Penetration Testing of HTTP/3.0 Servers

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Table of Contents

1. Introduction
2. Literature Survey
3. Motivation
4. Problem Statement
5. Proposed Work
6. Experimental Setup
7. Work Done
8. Experimental Results
9. Conclusion
10. References

Introduction

HTTP Protocols

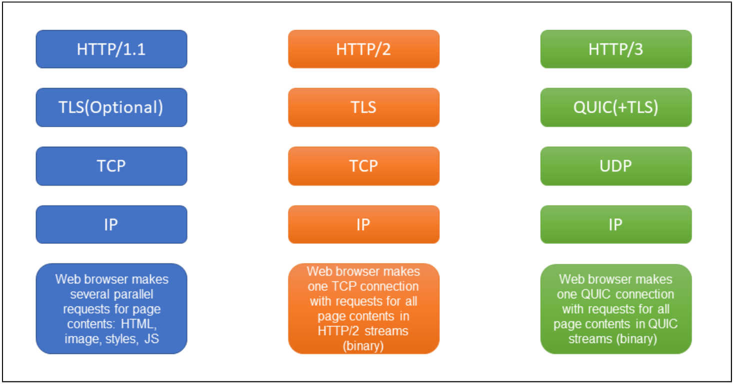

HTTP/1.1
TLS(Optional)
TCP
IP
Web browser makes several parallel requests for page contents: HTML, image, styles, JS
HTTP/2
TLS
TCP
IP
Web browser makes one TCP connection with requests for all page contents in HTTP/2 streams (binary)
HTTP/3
QUIC(+TLS)
UDP
IP
Web browser makes one QUIC connection with requests for all page contents in QUIC streams (binary)

Figure: 1. HTTP Versions

Introduction

QUIC Transport Protocol

- fast, secure, evolvable generic transport protocol
- integrates with TLS
- uses connection IDs frames
- reduced connection establishment time
- supports multiplexing
- solves head-of-line blocking problem in HTTP/2

Literature Survey

Author et al	Proposed Work	Shortcoming of work
Xudong Cao, Shangru Zhao, Yuqing Zhang, 2019 [1]	0-RTT Attack and Defense of QUIC Protocol	Tests the security mechanism of QUIC, & proposes a new attack against the protocol, proves feasibility of attack through experiments.
Adam Langley, Alistair Riddoch, Alyssa Wilk, 2017 [4]	The QUIC Transport Protocol: Design and Internet-Scale Deployment	Layering enables modularity but often at the cost of performance. Squashing the layers of HTTPS in QUIC allows to weed out inefficiencies in the HTTPS stack.
Efstratios Chatzoglou1, Vasileios Kouliaridis1, Georgios Karopoulos2 Georgios Kambourakisa, 2015 [2]	Revisiting QUIC attacks: A comprehensive review on QUIC security and a hands-on study Quick is QUIC?	1. A hands-on security evaluation performed against the six most popular QUIC and HTTP/3 enabled servers. 2. Identifying attacks against both IETF QUIC and gQUIC components.
Robert Lychev, Samuel Jero, Alexandra Boldyreva, 2015 [5]	How Secure and Quick is QUIC? Provable Security and Performance Analyses	1. In presence of attackers, QUIC maybe unable to attain 0-RTT connections. 2. Analysed the pitfalls of designing performance-driven secure protocols.
Igor Nogueira de Oliveira, Rafael Roque Aschoff, 2018 [7]	QUIC and TCP: A Performance Evaluation	Influence of RTT in the experiment was noticeable while packet loss ratio influence was inexpressive.

Literature Survey

Author et al	Proposed Work	Shortcoming of work
Robin Marx, Joris Herbots Wim Lamotte, Peter Quax, 2020 [6]	Same Standards, Different Decisions: A Study of QUIC and HTTP/3 Implementation Diversity	Analysed behaviour of 15 different QUIC implementations based on features such as Flow Control, Congestion Control, Prioritization and 0-RTT etc
Mehdi Yosofie, Benedikt Jaeger, 2019	Recent Progress on the QUIC Protocol	Discussed testing QUIC in production mode within Chrome/ Chromium on YouTube and other Google services by Google.
Sarah Cook, Bertrand Mathieu, Patrick Truong, 2017 [3]	QUIC: Better For What And For Whom?	QUIC outperforms HTTP/2 over TCP/TLS in unstable networks such as wireless mobile networks.

