

Lazy Eye Inspection: Capturing the State of Happy Eyeballs Implementations

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Motivation

Increasing number of connection initialization parameters

- IPv6 vs IPv4
- QUIC vs TLS/TCP
- Encrypted Client Hello vs normal TLS
- HTTP/3 vs HTTP/2 vs HTTP/1.1

Users want the best possible experience

- Best possible protocol stack! (speed, privacy, ...)
 - Any service is better than none!
- Possible solution: Happy Eyeballs

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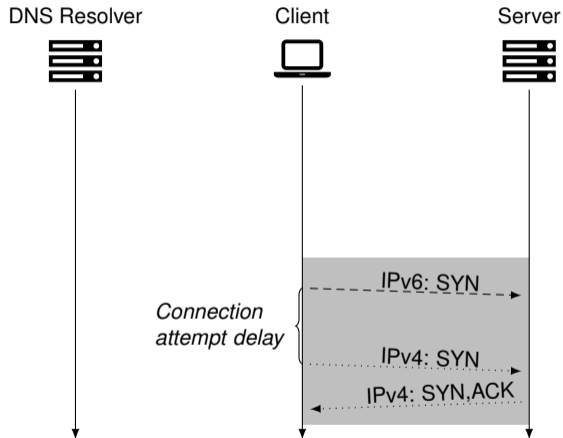
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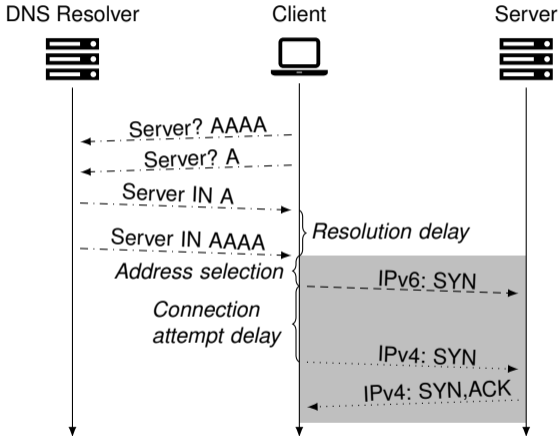
- Best possible protocol stack! (speed, privacy, . . .)
 - Any service is better than none!
- Possible solution: Happy Eyeballs

Happy Eyeballs



- Version 1 (RFC 6555, 2012):
 - Prioritize IPv6 when IPv6 and IPv4 are available
 - Guidelines for address selection
 - Guidelines for connection establishments and delays
- Version 2 (RFC 8305, 2017):
 - Incorporates DNS resolution to prioritize IPv6
 - Guidelines for DNS queries
 - Extended guidelines for address selection

Happy Eyeballs



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 - Guidelines for DNS queries
 - Extended guidelines for address selection

Happy Eyeballs

Parameter	HEv1 (2012)	HEv2 (2017)
Considered protocols	IPv4, IPv6	IPv4, IPv6, DNS
DNS Records	-	AAAA, A
Resolution Delay	-	50 ms
Address selection	IPv6 once, then IPv4	alternating
Fixed Conn. Attempt Delay	150-250 ms	250 ms
↳Min/Rec./Max when dynamic	-	10 ms / 100 ms / 2 s

Research Questions

How do web clients implement Happy Eyeballs?

One could look at the source code or ask browser developers
but we are researchers

What is the current state of Happy Eyeballs implementations by browsers?

How can we support the development of HEv3?

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How can we support the development of HEv3?

Measurement Approach

Web-based Testing Tool

- Measurements provided via a webpage
- Uses Javascript to initiate measurements
- Client interprets results and sends them to the server for evaluation
- Collect results in real networks, devices, and browser setups
- Available to **any device and browser** supporting Javascript

Code is open source and under active development

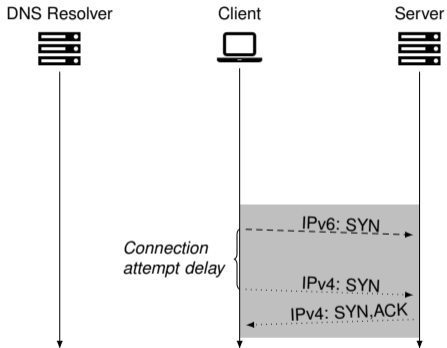
happy-eyeballs.net:



Web-based Testing Tool

Measurement Setup:

