CLOUDFLARE

Oblivious DNS over HTTPS (ODoH)

A Practical Privacy Enhancement to DNS

Measurements and Feasibility

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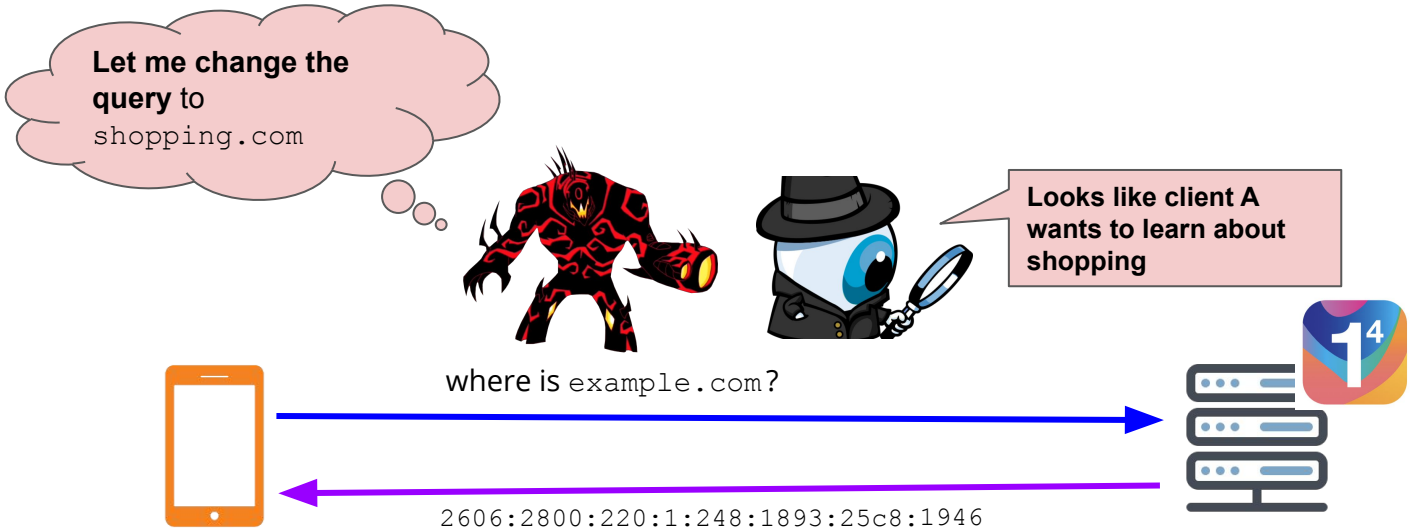
[*]*Cloudflare Inc.* [†]*University of Washington*

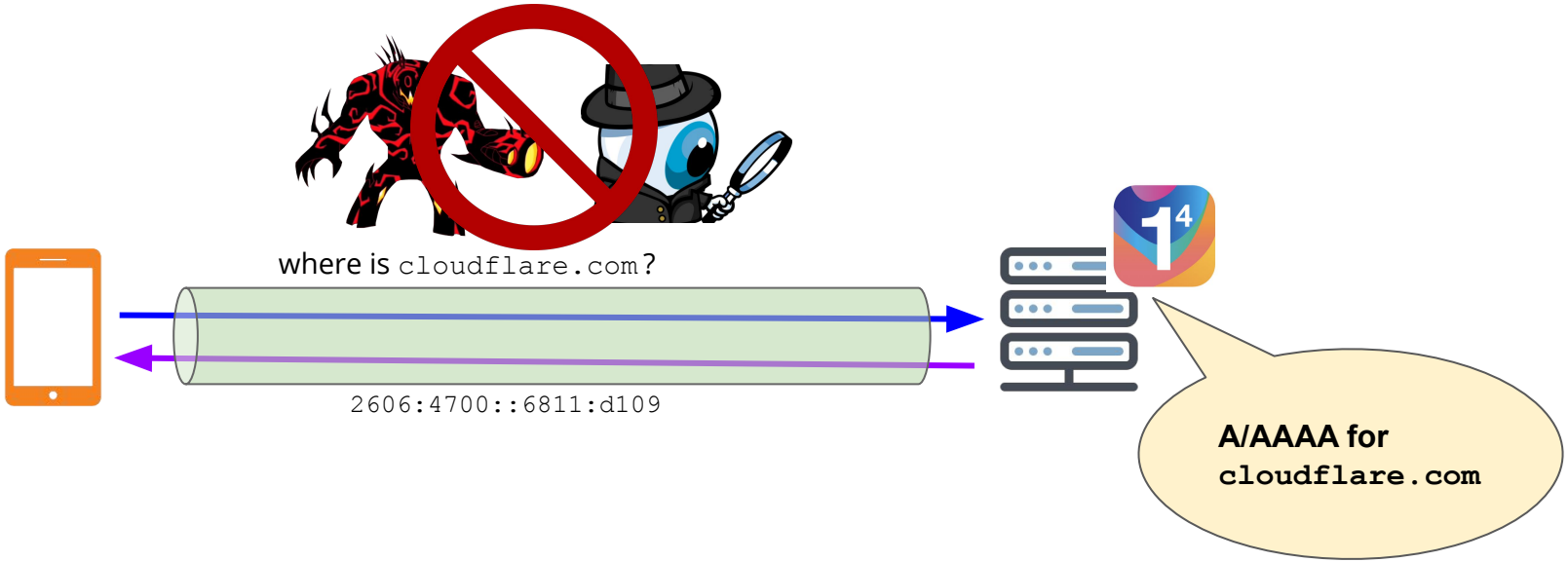
21st February 2021

Do53: Plain-text UDP exposes DNS messages

Most Widely Used Variant of the protocol (92% daily traffic to *1.1.1.1*)



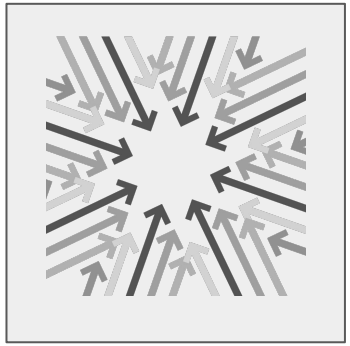
DoH: Encrypts Stub-to-Resolver link



DoH Analysis

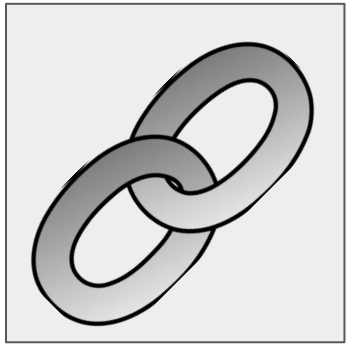
1. **[Böttger *et al.*]** Switch to DoH does not significantly impact page load times and improves user security. (IMC'19)
2. **[Hounsel *et al.*]** Performance of encrypted protocols vary by choice of DoH resolver. (Preprint'20)
3. **[Sundaresan *et al.*]** Page load times can be improved by prefetching. (SIGMETRICS'13)

The gaps in DoH that ODoH fills



Centralization of services

Small number of deployments



Association of query to clients

Resolver operators can associate query to clients

Privacy by Policy

Privacy backed by privacy policy. Needs explicit efforts like Mozilla TRR List.

Regulatory Concerns

Heavy regulation to prevent monetization attempts.