Motivation

- HTTP/3 a very recent HTTP protocol, eyecandy for hackers.
- HTTP/3 not allowed by many networks.
- Adoption of HTTP/3 is increasing so deciding which HTTP/3 implementation is better for use maybe helpful.
- To analyze features of HTTP/3 servers : faster connection set-up, less Head of Line blocking, connection migration.

Problem Statement

- HTTP /3 is a very new protocol, and it has a lot of available implementation.
- There are a lot of vulnerabilities in various implementation.
- Which implementation is best on the basis of PACKET RX time and HANDSHAKE time.

Proposed Work

- To try and compare implementations of QUIC supporting servers like **aioquic, nginx-quiche, openlitespeed, Cloudflare**.
- To study the behaviour of various servers implementing QUIC protocol by sending forgery packets.
- To compare different servers on the basis of performance i.e. HANDSHAKE TIME and PACKET RX time in handling forgery packets.

Experimental Setup

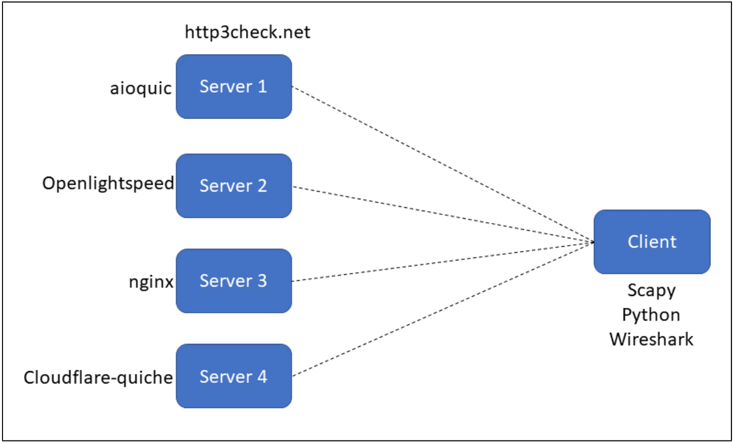


Figure: 2. Setup for Penetration Testing

Work Done

- Learned about HTTP protocols:.
    - **HTTP/1.1**: Web browser makes several parallel requests for page contents: HTML, image, styles, JS.
    - **HTTP/2**: Web browser makes one TCP connection with requests for all page contents in HTTP/2 streams (binary). Head of Line blocking issue exists in HTTP/2.
    - **HTTP/3**: Web browser makes one QUIC connection with requests for all page contents in QUIC streams (binary).
- Read about the **Head of Line blocking** problem in HTTP/2.
- Studied behaviour of different QUIC supporting servers with packet loss, delay, network change and compared QUIC with earlier versions.

Work Done

- Penetration testing performed to QUIC servers are as:

Experiment Number	Parameters Changed
1	Reduce header length of UDP layer
2	Changed frag flag of IP layer
3	Changed the flag of IP layer and dport in UDP layer
4	Changed IP Version and header length in IP version
5	Changed ihl variable in IP layer, Reduced header length in UDP layer and changed IP's id

Tools Used: Scapy, Wireshark, http3check.net

Work Done

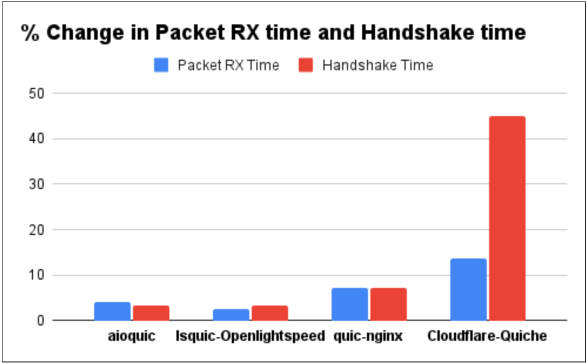
Steps for performing experiment:

- Start by taking a QUIC packet.
- Modify the data in packet using Scapy.
- Flood the test server by sending this QUIC packet.
- Measure PACKET RX time and HANDSHAKE time with the help of `http3check.net`
  - **PACKET RX** - Time between the first packet sent and the first packet received (measured in milliseconds).
  - **HANDSHAKE TIME** - Time between when the first packet is sent and when the handshake is completed (measured in milliseconds).

