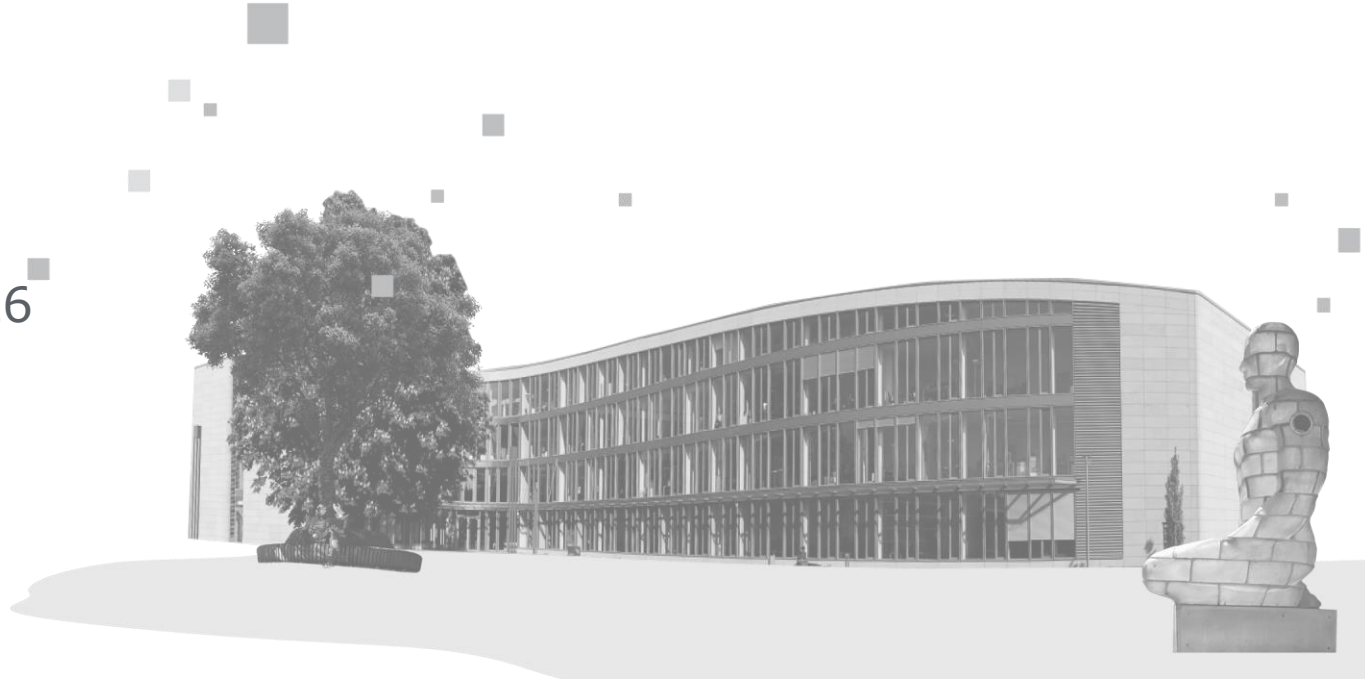
The Future of DNS Privacy

A Comparison of DNS over QUIC and DNS over HTTP/3

Philipp Bielefeld • Felix Hoffmann • Steffen Sasalla • vasilis ververis • Vaibhav Bajpai

Presenter: **Newton Masinde**



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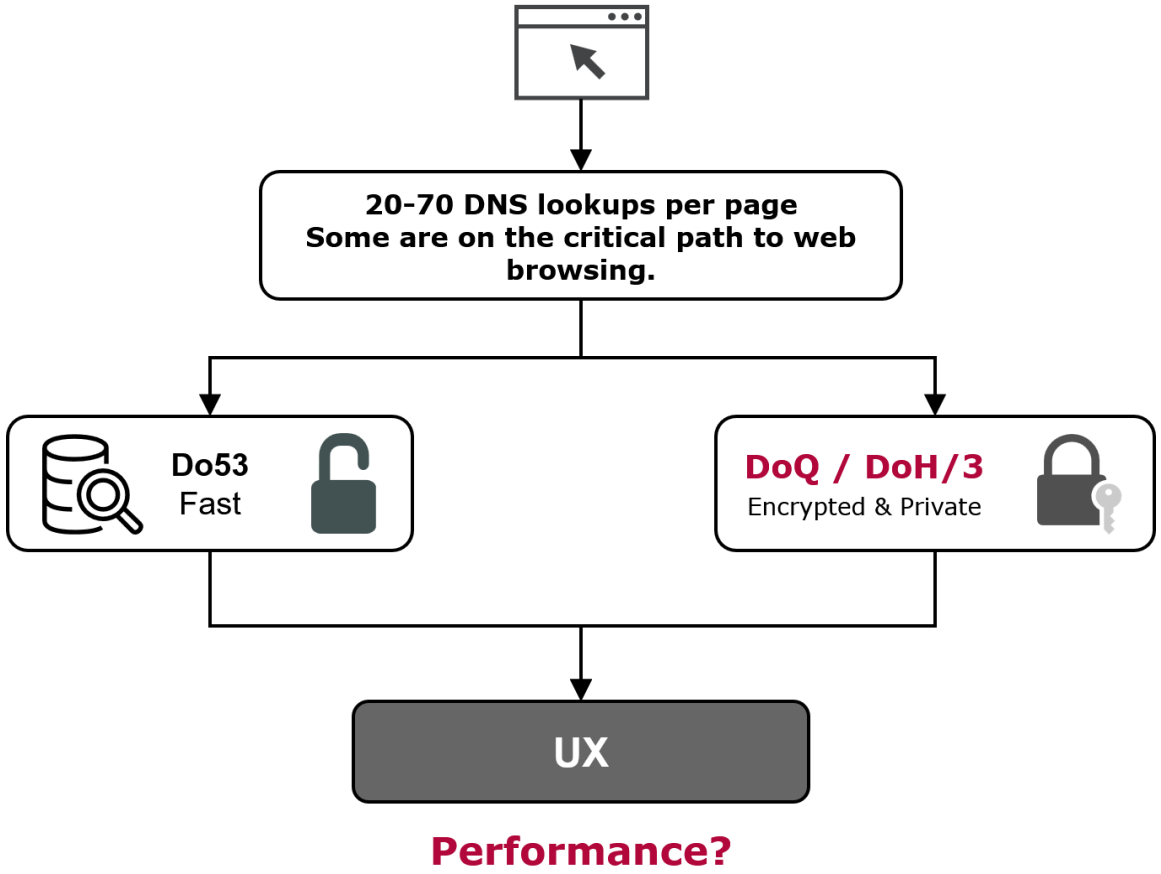
Why This Study?