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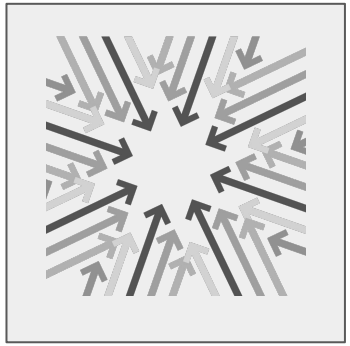

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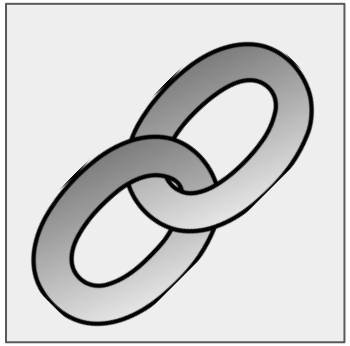

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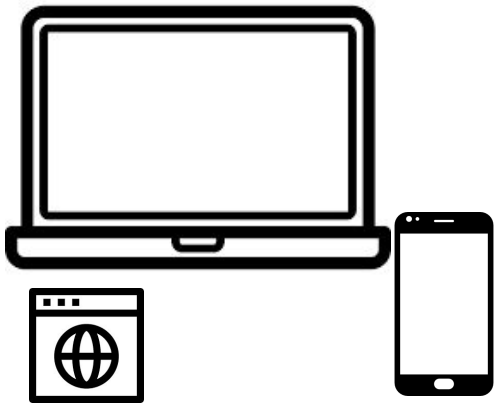
Components of ODoH

Clients



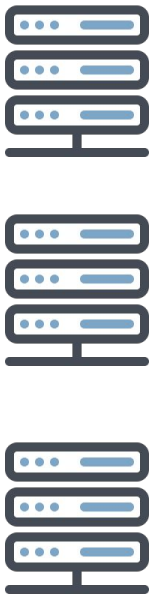
- Prepare DNS Query requests
- Receive DNS Answer responses
- Relays the request through a proxy

Goals:

1. Be able to successfully encrypt and decrypt the messages
2. Be unable to decrypt incorrectly received messages.
3. Identify maliciousness or attacks when they occur.

Components of ODoH

Proxy



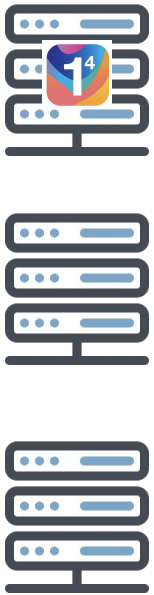
- Relay the encrypted requests to target
- Relay the encrypted responses to client
- Remove client IP addresses

Goals:

1. Remove client identifying information
2. Be unable to decrypt any messages from either the client or the target instances
3. Operated by an organization different from the target resolver

Components of ODoH

Targets

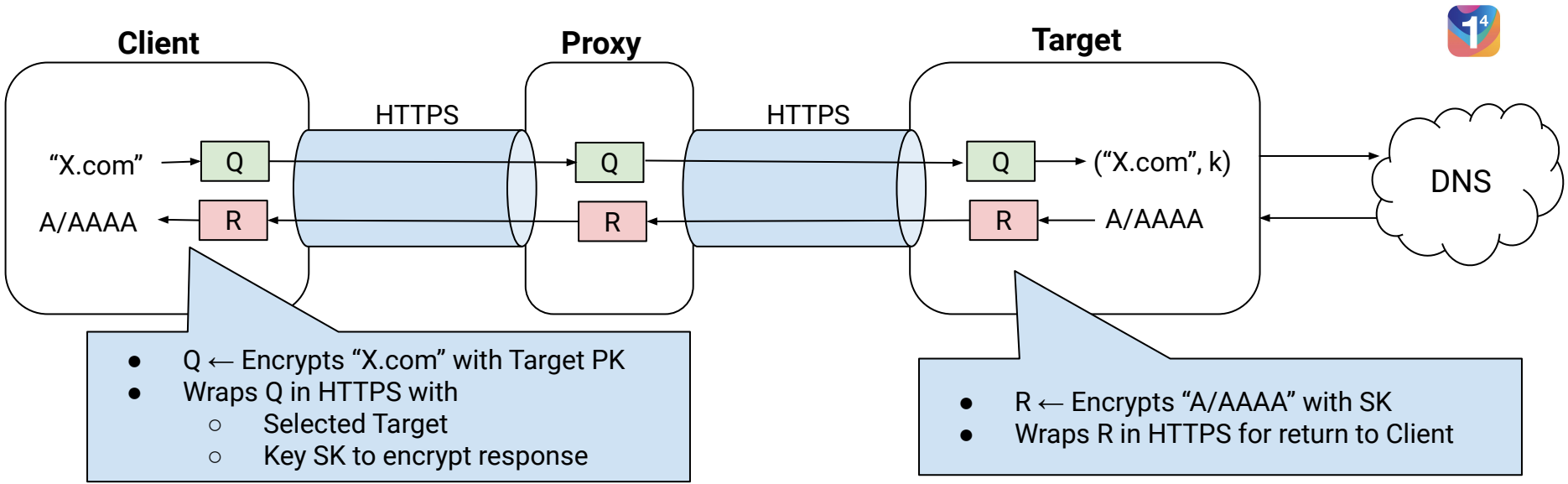


- Receive the encrypted requests from proxy
- Decrypt the query and Encrypt the answer

Goals:

1. Successfully decrypt the query
2. Obtain the answer from a resolver
3. Encrypt the answer and respond to proxy
4. Be unable to identify the actual client requesting the information.

ODoH Protocol



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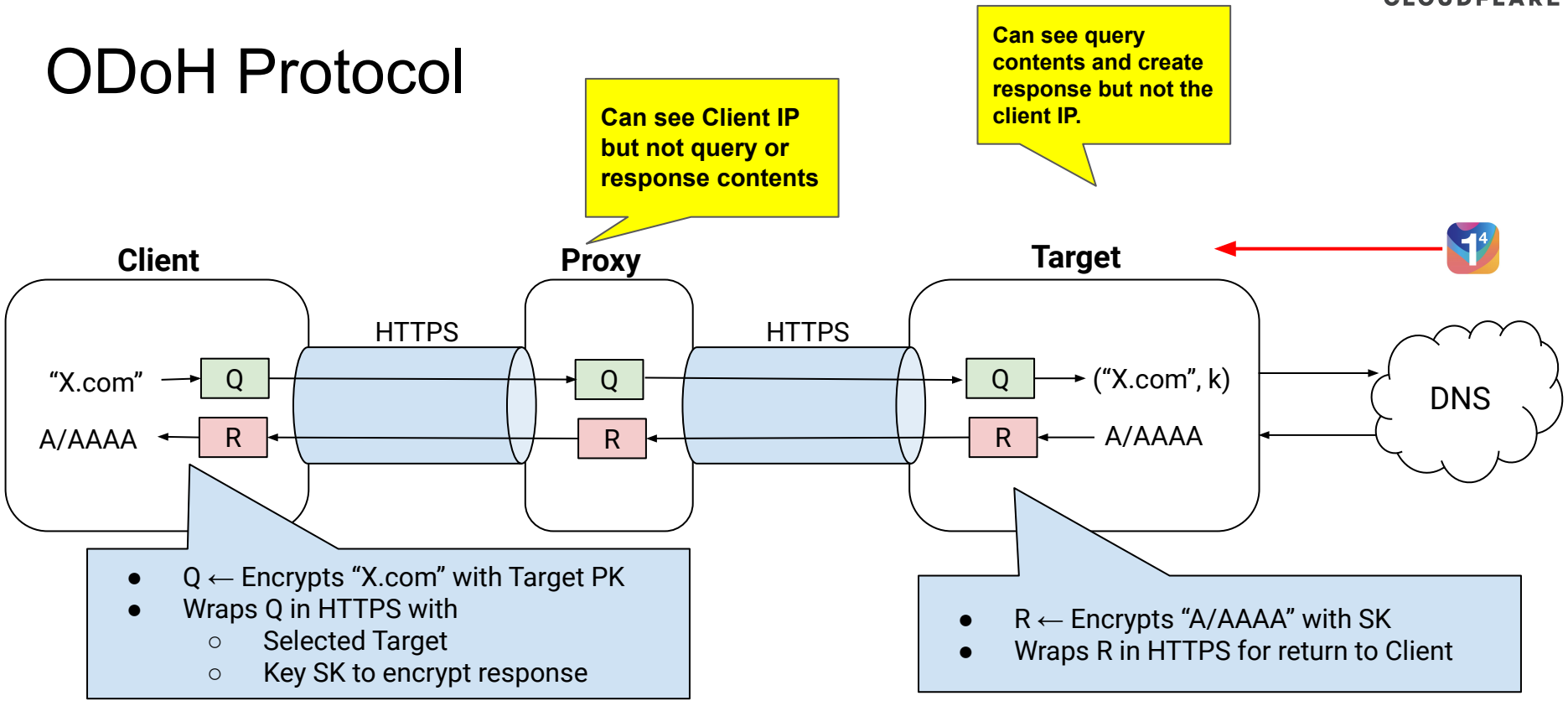

