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NET401

Deliver great experiences with QUIC on Amazon CloudFront

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Why is Jim Roskind talking about QUIC?

- Architected/designed/led development of QUIC
  - “Quick UDP internet connections” evolved into IETF HTTP/3 Standard
- 1995: Netscape on browser/server and security
  - Helped design SSL 2.0 (TLS 1.0); designed signed Java; was Netscape’s “Java Security Architect”
- 2008: Worked at Google on making Chrome (go faster)
  - Proposed/architected/designed . . .
    - Implemented metrics infrastructure (central to QUIC)
    - Implemented DNS pre-resolution, TCP pre-connection
- 2016: Amazon VP/Distinguished Engineer

QUIC: “Quick UDP Internet Connections”

- Protocol to supplant HTTP and more
- Cryptographic privacy and tamper resistance
  - TLS
- Multiplexes requests (like HTTP/2)
  - One congestion-controlled flow
  - Improved latency, reduced variance
- Sequenced UDP packets
  - Evolving congestion control

. . . but why do we need/want/use it??

QUIC is all about speed to user: Latency

- Faster and reliable connections
  - Fewer round trips to connect
  - Reduces time-to-first-byte
  - Reduces latency variance in delivered bytes
  - Better web performance in congested networks

- Amazon CloudFront supports HTTP/3!
  - Available worldwide
  - Full TLS Security

  . . . and you should enable it!

Don’t keep the customer waiting
Give customers what they want!

Overview

Context/justification

Background history of HTTP latency/bandwidth

Problems

Solutions

SnapChat deployment using Amazon CloudFront

Q&A

Context for developing a new protocol

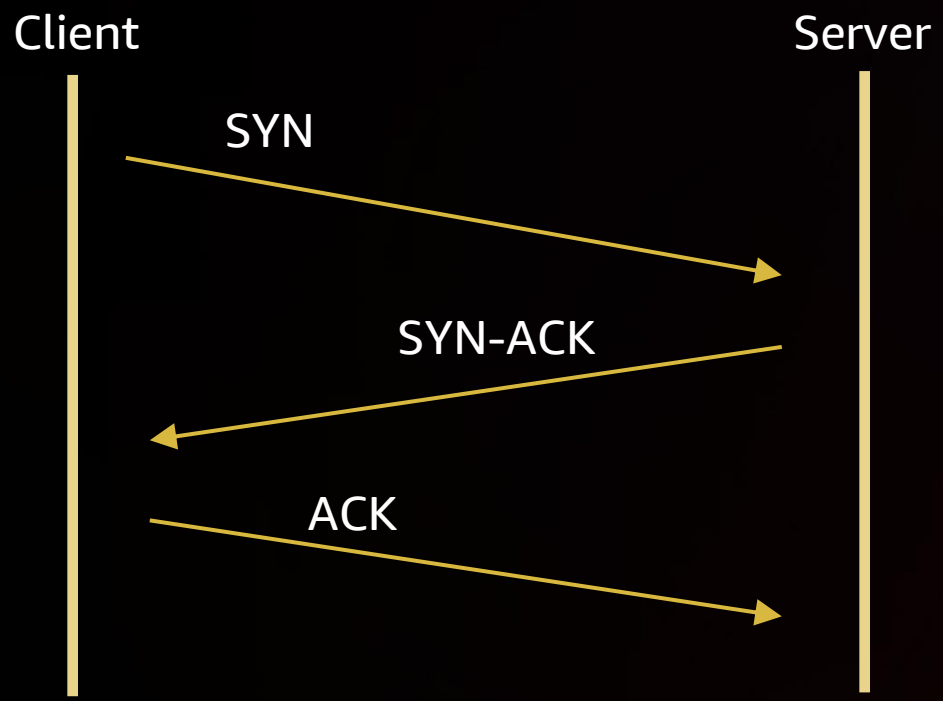
- Customer (obsessed?) measurement focus
  - Don’t keep the customer waiting: **Reduce latency**
- Stand on shoulders of (protocol) giants
  - Expertise history/support (TLS)
  - Recent development of SPDY (HTTP/2)
  - Customer metrics infrastructure (histograms)
- Luck

Details of pre-existing problems

RTT up to 400ms (almost a half second!)