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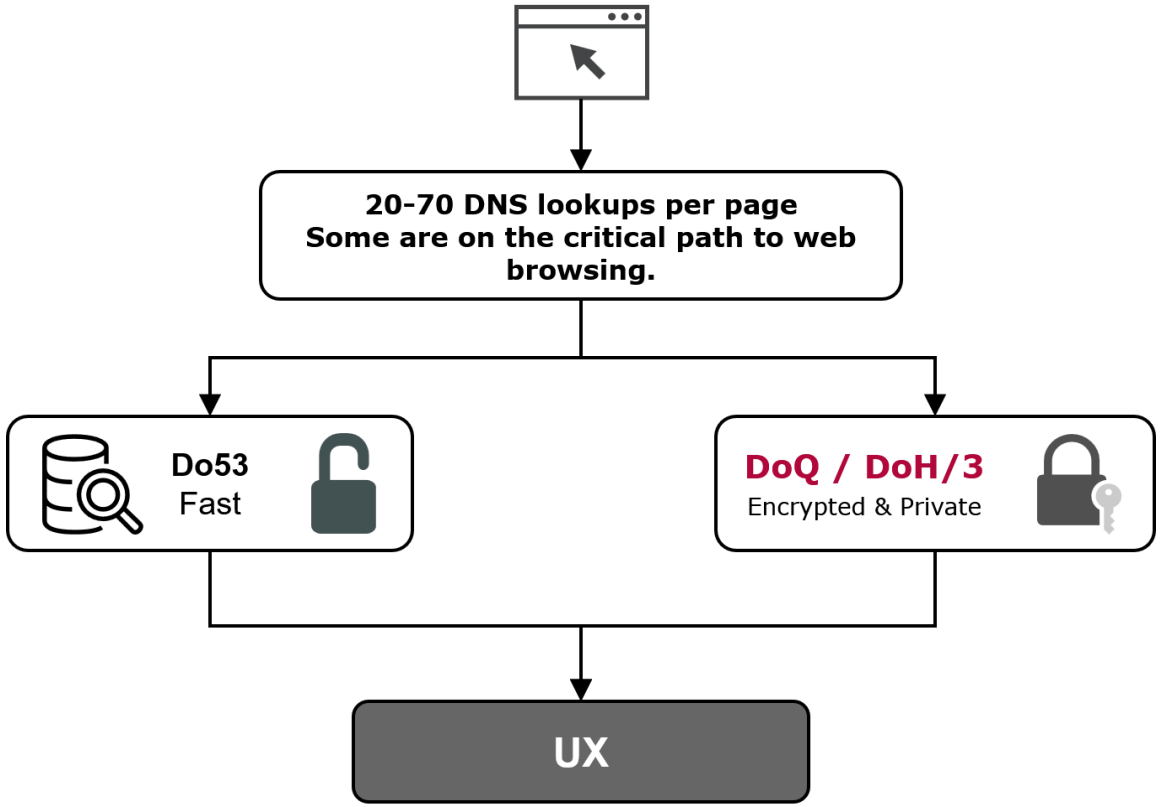

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Do users actually experience performance difference due to DoE enhancements?