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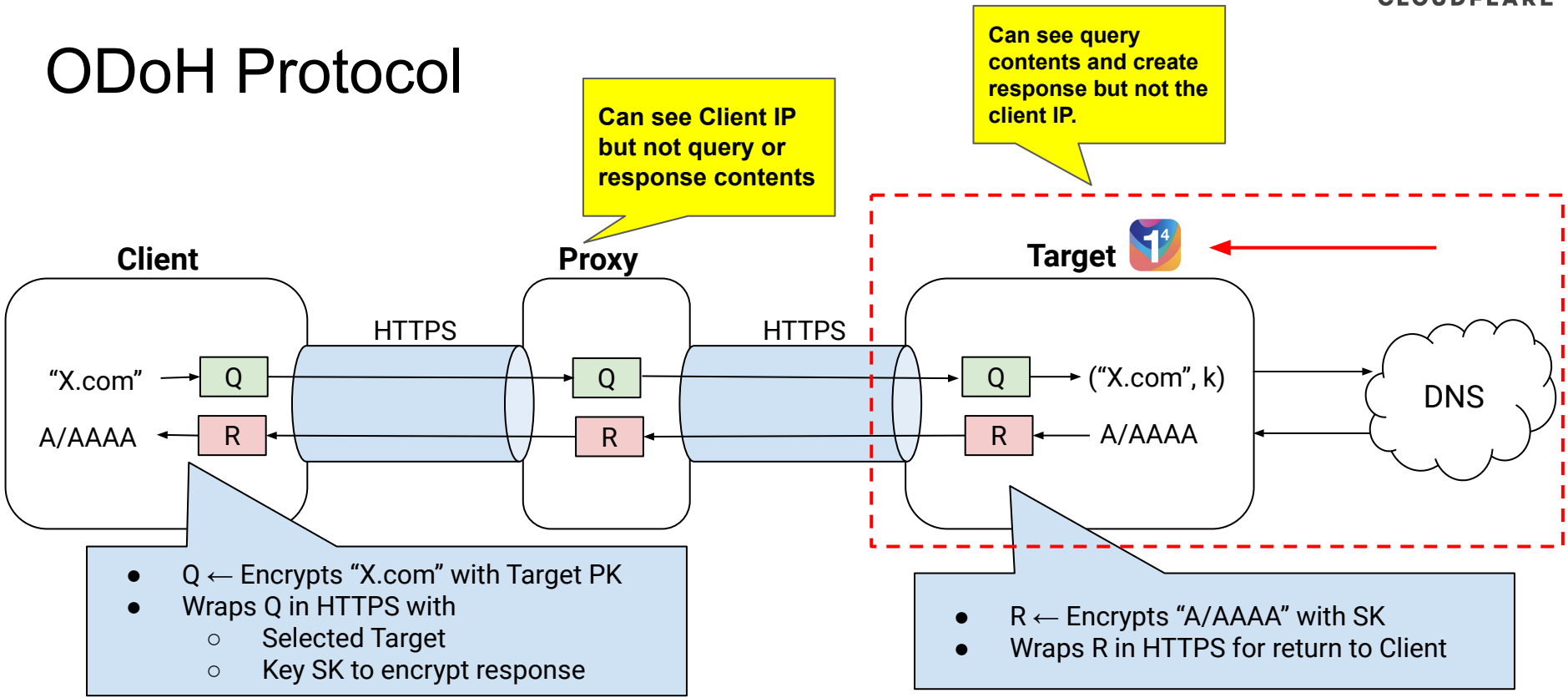


ODoH Measurements Questions

Q1: What is the impact of using ODoH on **DNS response times**?

Q2: How does the usage of ODoH affect **Page Load Times** & user experience?

Q3: How does ODoH **compare to other privacy enhancing protocol** variants?

ODoH Measurements - High Level Takeaways

Q1: What is the impact of using ODoH on DNS response times?

- ODoH's higher performance relies on **choosing low latency proxy-target pairs**.
- **Service co-location** between the Target and Resolver improves response time.
- **Reusing connections** improves DNS response times when using ODoH.

Q2: How does the usage of ODoH affect Page Load Times & user experience?

- Despite a higher DNS response time, Page Load Times have minimal impact.
- Page load times do not have a perceivable impact due to usage of ODoH. (1.3 sec → 1.6 sec)

Q3: How does ODoH compare to other privacy enhancing protocol variants?

- ODoH strikes an interesting middle ground compared to conventional DNS protocols and other privacy enhancing variants.

Measurement Setup and Deployments

Resolvers:

1.1.1.1

8.8.8.8

9.9.9.9

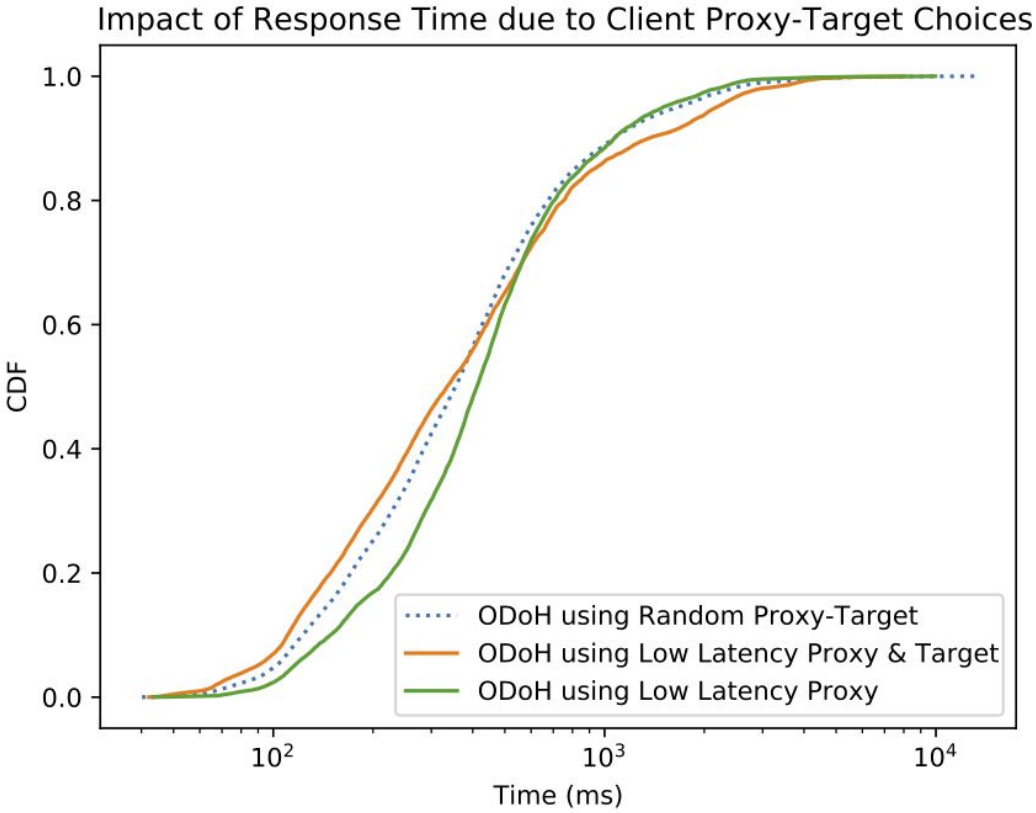
90 Client stubs
- 10 per vantage point

Experiment:
21,000 DNS req/day
or 15 requests/minute

Average bandwidth:
480 Mbit/s

Clients:
1 core Intel Xeon 2 GHz CPU 3.75GB RAM x86_64

Takeaway 1: Choose Low Latency Proxy-Target Pair



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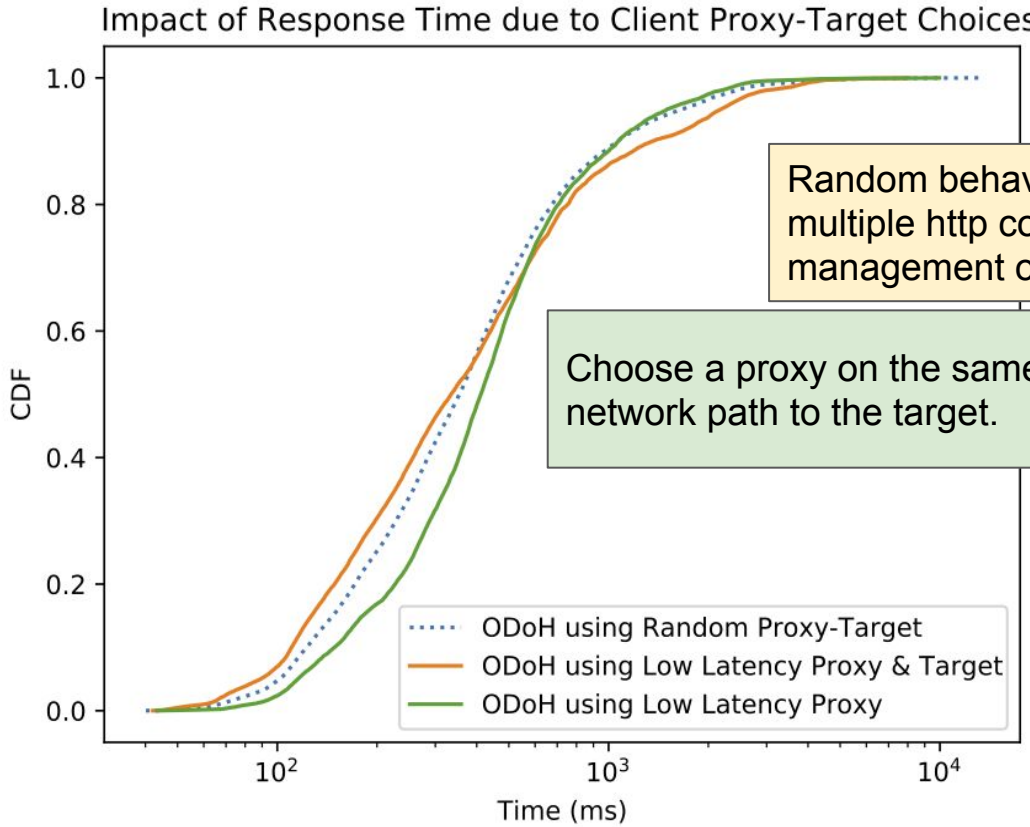
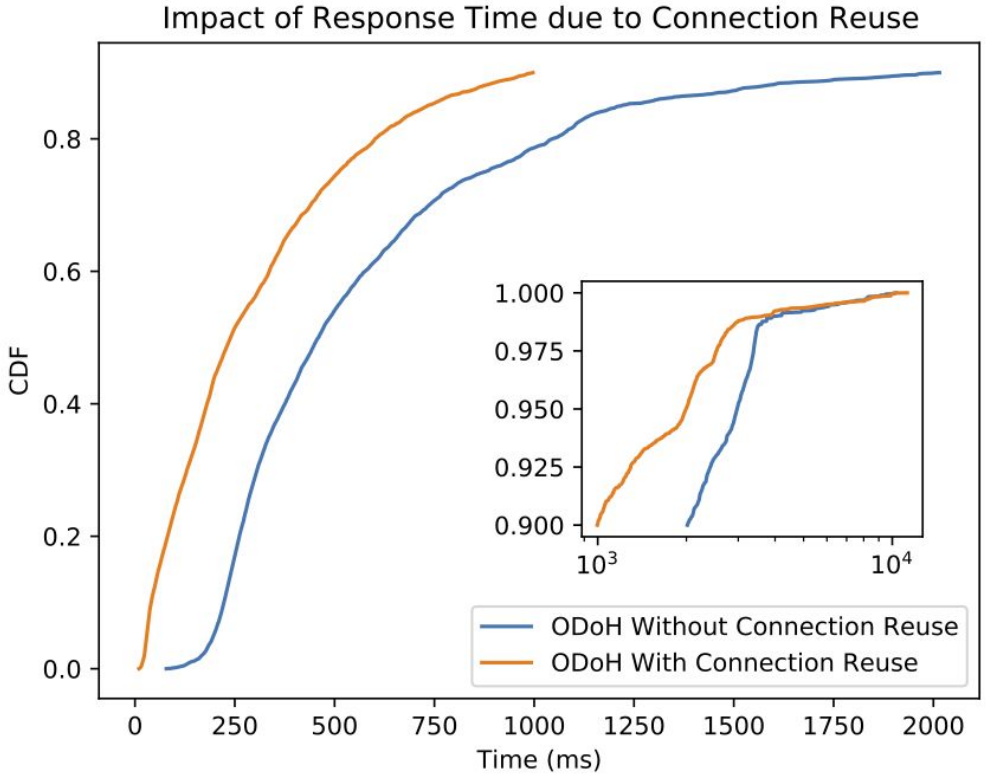


Random behaves better due to multiple http connection management of streams.

Choose a proxy on the same network path to the target.

Takeaway 2: Reuse connections!



