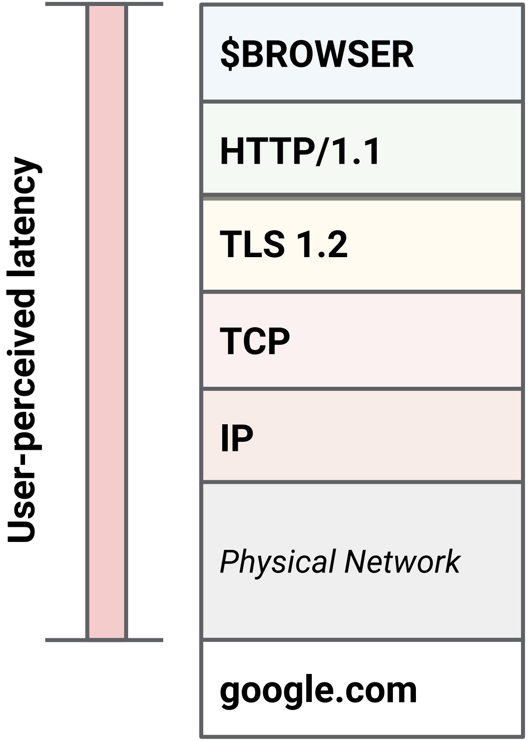
Google™

QUIC

Next generation multiplexed transport over UDP

How do you make the web faster?



User-perceived latency

$BROWSER

HTTP/1.1

TLS 1.2

TCP

IP

Physical Network

google.com

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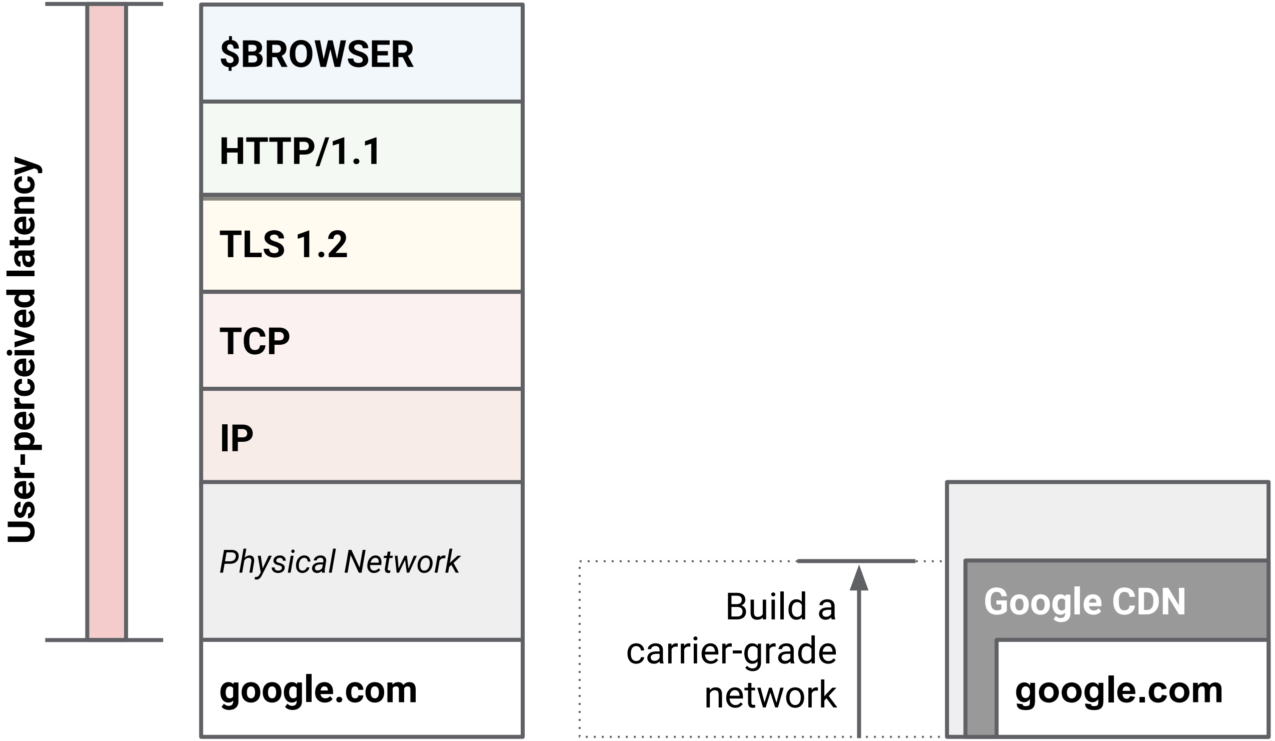