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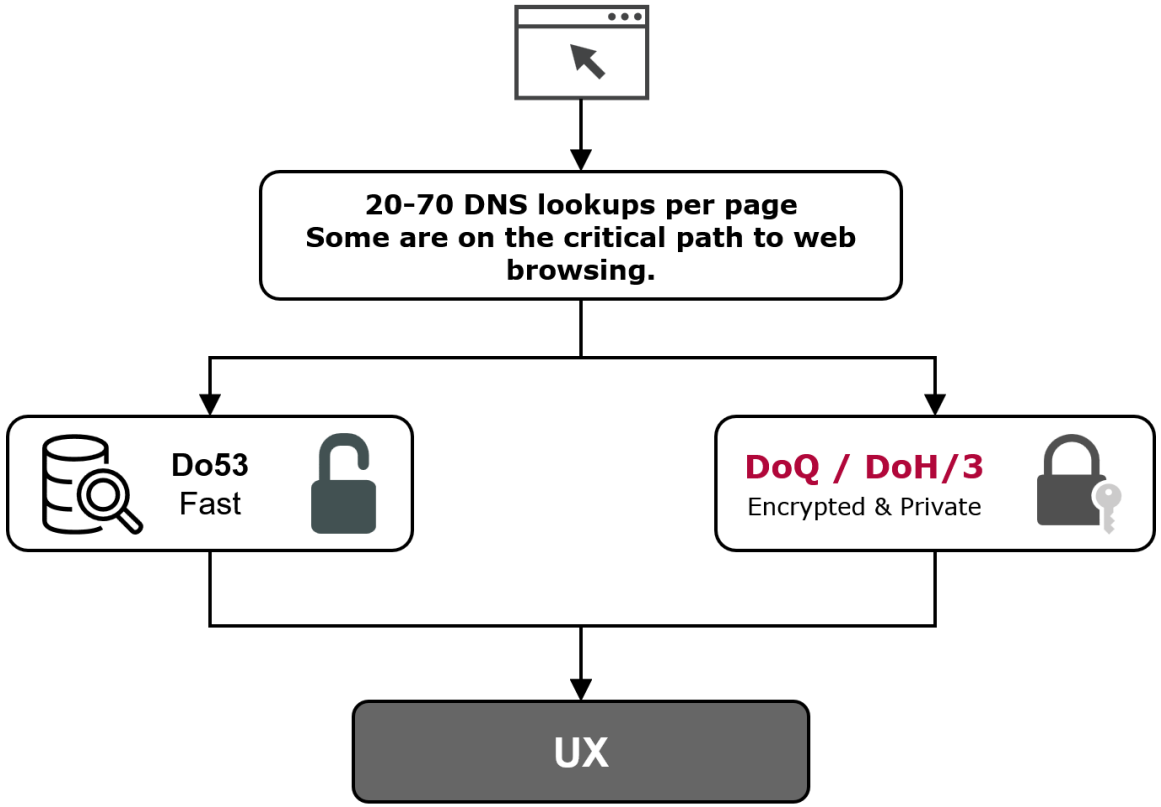

Performance?

Research Questions

RQ1: DEPLOYMENT READINESS

How ready are current DoQ and DoH/3 deployments for production use?

RQ2: WEB PERFORMANCE

Does encrypted DNS actually slow webpages?

RQ3: WEB COMPLEXITY

Are some websites affected more than others?

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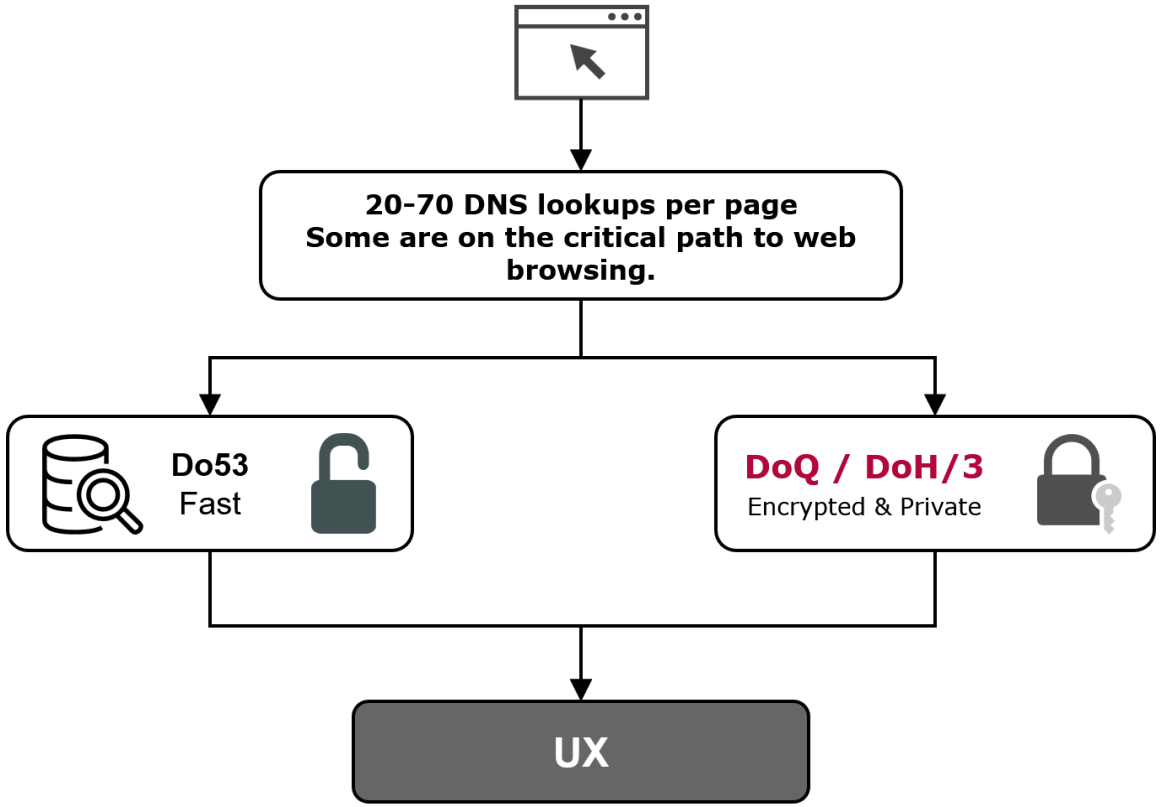

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Do users actually experience performance difference due to DoE enhancements?