- Speed of light
- US cross-continent speed-of-light RTT was 20ms
  - 60–100ms with packet handling :-/
- Target < 200ms
  - Insist on the highest standards!
- Can’t afford many round trips on critical path!
  - Each HTTP/1.0 request uses a fresh TCP connection
  - www.example.com: 150 HTTP requests on home page!

TCP connection establishment



Time-consuming RTT (round trip time)

400ms average to India!

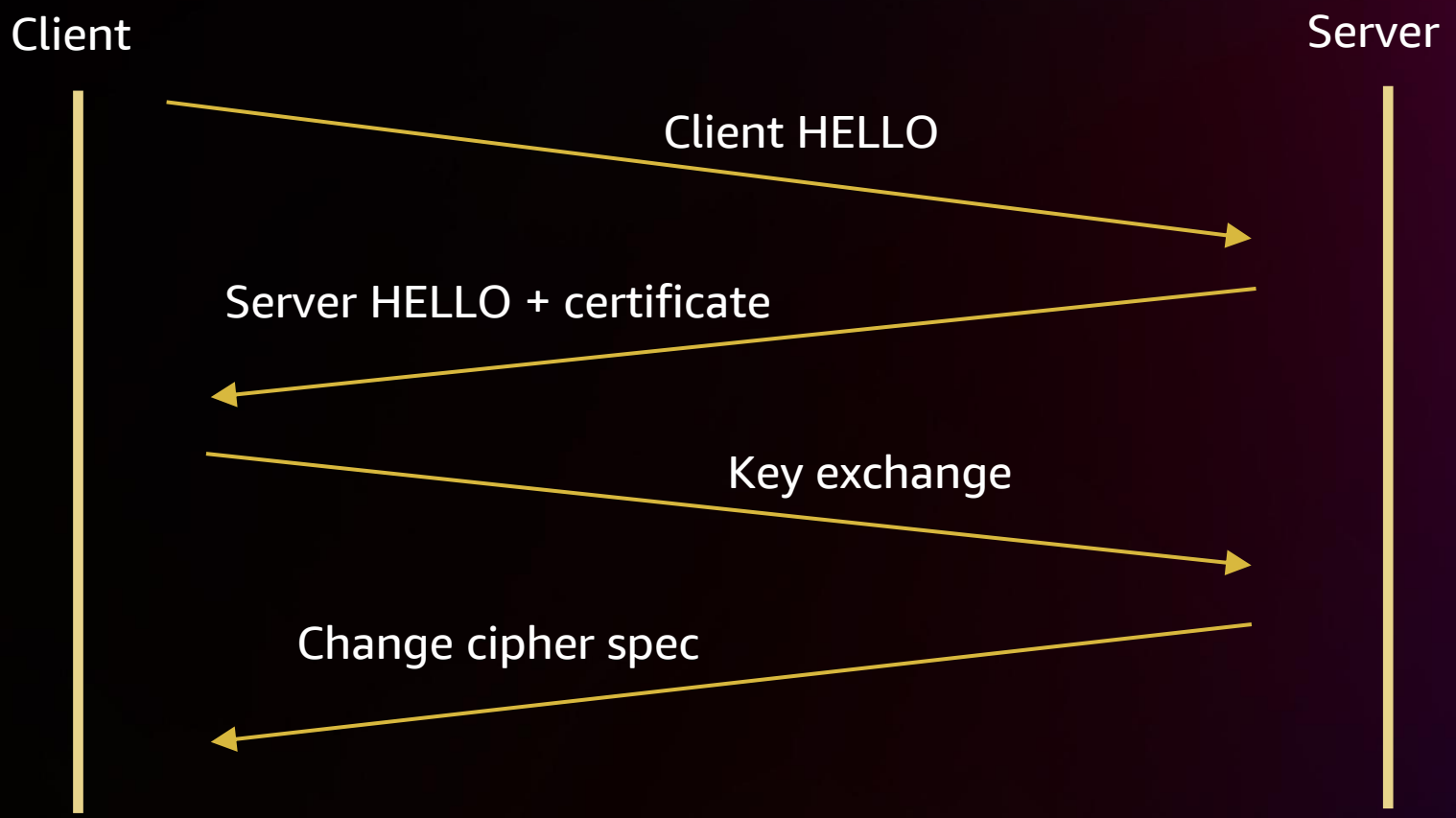
50ms median in USA

Why does TCP have to wait for SYN-ACK?

- SYN-flood (DOS) attacks
- Blowback attacks
- Servers **can't** be very trusting

- Security is lurking even at the TCP level
  - [TCP Fast Open tried to help . . .]