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Physical Network

google.com

Build a carrier-grade network

Google CDN

google.com

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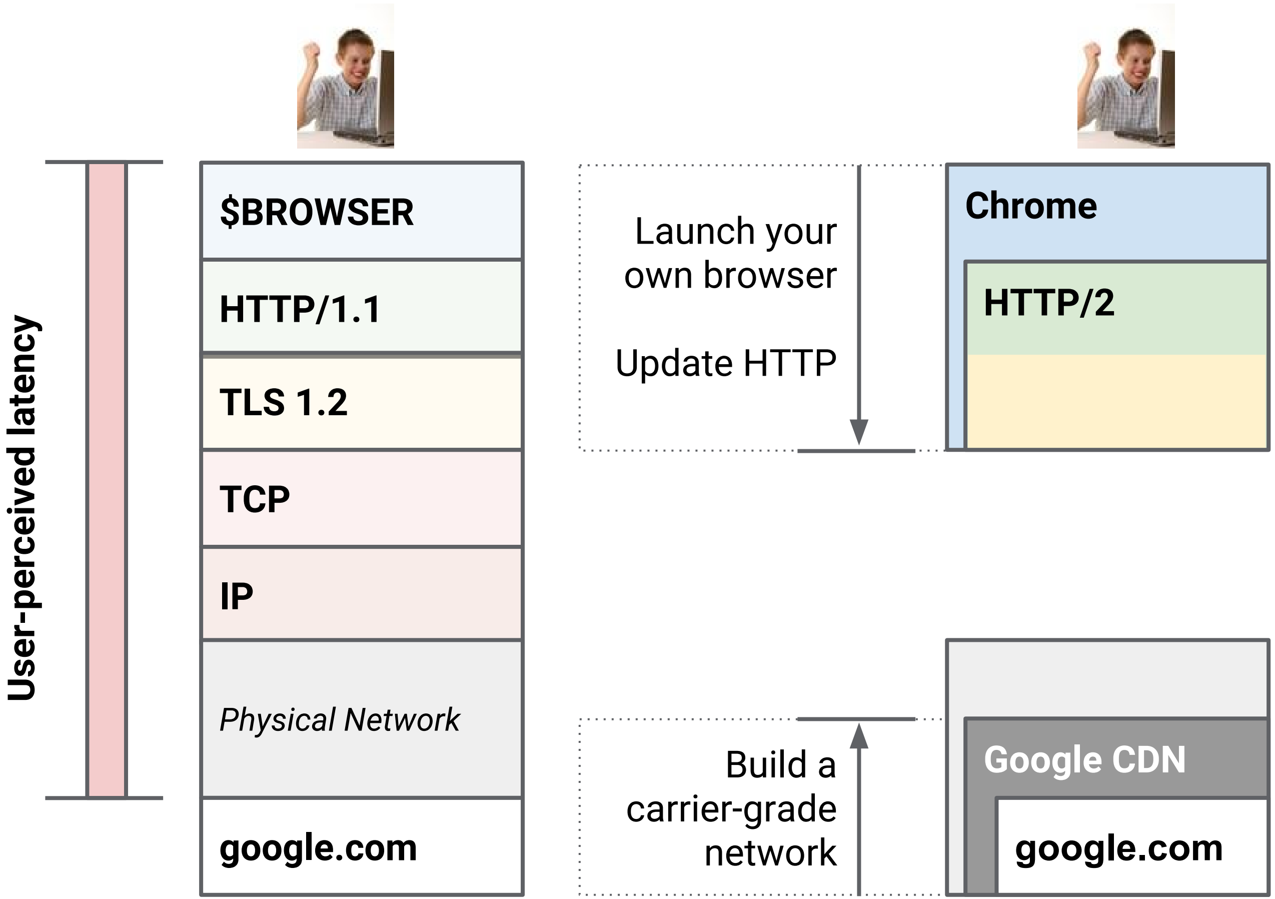