What is the performance penalty of encrypted DNS on User Experience?

Measurement Campaign

- Four Phases

Measurement Campaign

- Four Phases

INFRASTRUCTURE SETUP & DISCOVERY

Internet-wide Scans
IPv4 (ZMap scans)
IPv6 (Hitlist service)

3000+
DoE Resolvers

DNS PERFORMANCE EVALUATION

Resolver Measurements
RTT
Session Resumption
0-RTT

75K
Encrypted DNS Queries

WEBSITE PERFORMANCE ASSESSMENT

Real Web Browsing
Firefox
Selenium
Tranco Top-1M

~1.9M
Successful page loads

WEBSITE COMPLEXITY ANALYSIS

Complexity Analysis
Accessibility
Median page composition
Median load time

~570k
websites accessed

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INFRASTRUCTURE SETUP & DISCOVERY	DNS PERFORMANCE EVALUATION	WEBSITE PERFORMANCE ASSESSMENT	WEBSITE COMPLEXITY ANALYSIS
			
Internet-wide Scans IPv4 (ZMap scans) IPv6 (Hitlist service)	**Resolver Measurements** RTT Session Resumption 0-RTT	**Real Web Browsing** Firefox Selenium Tranco Top-1M	**Complexity Analysis** Accessibility Median page composition Median load time
3000+ DoE Resolvers	**75K** Encrypted DNS Queries	**~1.9M** Successful page loads	**~570k** websites accessed

Large-scale deployment + realistic user experience

Finding 1: DoQ Deployments Are More Mature Than Expected

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DoQ in the wild shows higher adoption of modern QUIC features than DoH/3.

	DoQ	DoH/3
Session Resumption	**~94%** (1039/1112)	~65% (131/202)
0-RTT support	**~66%** (733/1112)	Not observed
Median latency (RTT)	**88 ms**	883 ms

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DoH/3 measurement failures

High measurement failure

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DoH/3 measurement failures

High measurement failure

85%

Adguard contribution to DoH/3 measurement dataset

Affected DoH/3 values

Finding 2: Resolver Deployment Matters More than Protocol Choice

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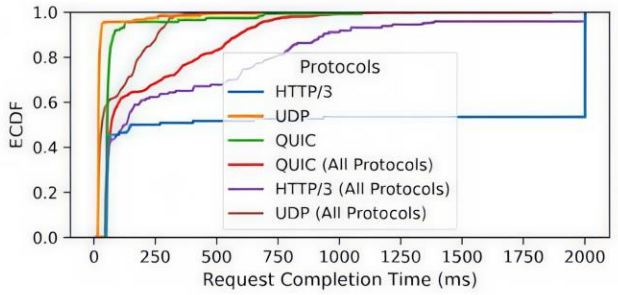
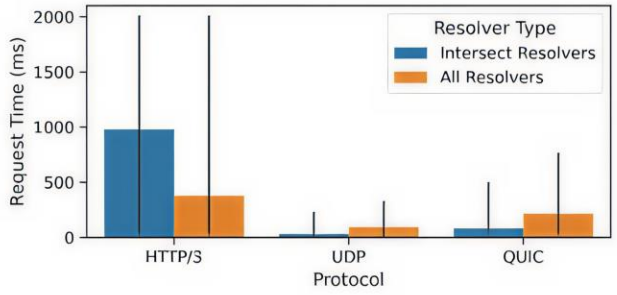


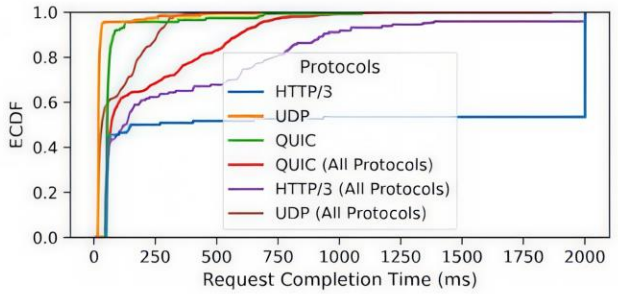
(a) CDF of DNS resolution times



(b) Mean and 95th percentile of resolution times

Fig. 10: Comparison of DNS resolve times between the subset of resolvers supporting all DoE protocols and the complete resolver set.