Work Done

Experiment 1: Reduce header length of UDP layer.

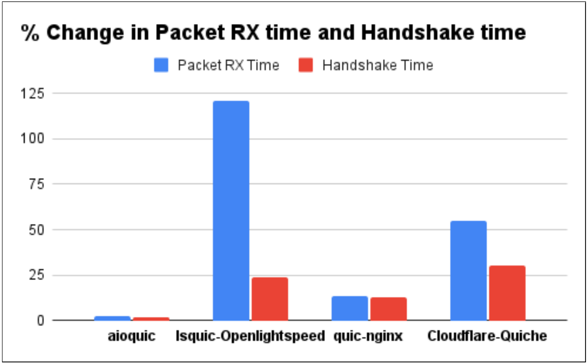
TYPE	aioquic	lsquic-Openlightspeed	quic-nginx	Cloudflare-Quiche
PACKET RX	185.07	8.89	171.08	7.43
HANDSHAKE	92.79	7.77	84.34	4.75



Work Done

Experiment 2: Changed frag flag of IP layer.

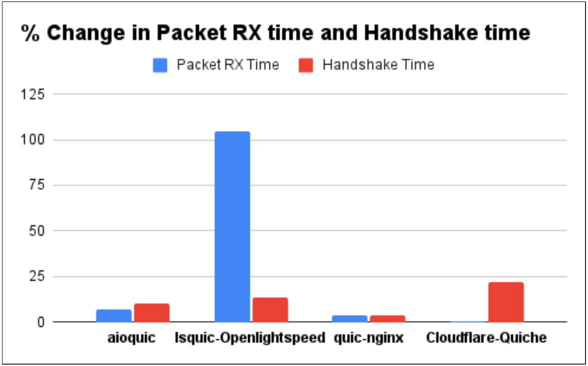
TYPE	aioquic	lsquic-Openlightspeed	quic-nginx	Cloudflare-Quiche
PACKET RX	182.25	20.16	180.58	10.10
HANDSHAKE	91.54	9.93	88.83	4.27



Work Done

Experiment 3: Changed the flag of IP layer and dport in UDP layer.

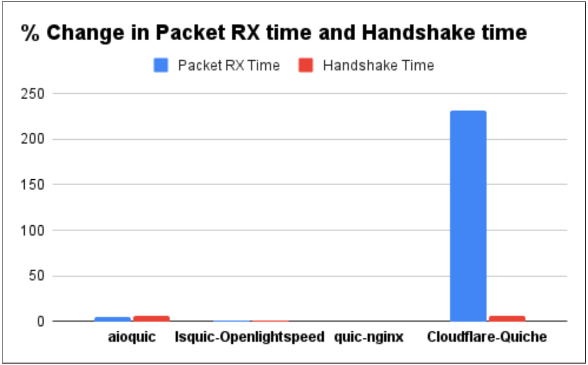
TYPE	aioquic	lsquic-Openlightspeed	quic-nginx	Cloudflare-Quiche
PACKET RX	190.50	18.62	165.13	6.49
HANDSHAKE	99.40	9.14	81.45	2.55



Work Done

Experiment 4: Changed IP Version and header length in IP version.