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Launch your own browser

Update HTTP

Build a carrier-grade network

Chrome

HTTP/2

Google CDN

google.com

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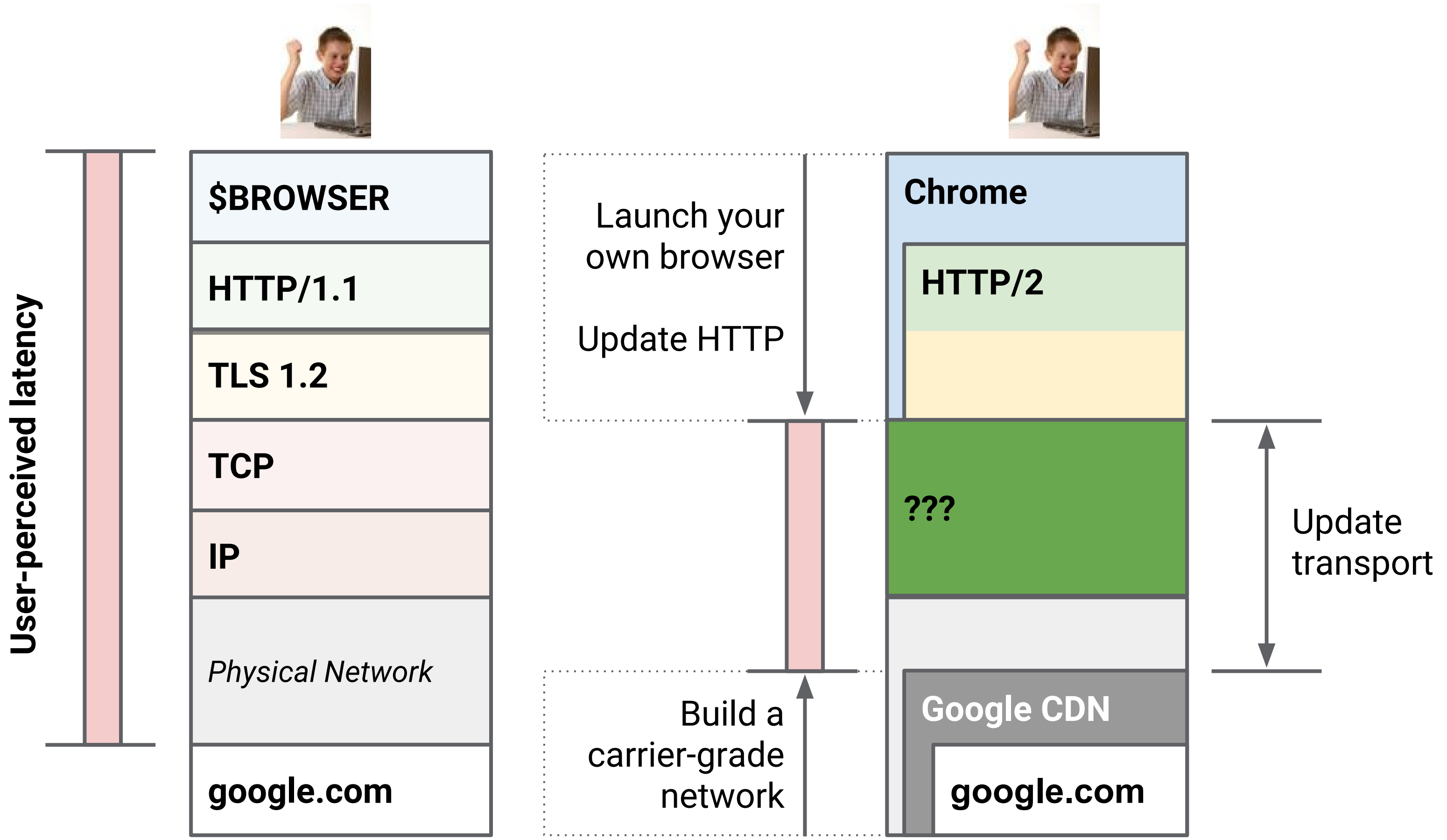

User-perceived latency

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HTTP/2

???

Google CDN

google.com

Update transport

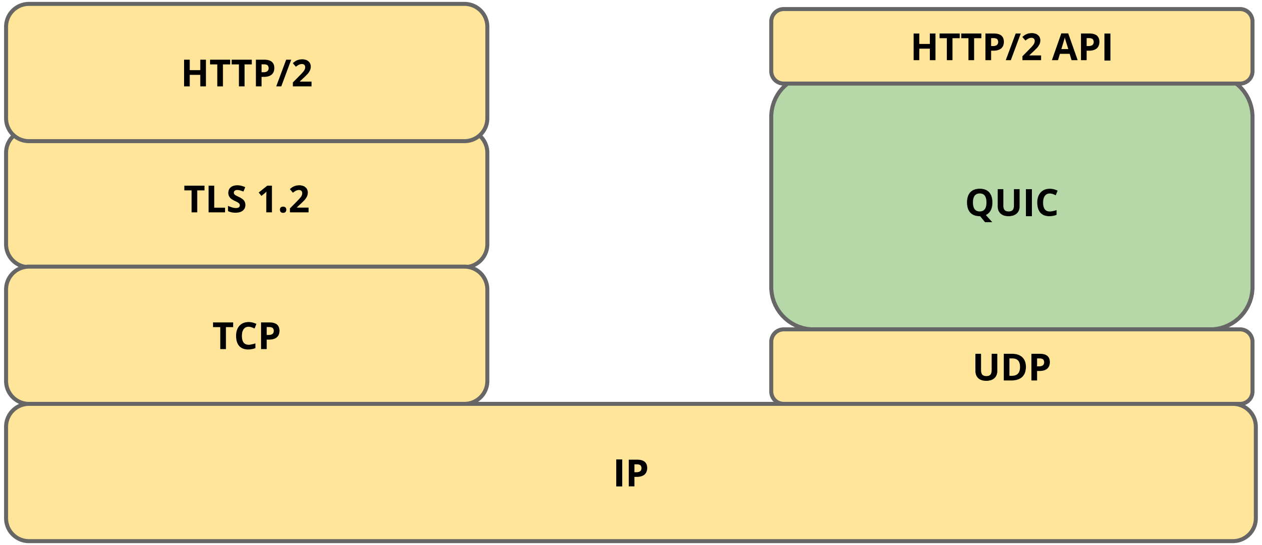
What is QUIC?

