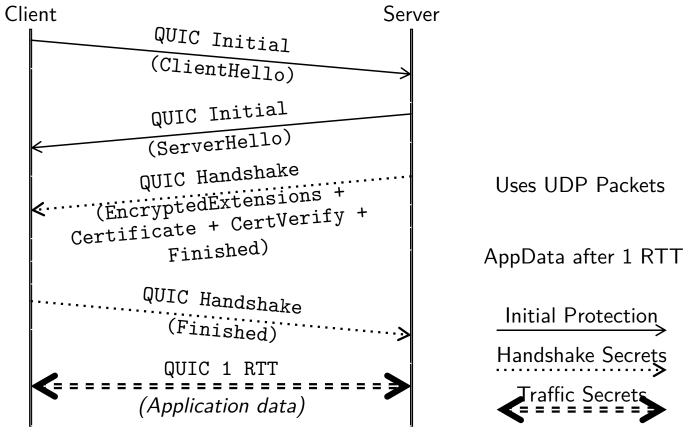

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However, do not forget that TCP is not slow on purpose, and that connection-oriented communications have benefits

Variants from the Happy Path

Version Negotiation

- in case the server does not like the client version
- the server sends its supported versions in a `VersionNegotiation`
- and the client has to come back

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TLS 1.3 Hello Retry Request

- if the TLS 1.3 `ClientHello` does not contain sufficient information
- the server Initial Packet will contain a TLS 1.3 `HelloRetryRequest`
- and the client has to come back with an updated `ClientHello`

QUIC Main Goals and Features

Performance properties

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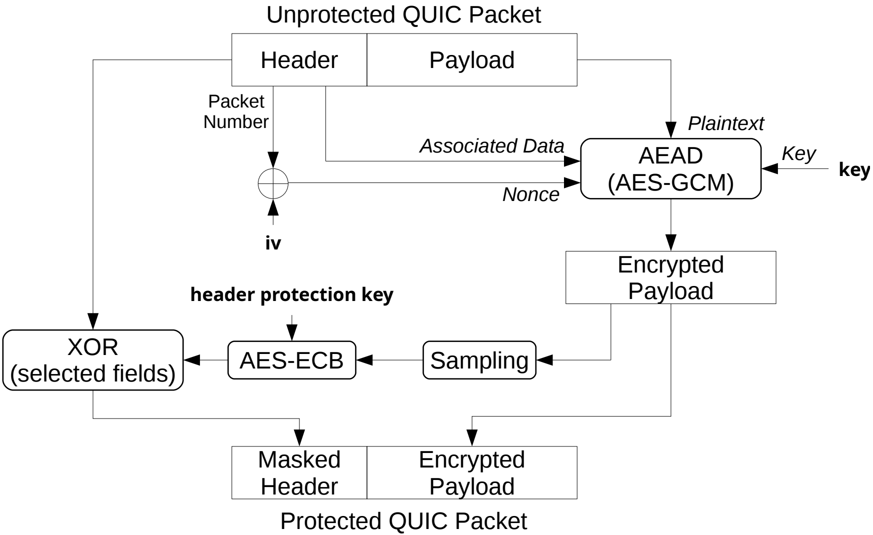
Compatibility with internet (debatable)

- detailed description of the protocol invariants across versions
- encrypt as much as possible (only parts of the header are in cleartext)

A Convoluted Procedure



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Expected benefit from the WG (highly debatable)

- protection against off-path attackers
- robustness against QUIC version-unaware middleboxes

Header Protection Keys

Parts of the Header are also protected

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Expected privacy benefit

- today, the only protected field is the Packet Number
- masking it should help provide unlinkability in case of address migration

Implementation of the Initial Exchange with Scapy (1/2)

Protecting a QUIC packet

1. build the header from its fields
2. build the payload from its fields
3. pad the payload so the packet size is long enough
4. report the payload length in the header to take the padding into account
5. derive secrets and IVs from the version and the DCID
6. derive the nonce from the IV and the Packet Number
7. encrypt the payload
8. extract the sample
9. encrypt the header

Implementation of the Initial Exchange with Scapy (2/2)

The protection procedures mix three types of steps

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We believe this mechanism offers limited benefits (restricted attacker model, cooperating middleboxes) which does *not* justify the induced complexity

Test Servers

In the QUIC WG wiki, existing implementations are listed

- 16 different stacks are listed
- corresponding to 20 public servers

We led measurement campaigns (related to different draft versions)

- several servers never answered any stimuli
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Warning: the presented results are partial data on still evolving implementations

Version Negotiation

Stimuli

1. a valid Initial Packet with a supported draft version
2. packet 1 with a yet-to-be defined version
3. a truncated version of packet 2

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Actual result
Several servers choke on the third packet, which shows that they interpret the packet length field, although this field could be redefined in the future (cf. `draft-quic-invariants`)

Client Initial Packet Length

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Observations

- several servers accept 300-byte long stimuli
- but only answer with up to 900 bytes

This is not ideal, nor dramatic.

Missing Parameters

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Deviations

- the sample packet in the draft does not conform to the requirements
- several implementations accommodate missing extensions
- one implementation only accepted our stimuli without ALPN

Frame Mangling

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- and even a Crypto frame inconsistently split!

Conclusion

- QUIC is a protocol still under development
- It is worth studying, since it could become an important part of the web traffic
- It is a complex beast

From the implementation point of view

- we wrote a first implementation of the protocol in Scapy
- we scanned public servers with corner case stimuli
- no server seems to conform to all the requirements we looked at
- *however, these stacks are fast-evolving implementations of a moving target*

Future work

Regarding our Scapy implementation

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Possible collaborations (or internships) if you (or your students) are interested

Questions?

Thank you for your attention

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