TLS adds another RTT+ after TCP connects



HTTP/1.1 supported pipelining

- (Try to) Reuse TCP/TLS connection
  - Minor problem: In-order-response
- Major problem: Broken implementations
  - Some servers clear input buffer after replying!?!
- No way to use it in the wild
  - Usable in datacenters (both endpoints controlled)
  - “In order replies” ➔ head-of-line (HOL) blocking

Circumventing TCP costs

- Multiple parallel HTTP (TCP) connections
- Servers don’t like being overloaded by impatient browsers
  - Limit browser to 6 connections per server (domain!)
- Big sites define “extra domains” (to hog bandwidth!)
  - www.example.com fetched 150 resources, 17 distinct domains
- Flows on one connection hurt other connections (latency variance!)

Standardization helps modernize TCP

- Initial congestion window bumped to 12–16 packets

. . . but still . . .

- Parallel streams battle for bandwidth
  - Variance in latency/packet loss is high
- HTTP resends client **header** info for **each** connection
  - Bandwidth is wasted, increasing congestion

HTTP/2 (SPDY) multiplexed streams

- Kudos to Mike Belshe and Roberto Peon!

- Each HTTP/GET or HTTP/PUT is a multiplexed stream
  - Large PUT won’t delay transmitting other GETs
- Responses are multiplexed/interspersed in any order
  - Servers respond ASAP (out-of-order!)

- Prioritize JavaScript and style sheet responses

SPDY (HTTP/2) removes redundancy

- Data compression of common headers
  - Send UserAgent string only once
  - Send cookies only once
  - Compress content across streams

- Streams share single flow congestion window
  - No fighting/variance among streams

HTTP/2 on TCP: Weaknesses

- TCP initial congestion window of 2 packets was terrible
  - Harmed HTTP/2 more than parallel HTTP/1
- 1–2% packet loss on internet
  - AIMD (additive increase, multiplicative decrease)
  - N% backoff harmed HTTP/2 more than HTTP/1
- In-order TCP delivery ➔ HOL blocking
  - SPDY used TCP, so kernel withheld packets
- TLS induced HOL blocking also (cipher block chaining)

QUIC: Quick UDP internet connections

TCP and TLS were holding HTTP back

- We wanted to avoid HOL blocking
  - TCP and TLS induced HOL blocking
- We wanted congestion control to evolve faster
  - Stop arguing with operating systems vendors
  - 5–10 year deploy/test is too slow

Was a new protocol feasible?

- Must handle packets separately
  - Critical to reduce HOL blocking
- Define a new IP protocol? (avoid UDP?)
  - Nope: Must use UDP

- Can clients reach web host servers using UDP?
- Network address translation (NAT) versus UDP?
- Load balancers versus UDP?
- Can servers handle high UDP loads?