QUIC

Quick **U**DP **I**nternet **C**onnections

- A reliable, multiplexed transport over UDP
- Always encrypted
- Reduces latency
- Runs in user-space
- Open sourced in Chromium

Where does it fit?



QUIC Works Great™ when...

You treat UDP like TCP:

- UDP port 443 open
- No UDP rate-limits
- No worse UDP QoS treatment
- Reasonable stateful FW/NAT timeouts
- 5-tuple traffic load balancing

Congestion control & reliability

QUIC builds on decades of experience with TCP

Incorporates TCP best practices

TCP Cubic - fair with TCP

FACK, TLP, F-RTO, Early Retransmit...

Adds signaling improvements that can’t be done to TCP

Loss detection - retransmission uses a new sequence number

More flexibility going forward

Improved congestion feedback, control over acking

Zero-RTT connection establishment

TCP

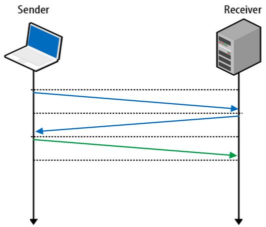
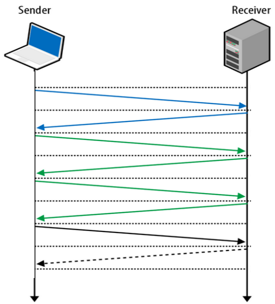


Figure 2-1. Three-way handshake

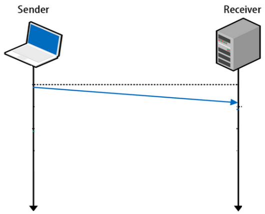
TCP + TLS



e 4-2. TLS handshake protocol

QUIC

(equivalent to TCP + TLS)



Always encrypted

Comparable to TLS
Perfect forward secrecy, with more efficient handshake

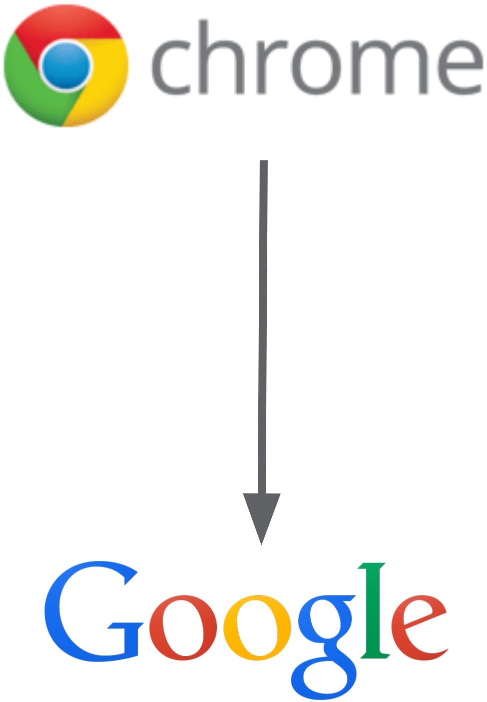
IP spoofing protection
Signed proof of address

Inspired TLS 1.3’s zero RTT handshake
Plan to adopt TLS 1.3 when complete

Effective

How quick is QUIC?

Measuring performance



Controlled Experiments

Client Side
Latency, Bandwidth, Quality of Experience, Errors

Server Side
Latency, Bandwidth, QUIC Success Rate

Fine Grained Analysis
By ASN, Server, OS, Version

Transparency
ISP view on peering.google.com

Performance on Google properties

Faster page loading times

- 5% faster on average
- 1 second faster for web search at 99th-percentile

Improved YouTube Quality of Experience

- 30% fewer rebuffers (video pauses)

More improvements to come

- Bandwidth resumption, forward error correction, etc

Recent Blog Post

Where are the gains from?

Zero-RTT

- Over 50% of the latency improvement (at median and 95th-percentile)

Improved loss recovery

- Over 10x fewer timeout based retransmissions improve tail latency and YouTube video rebuffer rates