- Connection attempt delay:
 - Added artificial delay using tc-netem
 - Different IP addresses assigned to specific delays
- Resolution Delay:
 - Custom authoritative name server
 - Delays responses based on queried domain



Connection Attempt Delay

Chrome

Test Run #	Started at	Delays [ms]																		
		0	50	100	150	200	250	300	400	500	600	750	1000	1250	1500	1750	2000	3000	4000	5000
1 (1/10) >	9/17/2025, 5:29:27 PM	v6	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (2/10) >	9/17/2025, 5:29:41 PM	v6	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (3/10) >	9/17/2025, 5:29:56 PM	v6	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (4/10) >	9/17/2025, 5:30:10 PM	v6	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4

- Attempts an IPv6 connection first
- Static connection attempt delay of 300ms
- Firefox uses a static delay of 250ms

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1 (2/10) >	9/17/2025, 5:29:41 PM	v6	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (3/10) >	9/17/2025, 5:29:56 PM	v6	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (4/10) >	9/17/2025, 5:30:10 PM	v6	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4

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Connection Attempt Delay

Safari

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		0	50	100	150	200	250	300	400	500	600	750	1000	1250	1500	1750	2000	3000	4000	5000
1 (1/10) ✕	9/19/2025, 8:51:39 PM	v6	v6	v6	v6	v6	v4	v4	v4	v4	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (2/10) ✕	9/19/2025, 8:52:02 PM	v6	v6	v6	v6	v6	v4	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (3/10) ✕	9/19/2025, 8:52:25 PM	v6	v6	v4	v4	v4	v4	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (4/10) ✕	9/19/2025, 8:52:45 PM	v6	v6	v6	v4	v6	v4	v4	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4

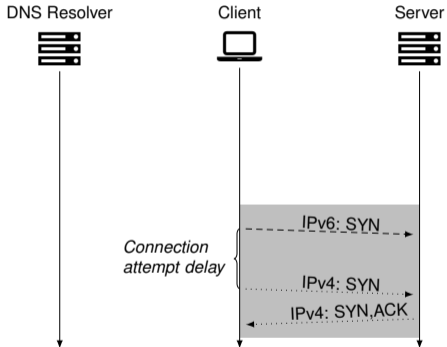
- Attempts an IPv6 connection first
- Dynamic connection attempt delay
- No clear pattern

Resolution Delay

Approach

Measurement Setup:

- Connection attempt delay:
 - Added artificial delay using tc-netem
 - Different IP addresses assigned to specific delays
- Resolution Delay:
 - Custom authoritative name server
 - Delays responses based on parameter in queried domain (e.g.,
... delay_aaaa-50... to delay the AAAA record for 50ms)

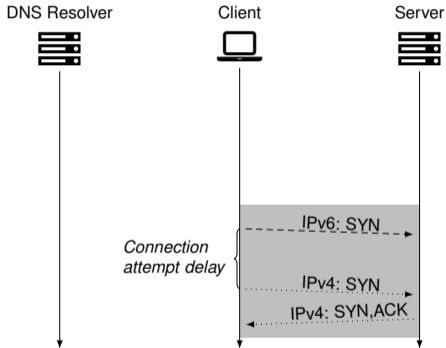


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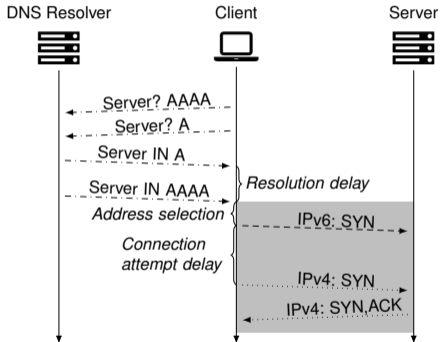


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		0	50	100	150	200	250	300	400	500	600	750	1000	1250	1500	1750	2000	3000	4000	5000	10000	60000
1 (1/10) Delay A ☒	9/19/2025, 8:57:48 PM	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6
1 (1/10) Delay AAAA ☒	9/19/2025, 8:57:48 PM	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (2/10) Delay A ☒	9/19/2025, 8:58:39 PM	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6
1 (2/10) Delay AAAA ☒	9/19/2025, 8:58:39 PM	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4