Measure: UDP reachability for our customers

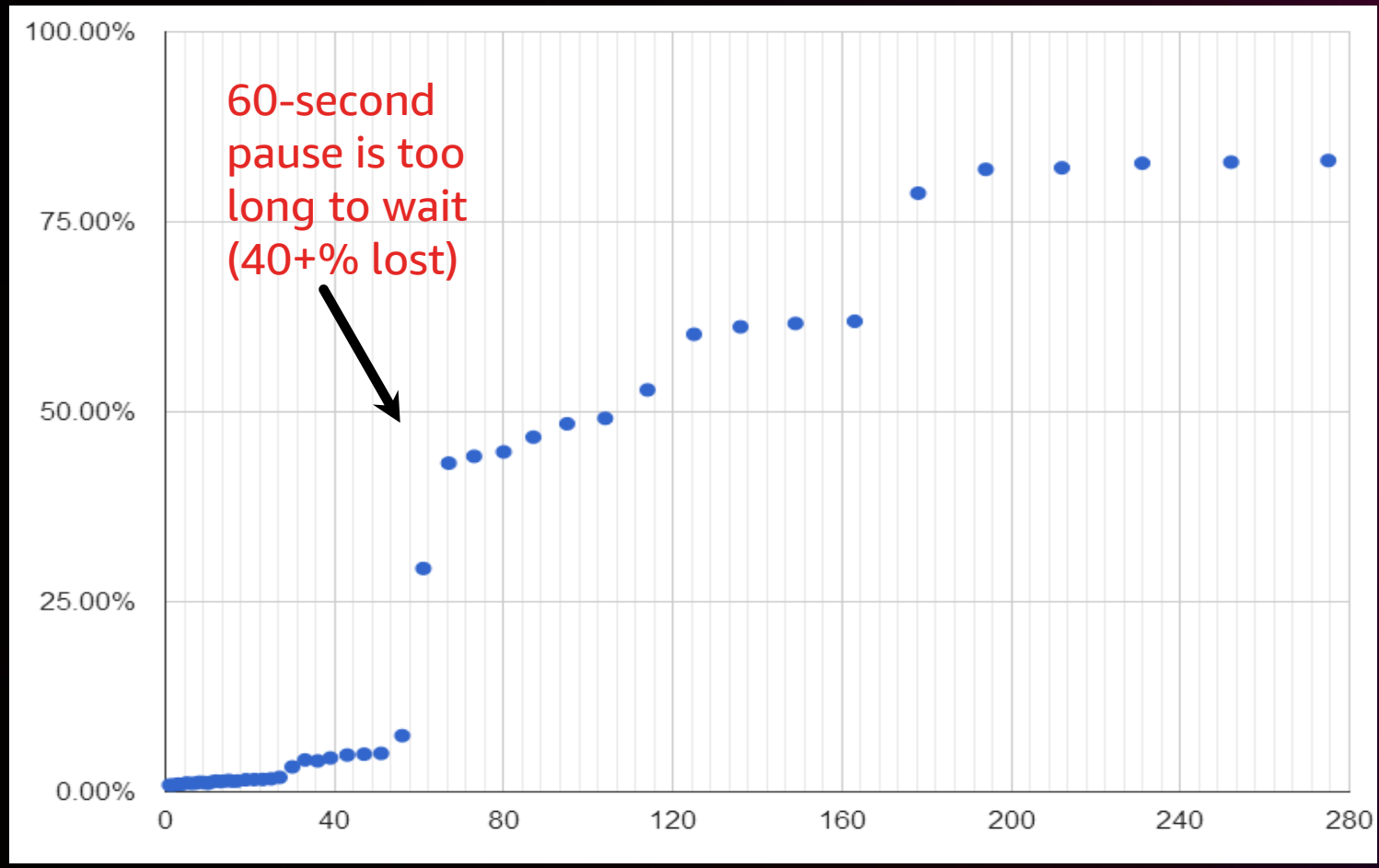
- Test reachability (around the world!)
- 93.5% of Chrome customers could reach Google via UDP
  - Fallback gracefully to TCP!
- “If you build it, they will come” (my optimistic mantra!)
  - We **must** create compelling advantages in QUIC

Measure: How do NATs handle UDP traffic?

- TCP has a FIN packet to drive NAT teardown

- NATs just “time out” and tear down UDP NAT binding
  - What is the timeout for actual customers??
  - How long can server pause/delay before NAT loses binding and packet is lost??
    - **We must test/measure**

Probability of losing server response



Seconds of delay before server attempts to respond

NAT timeout complications

- Must tolerate NAT timeout/rebinding
  - Need embedded connection ID

- Load-balancing complication

Can servers handle large UDP loads?

- TCP handling is highly evolved
  - TCP offload to hardware network interface cards (NICs) is common
  - Kernel hackers *assured* me UDP could be scaled up
- Load balancers would need to inspect connection ID
  - QUIC proof-of-concept needed before they would hack . . .
    . . . but they promised it could be done
- “Perpetual optimism is a force multiplier!” – Colin Powell

Can we bring value to customer?

- Can we (securely) start an encrypted stream faster?
- Can we befriend TCP congestion control?
- Can we improve on congestion control?
  - Reduce packet loss?
- Can we avoid HOL blocking?

Can we start an encrypted stream faster?

- Parallel discussion drove TCP FastOpen
  - Send a cryptographic token to attest to source IP ownership
  - Don’t let perfect be the enemy of the good
- TLS *rarely* changes server certificate
  - Speculate that certificate hasn’t changed!
- Measured: 75% of the time test servers accepted this
  - We **can** do better than TCP+TLS!