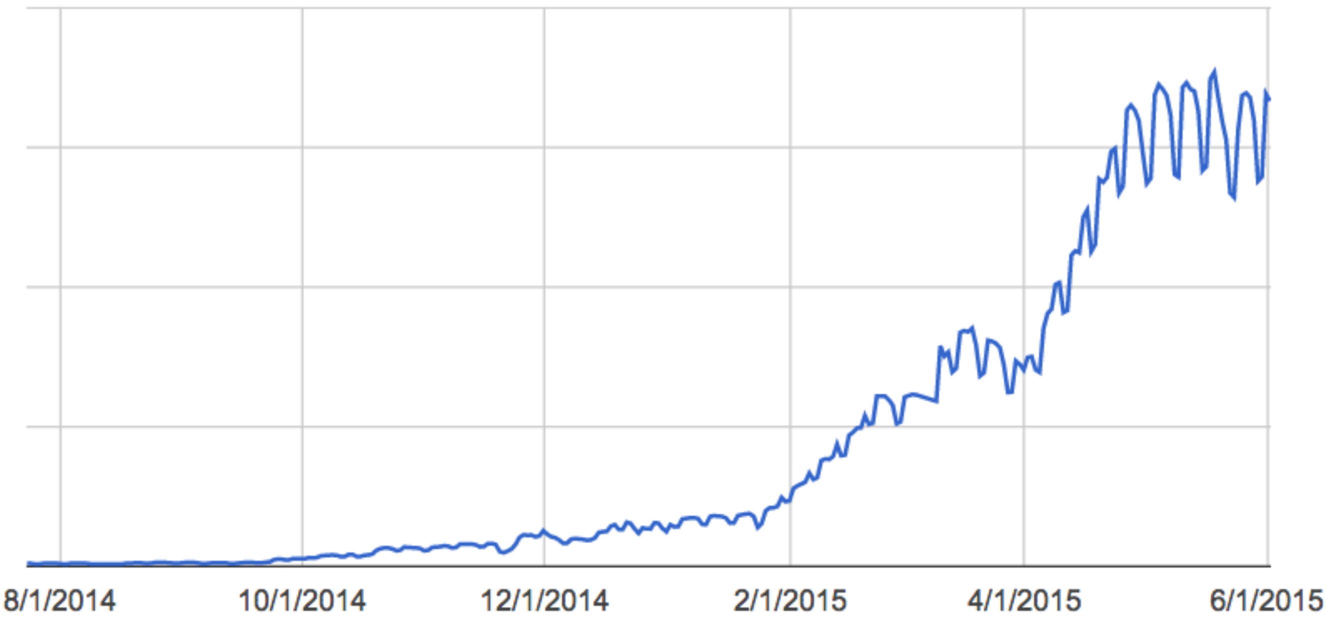
Other, smaller benefits

- e.g. head of line blocking, more efficient framing

Deployment timeline

Tested at scale, with millions of users

- Chrome Canary: June, 2013
- Chrome Stable: April, 2014
- Ramping up for Google traffic: January, 2015



Safe

What we're doing to protect users and networks

Client-side protection

What if UDP is blocked?

- Chrome seamlessly falls back to HTTP/TCP

What if the path MTU is too small?

- QUIC handshake fails, Chrome falls back to TCP

What if a client doesn’t want to use QUIC?

- Chrome flag / administrative policy to disable QUIC

When client-side protection is not enough...

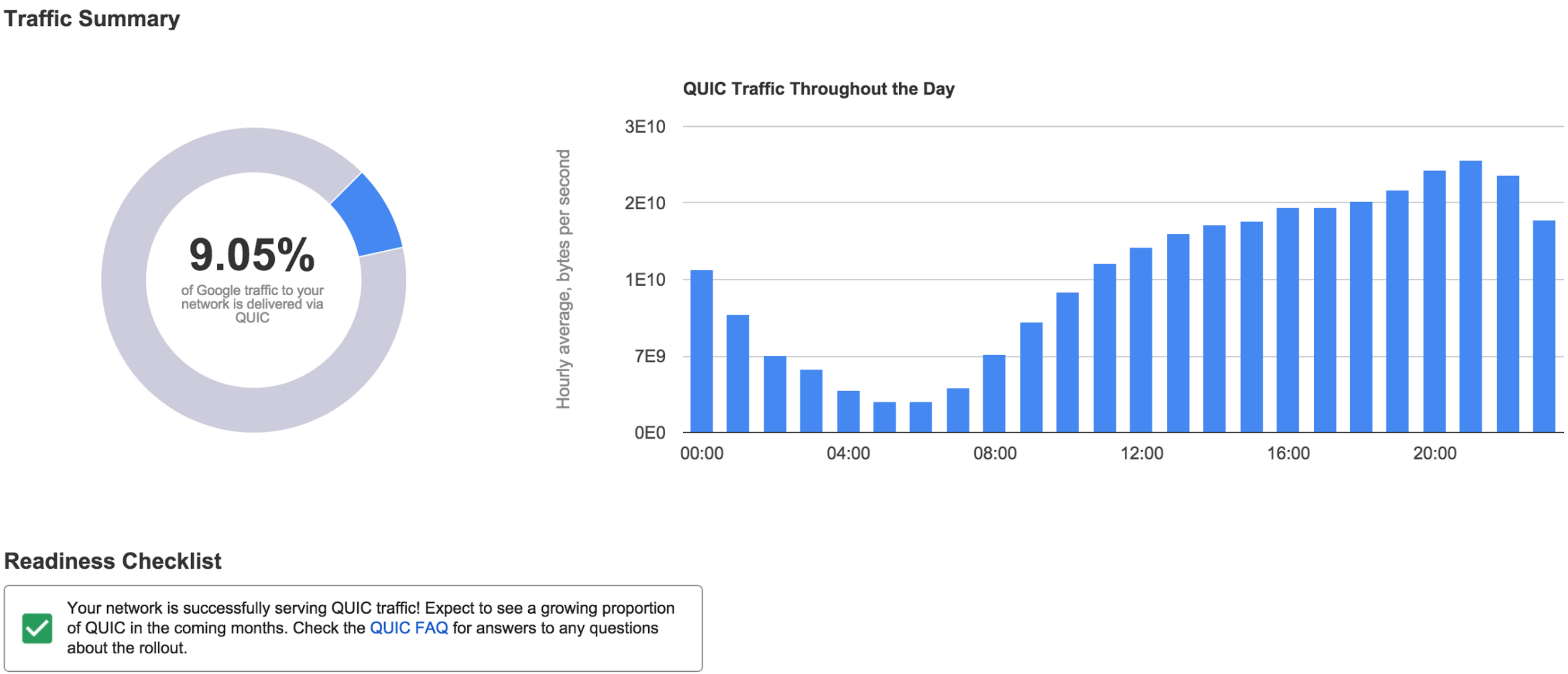
As a last resort, Google disables QUIC to specific ASNs