Finding 2: Resolver Deployment Matters More than Protocol Choice



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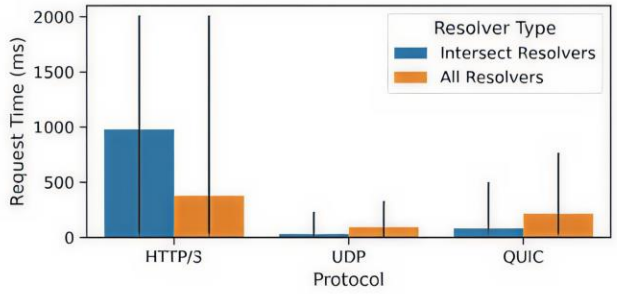

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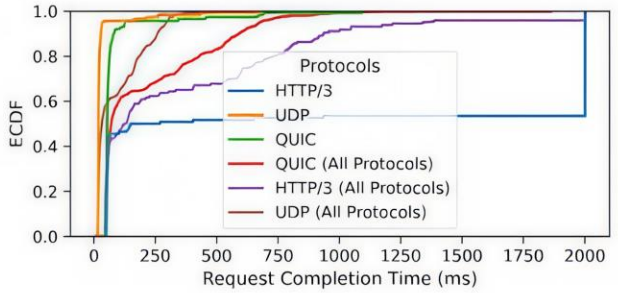

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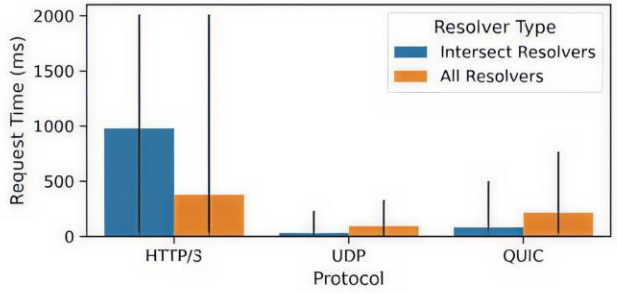

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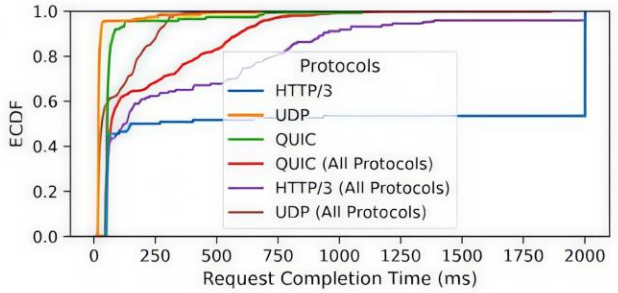

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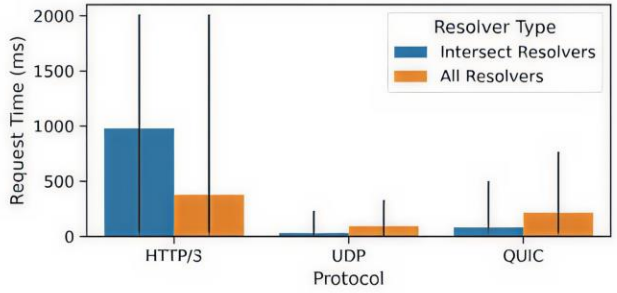

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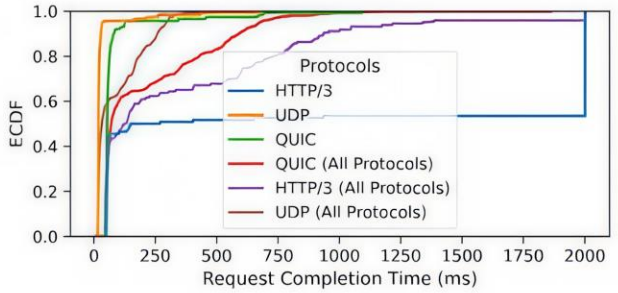

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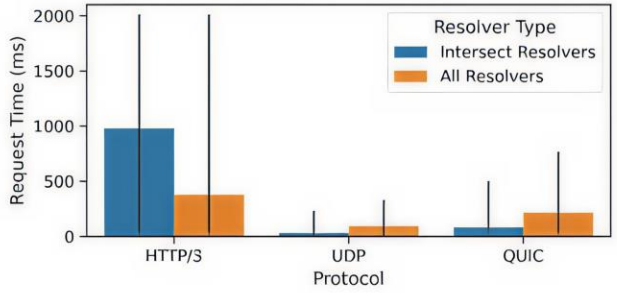

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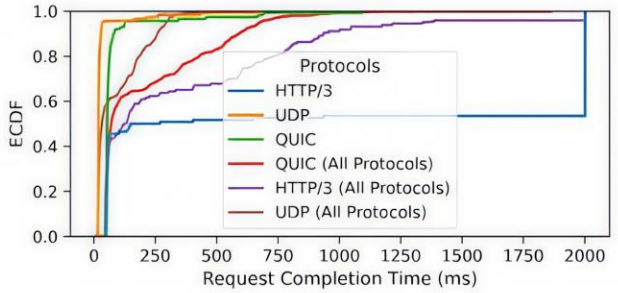

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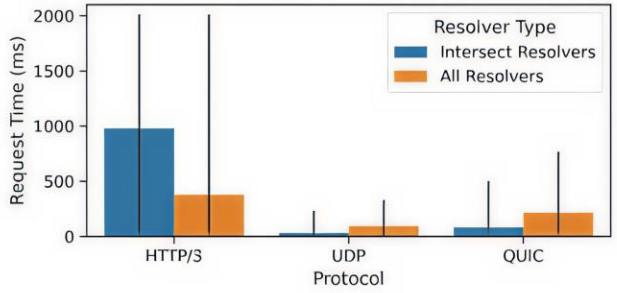