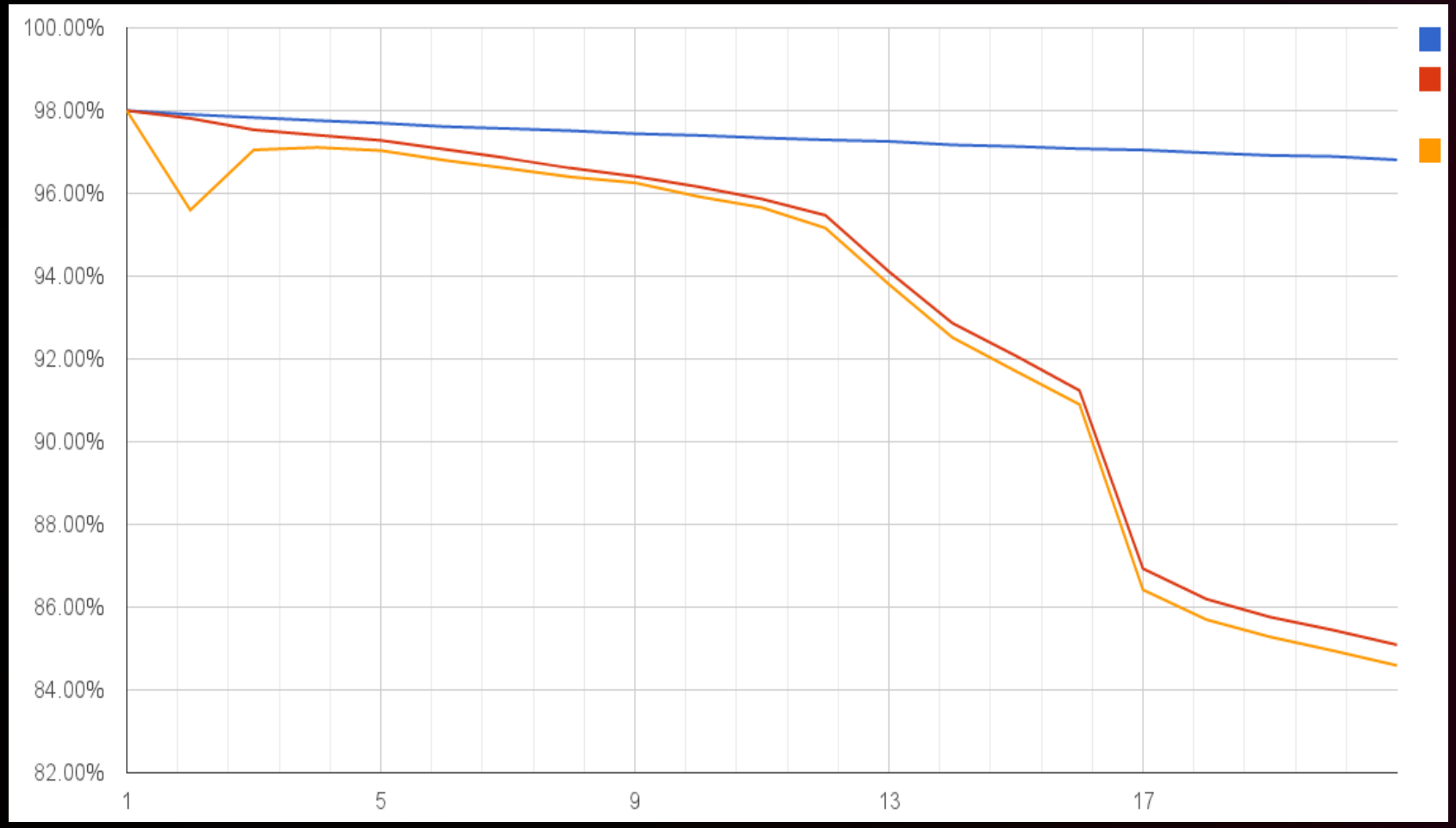
Can we befriend TCP congestion control?

- Rule 1: Don’t break the internet!
- Rule 2: If you help TCP, it won’t return the favor
  - TCP grabs all available bandwidth

- Initial congestion control will use TCP style

- Why do we “burst transmit” congestion windows?
  - Spreading out traffic, or “pacing” might help . . .
  - But we need to measure . . .