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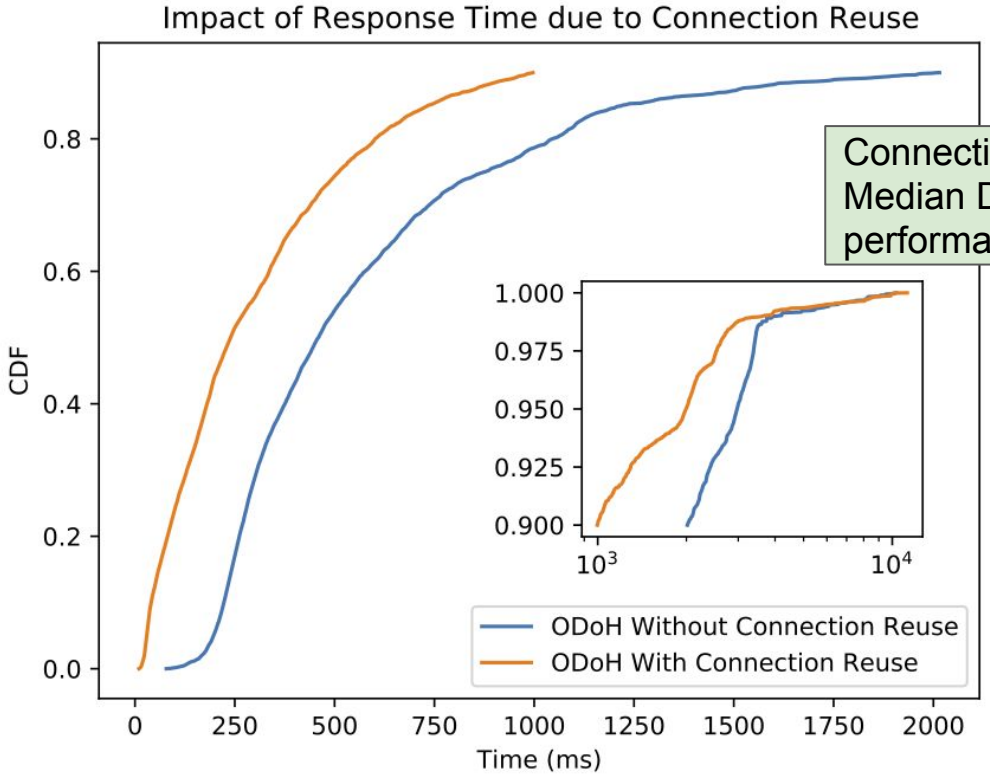
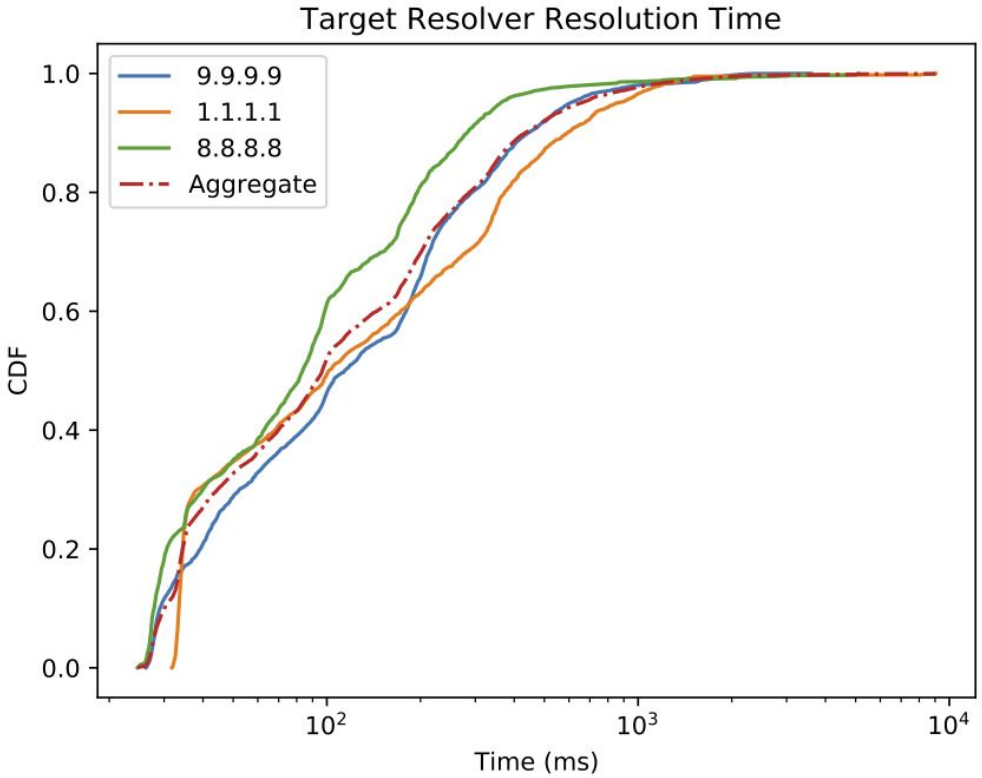


Connection reuse improves Median DNS response time performance by 48%.

Co-location is important: GCP Target favours 8.8.8.8



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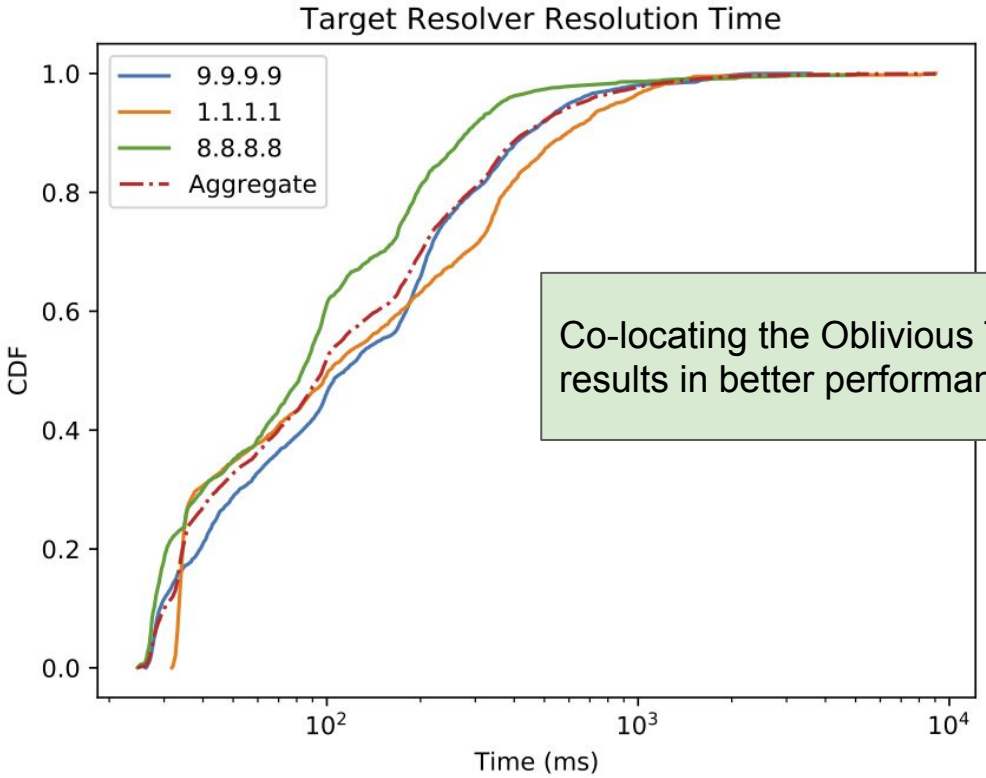
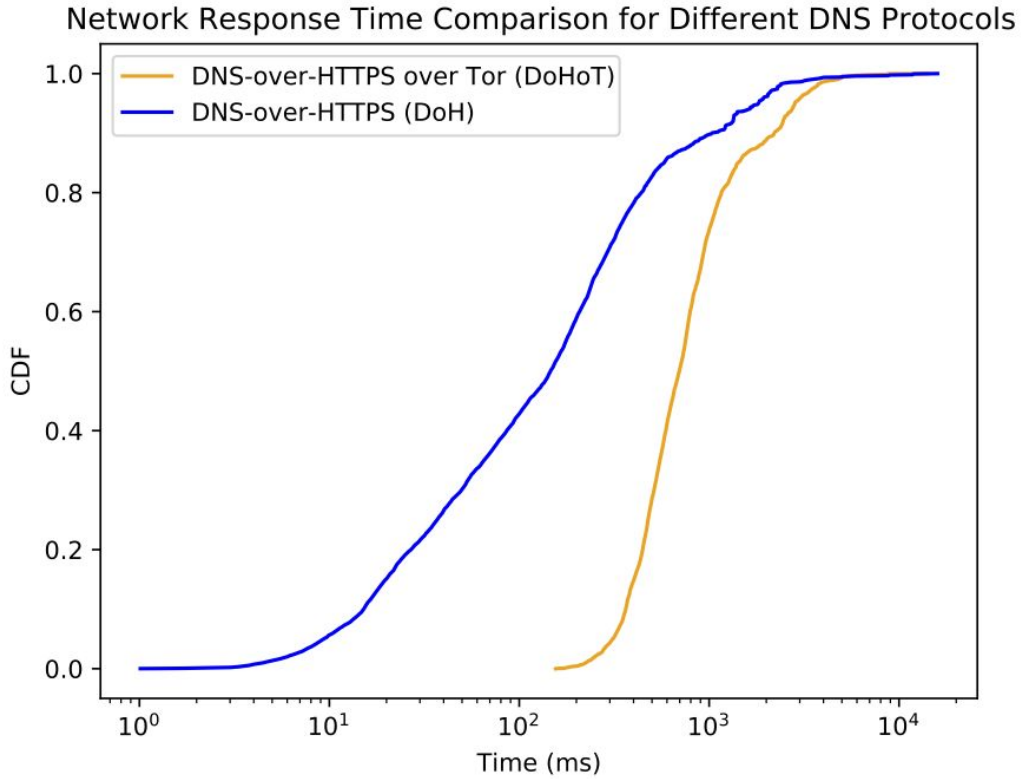