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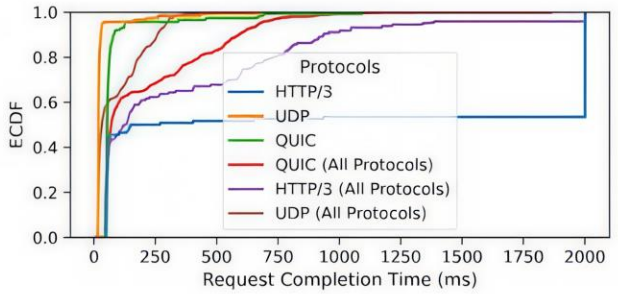

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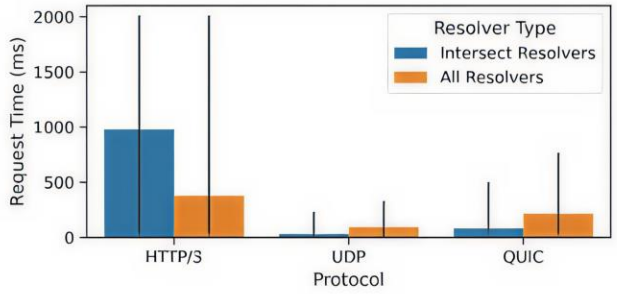

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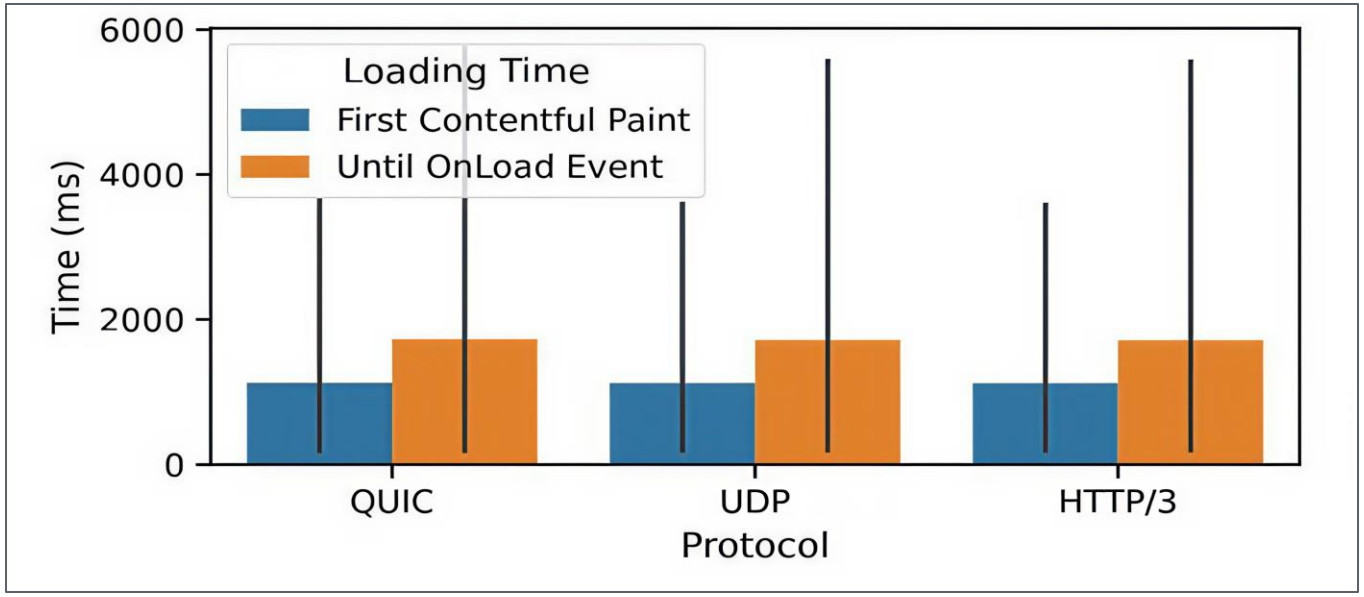