- This is used as a fallback to protocol features

Why do we disable QUIC delivery?

- Degraded quality of experience measured
- Indications of UDP rate limiting at peak times of day
- End user reports (via chromium.org)

QUIC on your network



Traffic Summary

9.05%
of Google traffic to your network is delivered via QUIC
QUIC Traffic Throughout the Day
Hourly average, bytes per second
3E10
2E10
1E10
7E9
0E0
00:00
04:00
08:00
12:00
16:00
20:00

Readiness Checklist

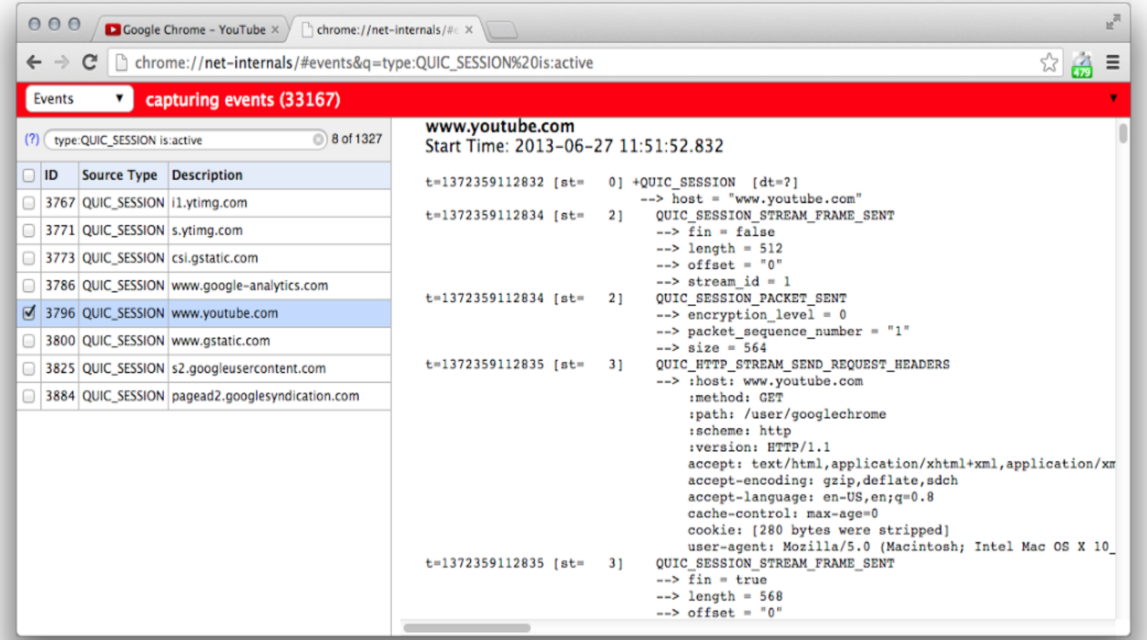
✓ Your network is successfully serving QUIC traffic! Expect to see a growing proportion of QUIC in the coming months. Check the QUIC FAQ for answers to any questions about the rollout.