Co-locating the Oblivious Target and the Resolver results in better performance.

Comparing ODoH With Other DNS Protocols



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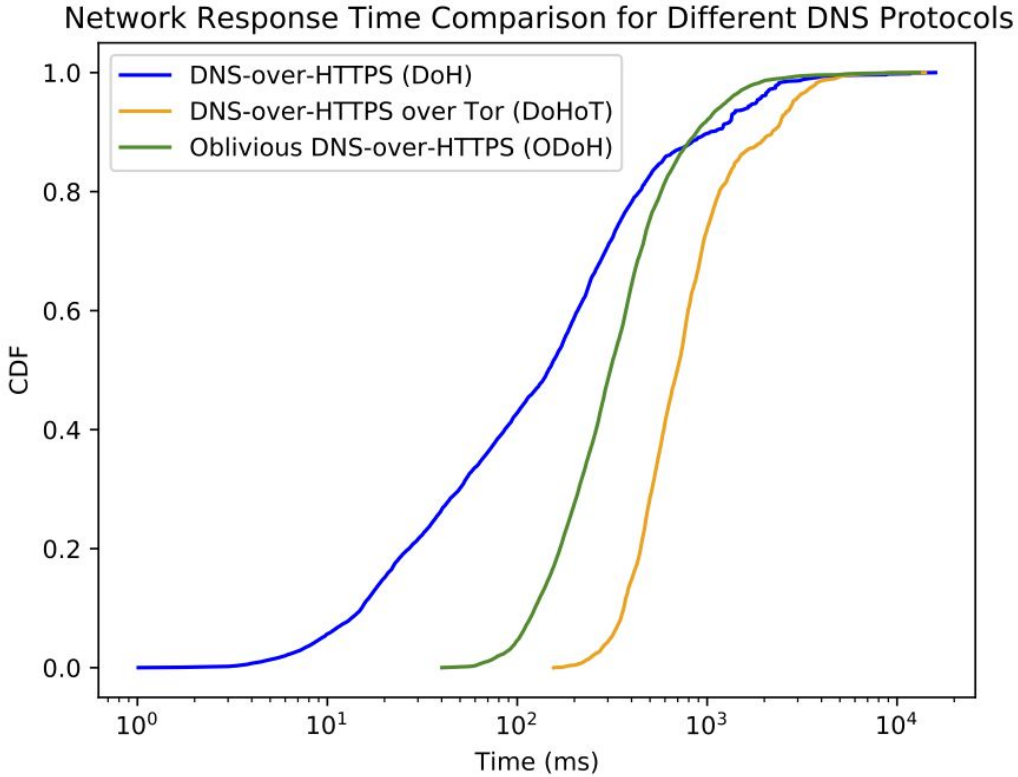

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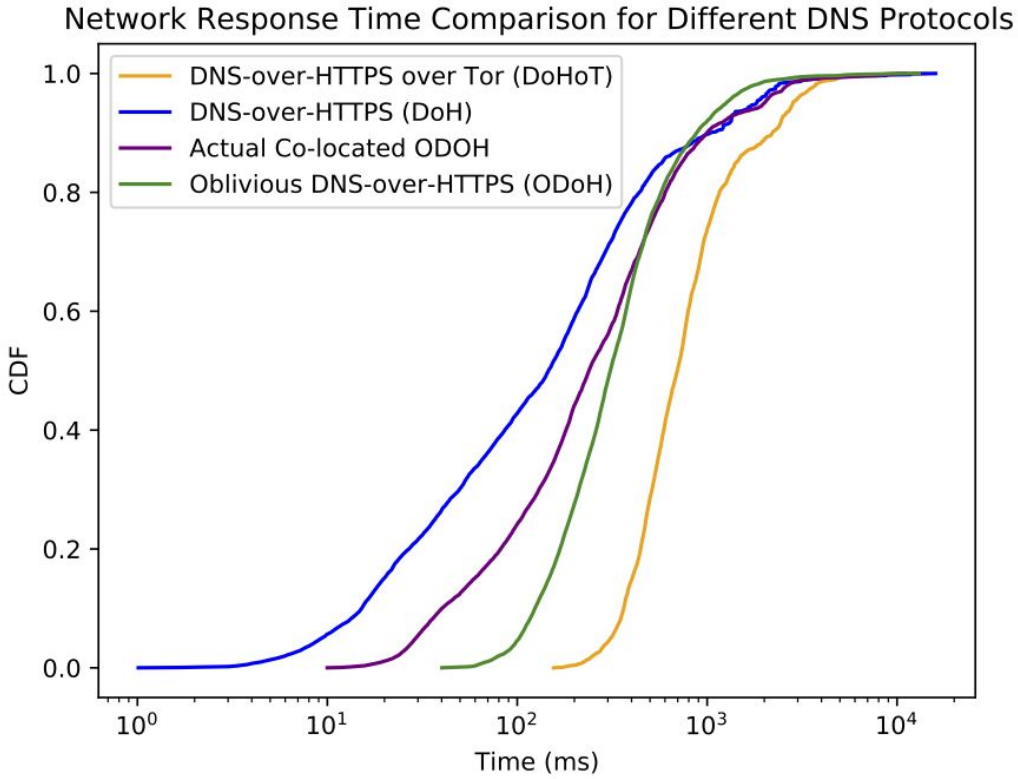