Fig: Overall page loading time per protocol

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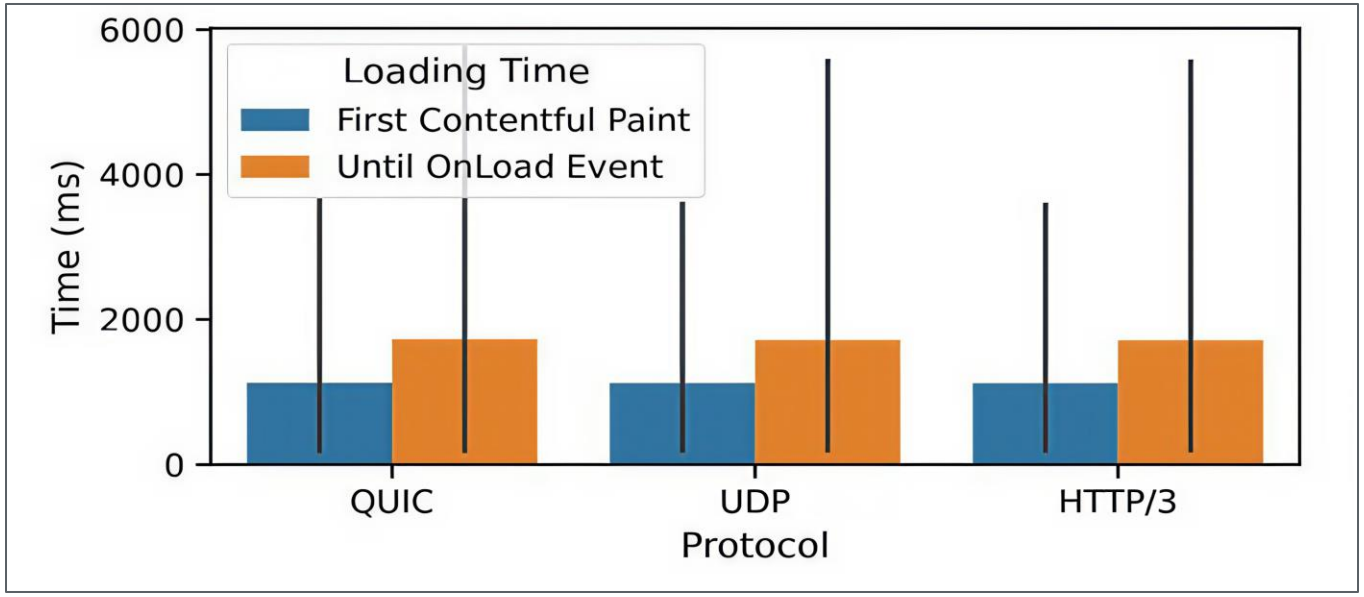

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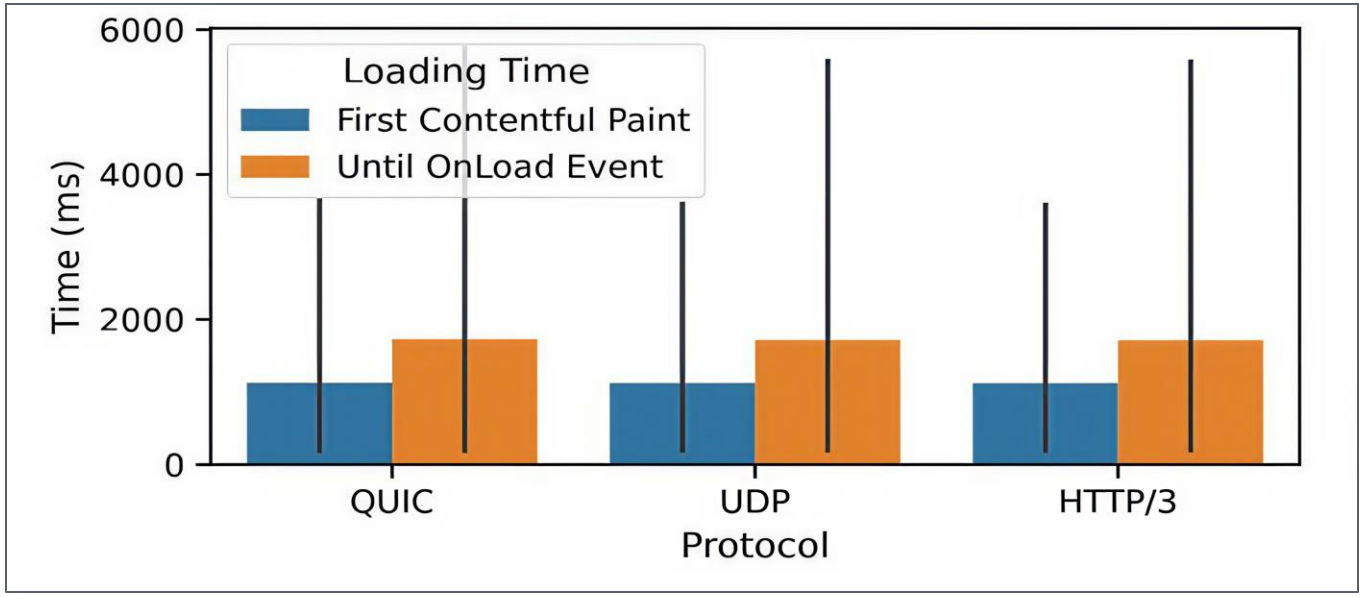