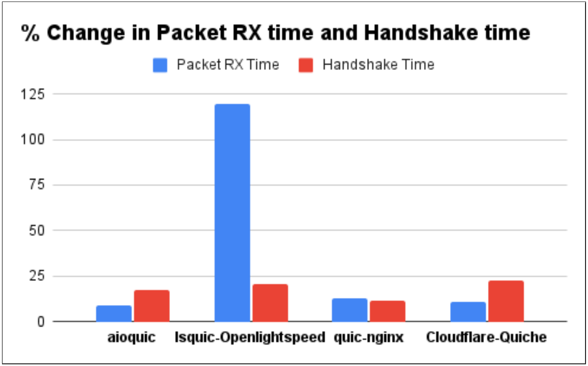
TYPE	aioquic	lsquic-Openlightspeed	quic-nginx	Cloudflare-Quiche
PACKET RX	187.02	9.04	159.58	21.65
HANDSHAKE	95.57	7.93	78.54	3.48



Work Done

Experiment 5: Changed ihl variable in IP layer, Reduced header length in UDP layer and changed IP's id.

TYPE	aioquic	lsquic-Openlightspeed	quic-nginx	Cloudflare-Quiche
PACKET RX	193.52	20.02	179.86	5.84
HANDSHAKE	105.38	9.69	87.65	2.53



Experimental Results

HANDSHAKE Time:

Server name	Normal	No change	Test1	Test2	Test3	Test4	Test5
aioquic	89.9	92.701	92.794	91.548	99.401	95.574	105.384
lsquic-Openlightspeed	8.037	10.202	7.776	9.931	9.141	7.934	9.697
Quic-nginx	78.673	81.089	84.344	88.836	81.459	78.548	87.652
Cloudflare-Quiche	3.283	3.205	4.758	4.27	2.557	3.488	2.533

Table: Handshake Time for servers on different tests

Server name	No change	Test1	Test2	Test3	Test4	Test5
aioquic	3.115	3.219	1.833	10.568	6.311	17.223
lsquic-Openlightspeed	26.937	3.247	23.566	13.736	1.281	20.654
Quic-nginx	3.070	7.208	12.918	3.541	0.158	11.413
Cloudflare-Quiche	2.375	44.928	30.063	22.113	6.244	22.844

Table: Percentage change in Handshake time

Experimental Results

PACKET RX Time:

Server name	Normal	No change	Test1	Test2	Test3	Test4	Test5
aioquic	177.846	184.673	185.077	182.25	190.506	187.027	193.529
lsquic-Openlightspeed	9.118	19.862	8.894	20.163	18.627	9.046	20.023
Quic-nginx	159.575	164.084	171.081	180.58	165.136	159.584	179.861
Cloudflare-Quiche	6.54	8.061	7.431	10.108	6.499	21.65	5.847

Table: Packet RX Time for servers on different tests

Server name	No change	Test1	Test2	Test3	Test4	Test5
aioquic	3.838	4.065	2.476	7.118	5.162	8.818
lsquic-Openlightspeed	117.832	2.456	121.134	104.288	0.789	119.598
Quic-nginx	2.825	7.210	13.163	3.484	0.005	12.712
Cloudflare-Quiche	23.256	13.623	54.556	0.626	231.039	10.596

Table: Percentage change in Packet RX Time

Experimental Results

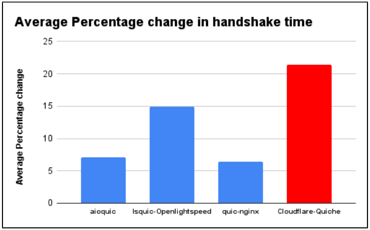


Figure: Average Handshake Time Graph

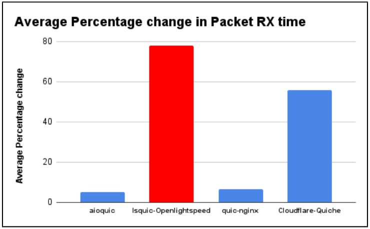


Figure: Average Packet RX Time Graph

Conclusion

- HTTP/3 is basically a improvement in terms of performance, security and not a reform.
- Main issue with QUIC lies in the initial phase of handshake because the client hello packet is unencrypted.
- Our experiment of pentesting shows that the order for using these servers is:
    - On the basis of Handshake time: **nginx** > **aioquic** > **openlightspeed** > **cloudflare**
    - On the basis of Packet RX time: **aioquic** > **nginx** > **cloudflare** > **openlightspeed**

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Thank You!