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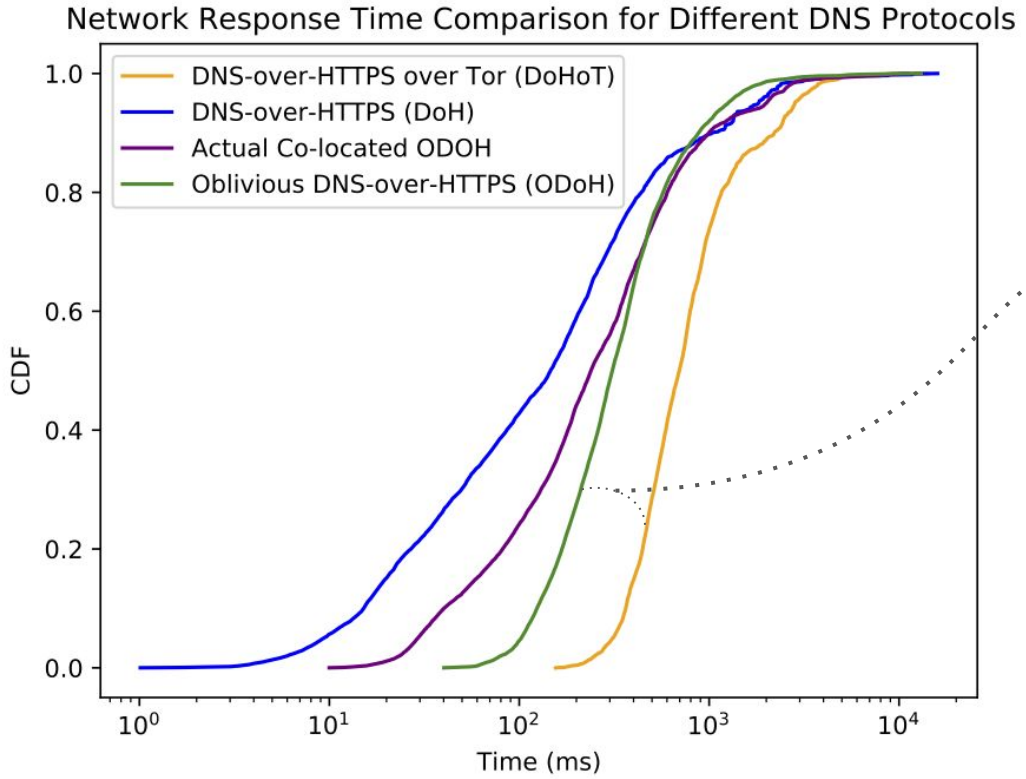
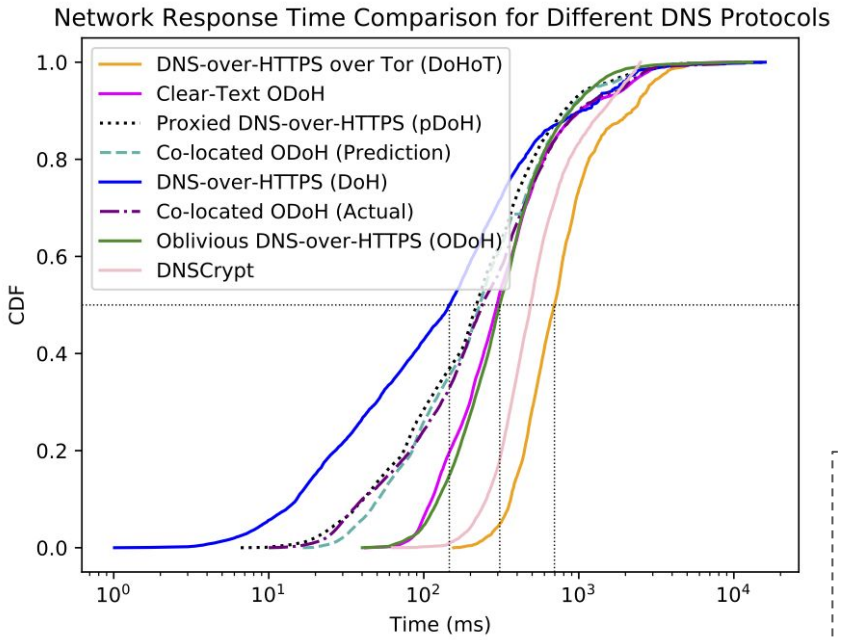


Encrypted DNS Protocols:

DNSCrypt and **Anonymous DNSCrypt**

Comparing Other Architectural Variants

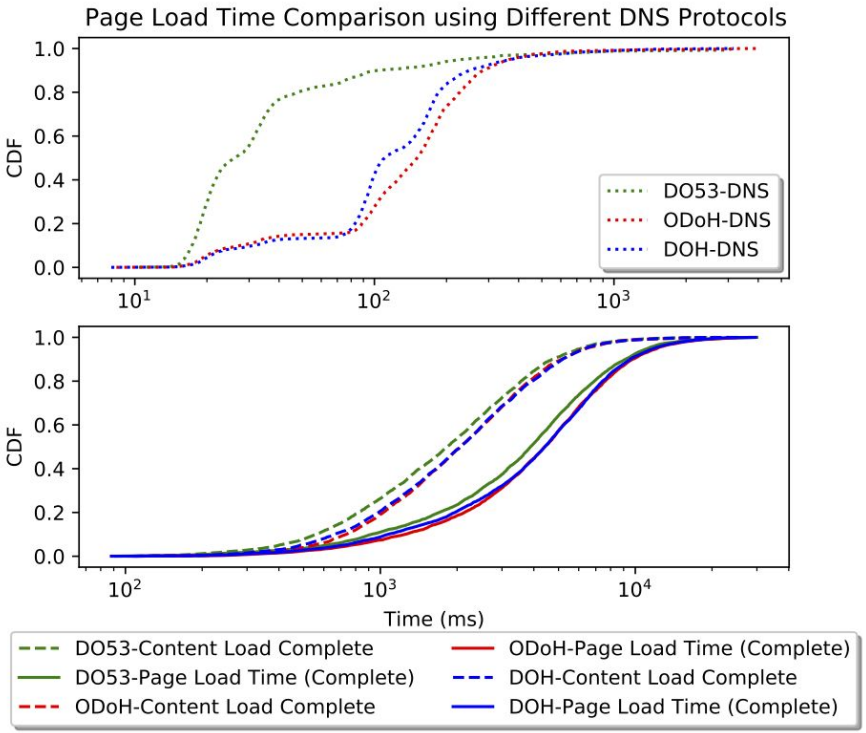


https://odoh.cloudflare-dns.com/

Protocol	Request Path	Security	Privacy
Plain DNS (Do53)	C → R	No	No
DNS over HTTPS (DoH)	C → R	Yes	No*
Proxied DoH	C → P → R	Yes	No
Oblivious DoH (ODoH)	**C → P → T → R**	**Yes**	**Yes**
Cleartext ODoH	C → P → T → R	Yes	No
Co-located ODoH	**C → P → (T+R)**	**Yes**	**Yes**
DNSCrypt	C → R	Yes	No*
Anonymous DNSCrypt	C → P → R	Yes	Yes
DoH over Tor (DoHoT)	C → Tor → R	Yes	Yes

C: Client, R: Resolver, T: Target, P: Proxy
* Privacy Policy Based Privacy

In-Browser Measurements



Measurements taken from a single vantage point (Chrome using Local Stub resolver[1]):

- Client node in a lab university wireless network (200 Mbps DL / 8Mbps UL)
- Experimental setup with on-path proxy
- 5000 random and top chosen websites from the Top 1M in Tranco dataset
- PLT taken after entire navigation page is rendered

Page load times increase by ~20% (without co-location) and ~13% (with colocation) compared to Do53 based usage and can be attributed to network topology differences.

[1] https://github.com/cloudflare/cloudflared

Summary and Conclusion

1. Performance impacts in the protocol are **purely network topology effects**.
2. **Service co-location** will result in **increased response time performance**.
3. Client **choosing on-path proxy** results in higher response time performance.
4. Clients are encouraged to **reuse https connections** to avoid TLS+TCP handshake overheads.
5. ODoH has minimal total page load time impacts or perceivable user experience impacts.
6. **ODoH is a practical privacy enhancing protocol for DNS.**

Available Code and Paper

Please find the server and client implementations at:

- https://github.com/cloudflare/odoh-server-go
- https://github.com/cloudflare/odoh-proxy-worker
- More variants on https://github.com/cloudflare/

The library implementations:

- https://github.com/cloudflare/odoh-rs
- https://github.com/cloudflare/odoh-go

Clients:

- https://github.com/cloudflare/odoh-client-go
- https://github.com/cloudflare/odoh-client-rs