Paced vs. streaming: Probability of ACK



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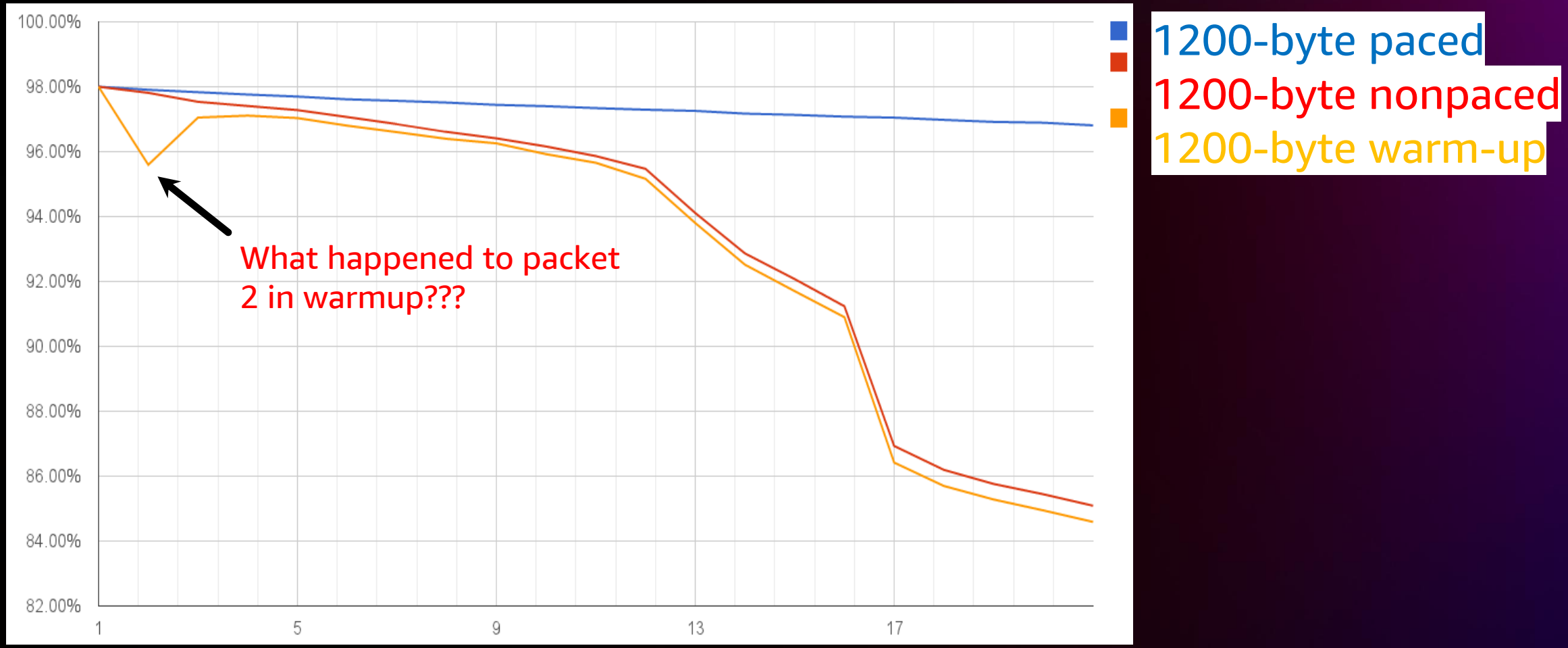
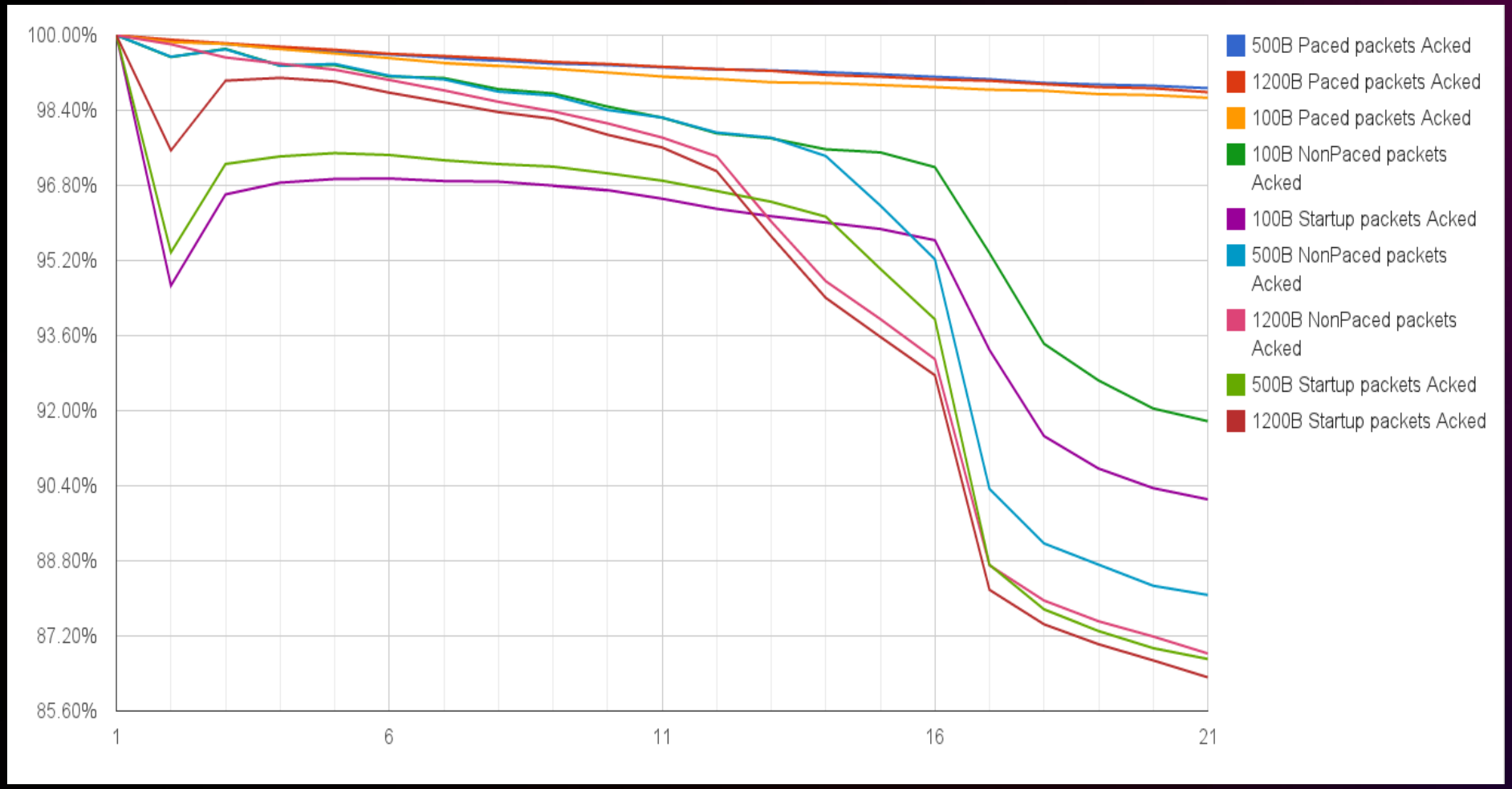
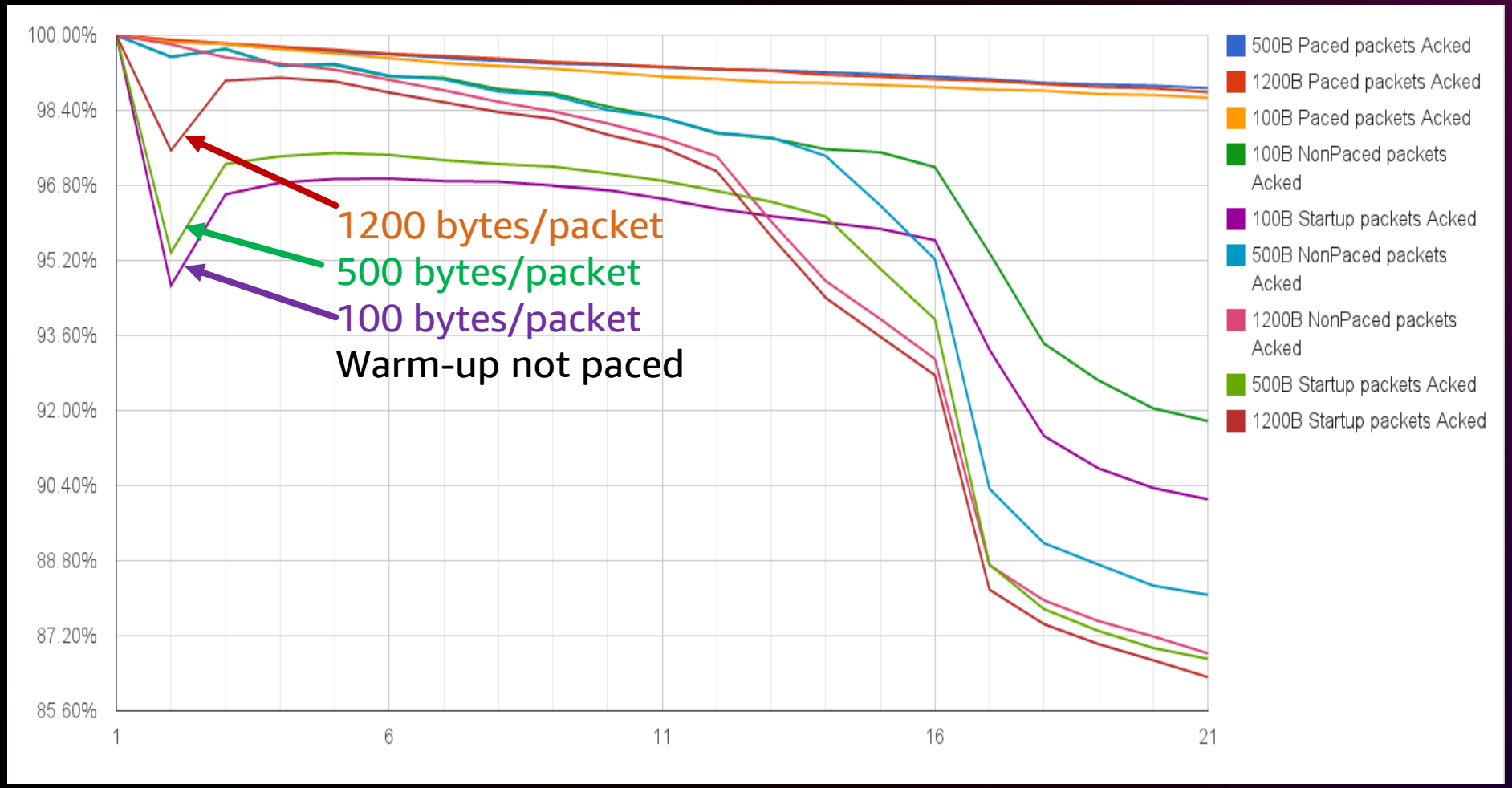