Get access at peering.google.com/quicfaq

Debugging Tools: Chrome

chrome://net-internals

- Active QUIC sessions
- Captures all events
- Important for filing Chromium bugs



Google Chrome - YouTube
chrome://net-internals/#e
chrome://net-internals/#events&q=type:QUIC_SESSION%20is:active
479
Events
capturing events (33167)
(?)
type:QUIC_SESSION is:active
8 of 1327

□	ID	Source Type	Description
□	3767	QUIC_SESSION	i1.ytimg.com
□	3771	QUIC_SESSION	s.ytimg.com
□	3773	QUIC_SESSION	csi.gstatic.com
□	3786	QUIC_SESSION	www.google-analytics.com
☑	3796	QUIC_SESSION	www.youtube.com
□	3800	QUIC_SESSION	www.gstatic.com
□	3825	QUIC_SESSION	s2.googleusercontent.com
□	3884	QUIC_SESSION	pagead2.googlesyndication.com

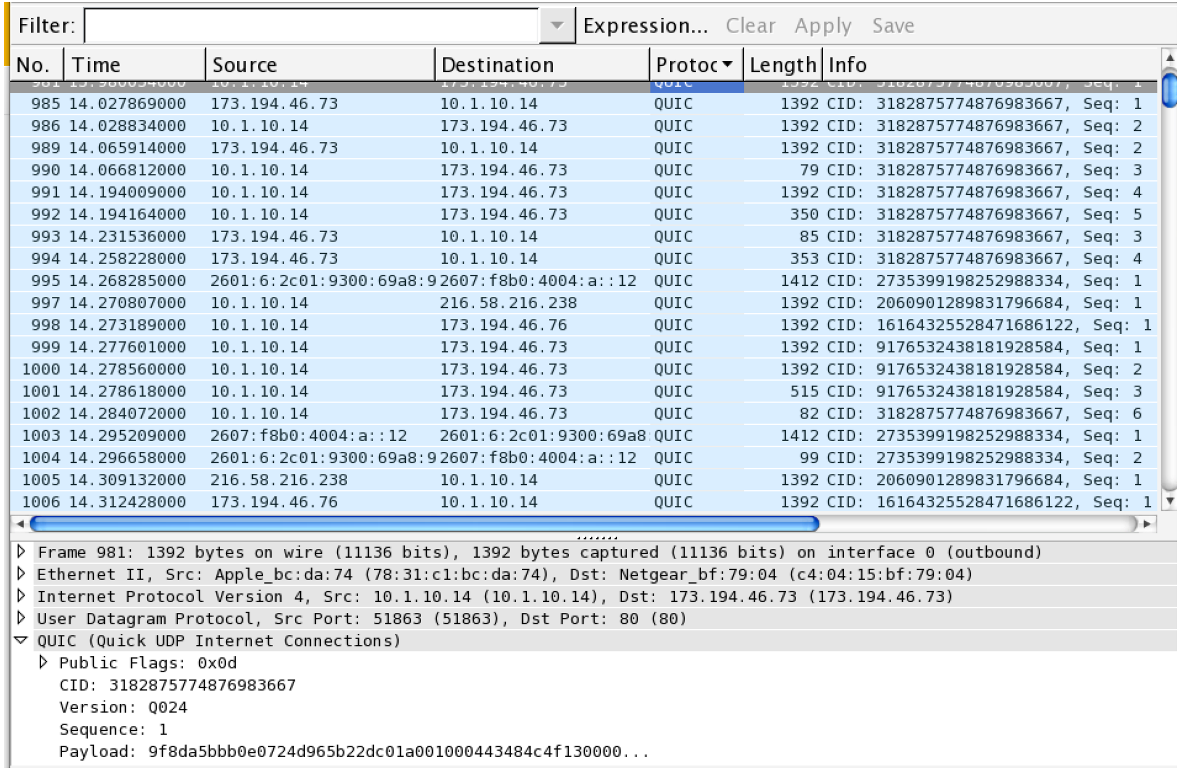
www.youtube.com
Start Time: 2013-06-27 11:51:52.832

```
t=1372359112832 [st=   0] +QUIC_SESSION  [dt=?]
                           --> host = "www.youtube.com"
t=1372359112834 [st=   2]    QUIC_SESSION_STREAM_FRAME_SENT
                             --> fin = false
                             --> length = 512
                             --> offset = "0"
                             --> stream_id = 1
t=1372359112834 [st=   2]    QUIC_SESSION_PACKET_SENT
                             --> encryption_level = 0
                             --> packet_sequence_number = "1"
                             --> size = 564
t=1372359112835 [st=   3]    QUIC_HTTP_STREAM_SEND_REQUEST_HEADERS
                             --> :host: www.youtube.com
                                 :method: GET
                                 :path: /user/googlechrome
                                 :scheme: http
                                 :version: HTTP/1.1
                                 accept: text/html,application/xhtml+xml,application/xm
                                 accept-encoding: gzip,deflate,sdch
                                 accept-language: en-US,en;q=0.8
                                 cache-control: max-age=0
                                 cookie: [280 bytes were stripped]
                                 user-agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_
t=1372359112835 [st=   3]    QUIC_SESSION_STREAM_FRAME_SENT
                             --> fin = true
                             --> length = 568
                             --> offset = "0"
```