- Implements a resolution delay of 50 ms
- Recommendation in RFC 8305

Resolution Delay

Firefox

Test Run #	Started at	Delays [ms]																				
		0	50	100	150	200	250	300	400	500	600	750	1000	1250	1500	1750	2000	3000	4000	5000	10000	60000
1 (1/10) Delay A ∞	9/17/2025, 5:50:36 PM	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	err	v6	v6	err	v6
1 (1/10) Delay AAAA ∞	9/17/2025, 5:50:36 PM	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4
1 (2/10) Delay A ∞	9/17/2025, 5:53:40 PM	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	err	err	err	err	err	err	err	err
1 (2/10) Delay AAAA ∞	9/17/2025, 5:53:40 PM	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4

- No resolution delay
- Long test runtime
- → Browser waits for DNS responses for both record types
- Connections time out if no A record is available

Discussion

The behavior does not only depend on the browser:

- Most browsers do not implement resolution delay in their current stable version
 - In some cases, a delayed A record leads to connection errors in general
- DNS resolvers have different cache or timeout behavior
 - Large delays might lead to timeouts
 - Resolvers might implement HE themselves
- Proxy/tunnel setups influence the behaviors
 - e.g., Akamai and Cloudflare show different behavior used as iCloud Private Relay egress proxies

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Conclusion

Summary

- Only Safari supports Happy Eyeballs version 2; others support only version 1
- Resolution delay could heavily impact user experience
- Happy Eyeballs evaluations need to take network conditions into account
- We are expanding our measurement tools for version 3 test cases

happy-eyeballs.net:



Code:



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- Only Safari supports Happy Eyeballs version 2; others support only version 1
- Resolution delay could heavily impact user experience
- Happy Eyeballs evaluations need to take network conditions into account
- We are expanding our measurement tools for version 3 test cases

Add HEv3 functionality

- Add SVCB/HTTPS resource records
- Add QUIC/H3/ECH support
- Extend configurations

happy-eyeballs.net:



Code:



Backup Slides

Happy Eyeballs Parameter

Parameter	HEv1 (2012)	HEv2 (2017)
Considered protocols	IPv4, IPv6	IPv4, IPv6, DNS
DNS Records	-	AAAA, A
Resolution Delay	-	50 ms
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Fixed Conn. Attempt Delay	150-250 ms	250 ms
↳Min/Rec./Max when dynamic	-	10 ms / 100 ms / 2 s

Test Approach Comparison

Local Testbed Framework

- Client and server directly connected in a testbed
- Client uses Selenium capable browser containers for the measurements
- Packet traces are used to infer CAD and RD values
- Not impacted by unknown caching effects
- Limited to available containers

Web-based Testing Tool

- Collect results in real networks, devices, and browser setups
- Uses Javascript to perform the measurements
- Client interprets results and sends them to the server for evaluation
- Fixed number of delay scenarios
- Could be influenced by caching
- Can be used on any browser and device with Javascript support

Firefox Connection Attempt Delay

Test Run #	Started at	Delays [ms]																		
		0	50	100	150	200	250	300	400	500	600	750	1000	1250	1500	1750	2000	3000	4000	5000
1 (1/10) ❌	9/17/2025, 5:46:13 PM	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (2/10) ❌	9/17/2025, 5:46:26 PM	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (3/10) ❌	9/17/2025, 5:46:39 PM	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (4/10) ❌	9/17/2025, 5:46:51 PM	v6	v6	v6	v6	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4	v4

- Attempts an IPv6 connection first
- Static connection attempt delay of 250ms

Chrome Resolution Delay

Test Run #	Started at	Delays [ms]																				
		0	50	100	150	200	250	300	400	500	600	750	1000	1250	1500	1750	2000	3000	4000	5000	10000	60000
1 (1/10) Delay A ☒	9/17/2025, 5:37:37 PM	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6
1 (1/10) Delay AAAA ☒	9/17/2025, 5:37:37 PM	v6	v6	v6	v6	v4	v6	v6	v4	v6	v4	v4	v6	v4	v4	v4	v4	v4	v4	v4	v4	v4
1 (2/10) Delay A ☒	9/17/2025, 5:39:23 PM	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6	v6
1 (2/10) Delay AAAA ☒	9/17/2025, 5:39:23 PM	v6	v6	v6	v4	v6	v4	v6	v6	v4	v6	v4	v6	v6	v4	v4	v4	v4	v4	v4	v4	v4

- No resolution delay
- Long test runtime
- → Browser waits for DNS responses for both record types
- Non-deterministic timeout during resolution