Email: sudheesh@cs.washington.edu / sudheesh@cloudflare.com

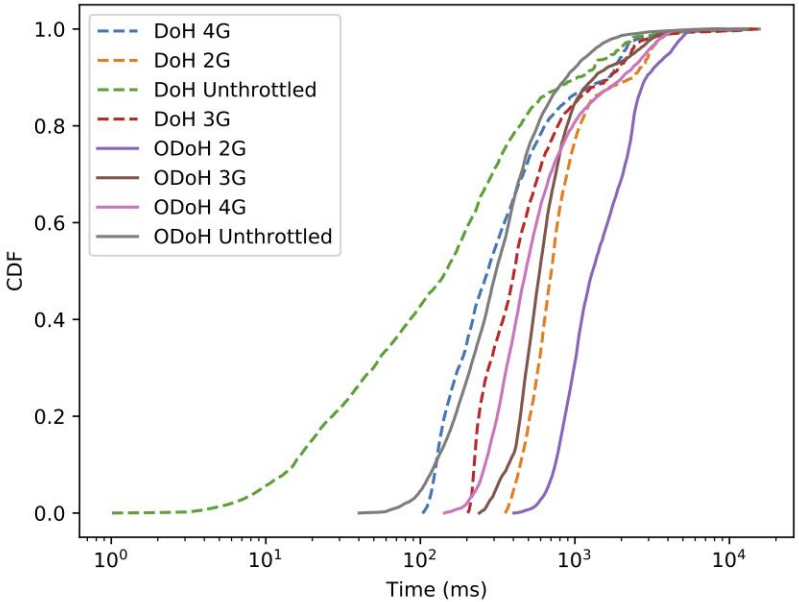
A special shoutout to:
- Tommy Pauly
- Eric Kinnear
- Wesley Evans

And countless others who made this work possible.

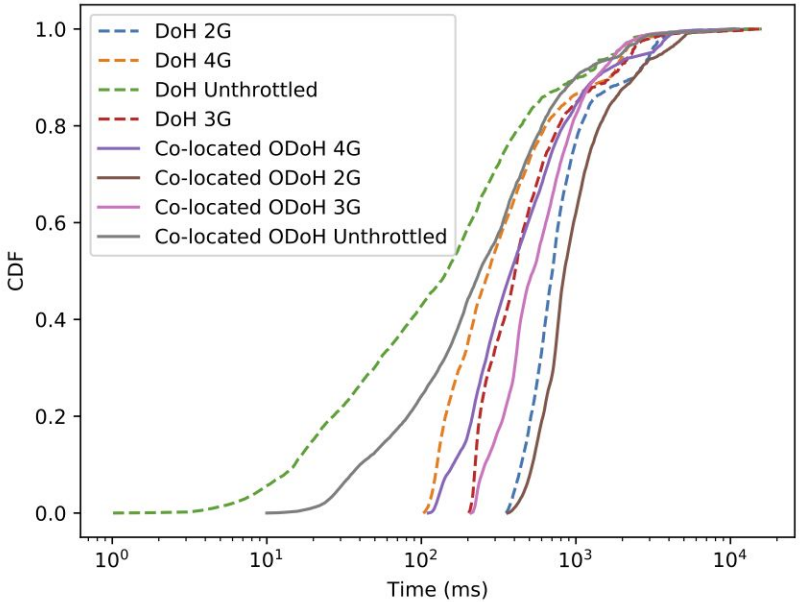
Backup Slides

Network Type Impacts

Without Colocation

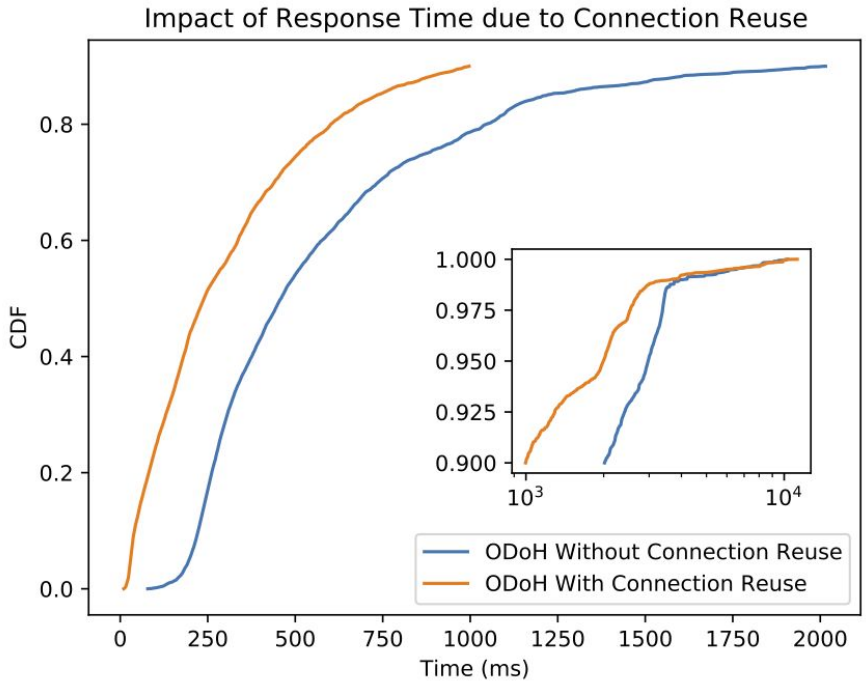


With Colocation



2G: 0.56 Mbps with 350ms latency	**3G:** 1.25 Mbps with 200ms latency	**4G:** 12 Mbps with 100ms latency

Takeaway 2: Reuse connections!



Connection reuse improves DNS response time performance by 48%.

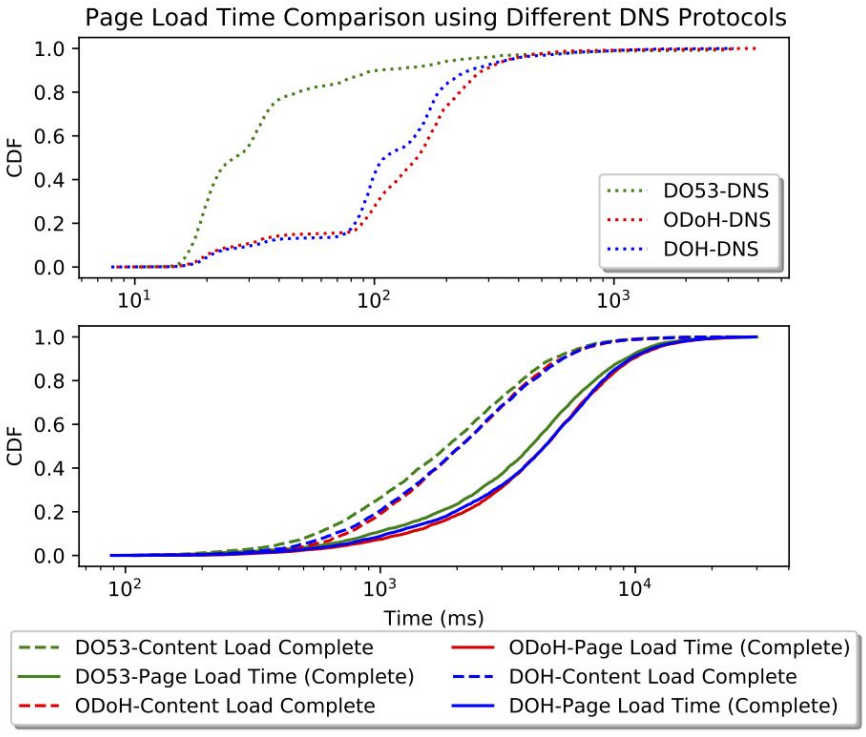
Some leakage of client identity due to reuse of session keys

- **No sensitive information** in either cleartext or encrypted form **is leaked**

Possible for clients to configure and force new connections if necessary.

Page Load Time Impacts (Top vs Random)

Top 5K Websites



Random 5K Websites