Debugging Tools: Wireshark

Parses

- Protocol: QUIC
- CID: Connection ID
- Seq: Sequence number
- Version: ie: Q024
- Public flags: 1 byte
- Payload: Encrypted



No.	Time	Source	Destination	Protoc	Length	Info
981	13.980054000	10.1.10.14	173.194.46.73	QUIC	1392	CID: 3182875774876983667, Seq: 1
985	14.027869000	173.194.46.73	10.1.10.14	QUIC	1392	CID: 3182875774876983667, Seq: 1
986	14.028834000	10.1.10.14	173.194.46.73	QUIC	1392	CID: 3182875774876983667, Seq: 2
989	14.065914000	173.194.46.73	10.1.10.14	QUIC	1392	CID: 3182875774876983667, Seq: 2
990	14.066812000	10.1.10.14	173.194.46.73	QUIC	79	CID: 3182875774876983667, Seq: 3
991	14.194009000	10.1.10.14	173.194.46.73	QUIC	1392	CID: 3182875774876983667, Seq: 4
992	14.194164000	10.1.10.14	173.194.46.73	QUIC	350	CID: 3182875774876983667, Seq: 5
993	14.231536000	173.194.46.73	10.1.10.14	QUIC	85	CID: 3182875774876983667, Seq: 3
994	14.258228000	173.194.46.73	10.1.10.14	QUIC	353	CID: 3182875774876983667, Seq: 4
995	14.268285000	2601:6:2c01:9300:69a8:9	2607:f8b0:4004:a::12	QUIC	1412	CID: 2735399198252988334, Seq: 1
997	14.270807000	10.1.10.14	216.58.216.238	QUIC	1392	CID: 2060901289831796684, Seq: 1
998	14.273189000	10.1.10.14	173.194.46.76	QUIC	1392	CID: 16164325528471686122, Seq: 1
999	14.277601000	10.1.10.14	173.194.46.73	QUIC	1392	CID: 9176532438181928584, Seq: 1
1000	14.278560000	10.1.10.14	173.194.46.73	QUIC	1392	CID: 9176532438181928584, Seq: 2
1001	14.278618000	10.1.10.14	173.194.46.73	QUIC	515	CID: 9176532438181928584, Seq: 3
1002	14.284072000	10.1.10.14	173.194.46.73	QUIC	82	CID: 3182875774876983667, Seq: 6
1003	14.295209000	2607:f8b0:4004:a::12	2601:6:2c01:9300:69a8	QUIC	1412	CID: 2735399198252988334, Seq: 1
1004	14.296658000	2601:6:2c01:9300:69a8:9	2607:f8b0:4004:a::12	QUIC	99	CID: 2735399198252988334, Seq: 2
1005	14.309132000	216.58.216.238	10.1.10.14	QUIC	1392	CID: 2060901289831796684, Seq: 1
1006	14.312428000	173.194.46.76	10.1.10.14	QUIC	1392	CID: 16164325528471686122, Seq: 1

```
▷ Frame 981: 1392 bytes on wire (11136 bits), 1392 bytes captured (11136 bits) on interface 0 (outbound)
▷ Ethernet II, Src: Apple_bc:da:74 (78:31:c1:bc:da:74), Dst: Netgear_bf:79:04 (c4:04:15:bf:79:04)
▷ Internet Protocol Version 4, Src: 10.1.10.14 (10.1.10.14), Dst: 173.194.46.73 (173.194.46.73)
▷ User Datagram Protocol, Src Port: 51863 (51863), Dst Port: 80 (80)
▽ QUIC (Quick UDP Internet Connections)
  ▷ Public Flags: 0x0d
    CID: 3182875774876983667
    Version: Q024
    Sequence: 1
    Payload: 9f8da5bbb0e0724d965b22dc01a001000443484c4f130000...
```

What’s Next?

Future Improvements

- Forward Error Correction
- Connection Mobility
- Multipath
- Congestion Control

Open source implementations

Servers

- Open source test server included in Chromium
- Working to support QUIC in Apache Traffic Server

Clients

- Open source Chromium client library for desktop and mobile
- Google Chrome and some Google Android apps
- Working with other browsers.

QUIC at the IETF

Nov 2013	Initially Presented
Mar 2015	QUIC Crypto
July 2015	Updated presentation
Ongoing	Including Zero-RTT handshake in TLS 1.3

Review: QUIC Summary

- Reliable, multiplexed transport
- Runs over UDP
- Always encrypted
- Lower latency connection establishment
- Optional FEC
- Rapidly evolving user-space implementation
- Open source

Review: Providing Safe Passage

Treat UDP like TCP:

- UDP port 443 open
- No UDP rate-limits
- No differential UDP QoS
- Reasonable stateful FW/NAT timeouts
- Sensible hash-based traffic distribution

QUIC

ISP Resources for QUIC: peering.google.com/quicfaq

Ian Swett
ianswett@google.com