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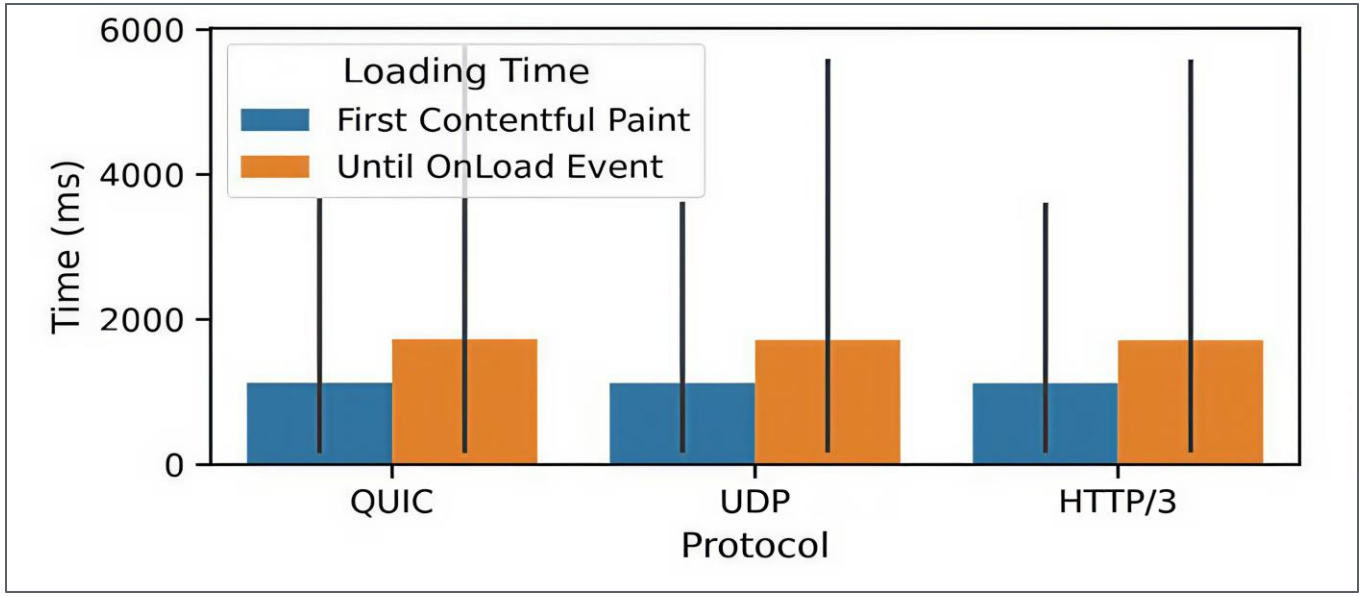

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Why?

DNS resolution overlaps other browser activities.

Browser parallelism hides DNS latency

Finding 4: Website Complexity Does Not Amplify DNS Overhead

Even complex websites experience little additional delay.

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WEBSITE COMPLEXITY

~572K	~1.2 MB	~42	~7	~0.9 s
Websites Large-scale evaluation	Median Payload	Median Objects	DNS Servers contacted (~5 external)	Median Load Time

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PERFORMANCE IMPACT

25-93 ms
DNS Query Duration
Hidden by browser parallelism

≤0.45
Complexity Correlation
No meaningful amplification

-0.2 to 0.3
MIME-Type Correlation
Stable across content types

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Website complexity **increases** overall page load time

NOT

the relative cost of encrypted DNS

Engineering Implications

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DEPLOYMENT

DoQ deployments are mature
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USER EXPERIENCE

Negligible page load difference across protocols
(≤1%)

Ongoing Works – DDR Measurements

Table: Top DoE target endpoints across IPv4 and IPv6

Provider	Target/Service	IPv4							IPv6						
		Count	Share	DoH/1.1	DoH/2	DoH/3	DoT	DoQ	Count	Share	DoH/1.1	DoH/2	DoH/3	DoT	DoQ
Google	dns.google.	287,087	79.06 %	–	✓	✓	✓	–	6,998	83.15 %	–	✓	✓	✓	–
Cloudflare	one.one.one.one.	35,696	9.83 %	–	✓	✓	✓	–	791	9.40 %	–	✓	✓	✓	–
	family.cloudflare-dns.com.	1,612	0.44 %	–	✓	✓	✓	–	24	0.29 %	–	✓	✓	✓	–
	security.cloudflare-dns.com.	979	0.27 %	–	✓	✓	✓	–	37	0.44 %	–	✓	✓	✓	–
Cisco	dns.opendns.com.	6,912	1.90 %	–	✓	–	✓	–	106	1.26 %	–	✓	–	✓	–
	dns.umbrella.com.	6,912	1.90 %	–	✓	–	✓	–	106	1.26 %	–	✓	–	✓	–
	doh.opendns.com.	6,842	1.88 %	–	✓	–	–	–	106	1.26 %	–	✓	–	–	–
	doh.umbrella.com.	6,842	1.88 %	–	✓	–	–	–	106	1.26 %	–	✓	–	–	–
	familyshield.opendns.com.	1,755	0.48 %	–	✓	–	✓	–	0	0.00 %	–	–	–	–	–
Quad9	dns.quad9.net.	8,505	2.34 %	–	✓	–	✓	–	142	1.69 %	–	✓	–	✓	–
Total	–	**363,142**	**100.00 %**	–	–	–	–	–	**8,416**	**100.00 %**	–	–	–	–	–

Finding 4: Website Complexity Does Not Amplify DNS Overhead

Metric	Statistic	Significance
Study Scale	**572,345 websites**	Large-scale representative dataset
Median Webpage Size	**1.2 MB**	Establishes typical data payload
Median Resource Count	**42 Objects**	Portrays structural density
Median DNS Infrastructure	**7 (~5 external)**	Reflects high reliance on 3rd party microservices
Median Page Load Time	**~0.9 seconds**	Overall performance benchmark over all protocols
Query Duration	**25-93 ms**	Easily overlapped by browser activity
Complexity penalty correlation	**Weak (≤0.45)**	**Complexity does not meaningfully amplify performance penalty of DoE overhead**
Total Load Time Correlation	**Positive**	**Complexity increases total load time but does not change the relative cost of DoE**
MIME-Type Correlation	**Weak (-0.2 to 0.3)**	**Specific content types do not significant affect the penalty**
Performance Penalty Stability	**Stabilizes near zero**	**Browser task parallelization absorbs the minor overhead of encrypted handshakes**