Relative packet-ACK probability



Compare 1200- vs. 500- vs. 100-byte packets; paced vs. nonpaced vs. warm-up

Relative packet-ACK probability



Compare 1200- vs. 500- vs. 100-byte packets; paced vs. nonpaced vs. warm-up

QUIC: Loose ends

QUIC from 50,000 feet: Adopt, migrate, use

- How browsers discover QUIC support
- Clients re-test QUIC viability
- Faster than TCP+TLS connection using speculation

- Limited blast radius for a lost packet
- Integrated encryption with packet sequence numbers
  - Avoid cipher-block chaining

Browser discovery of QUIC server support

- Prior HTTPS over TCP can indicate QUIC support
- Browser (Chrome) remembers the offer
  - Browser remembers Server’s public key certificate
  - Browser remembers signed IP-address-used token

- Future connections go faster than the first one
  - Browser “locally optimizes” for customer’s needs

Can QUIC reach the server each day?

- Browser races QUIC HELLO against TCP/TLS connect
  - If there is no UDP response, TCP proceeds

- If QUIC connection works, TCP is abandoned

What happens after QUIC HELLO?

- Packets and streams are bidirectional
  - ACKs piggyback with real data
  - Congestion control algorithms will evolve

Head of line blocking: No more

- Streams generally honor UDP packet boundaries
  - Packet loss (resend) usually slows only one stream
  - Multiplexing better than HTTP/2
    - Impossible in TCP, but explicit with QUIC/UDP
- Packets are individually numbered/encrypted
  - No cipher block chaining (CBC)
  - Each packet decrypted separately!
- HOL blocking has minimal blast radius
  - YouTube reported big improvement in rebuffer rate

How are packets acknowledged?

- Packets are ACKed in a control stream
  - All packets are encrypted
  - Malicious third party can’t inject a TCP-style FIN
- Selective ACK can hitchhike with “real data” packets
  - Third party can’t even deduce packet-loss stats!
  - TLS running on TCP exposes ACKs, creating vulnerabilities
    - Optimistic ACK attack anyone?

How are packet losses handled?

- QUIC “rebundles” lost **data** in new packet
  - QUIC never retransmits lost **packets**
  - QUIC can better understand packet losses
  - TCP retransmits **all** lost packets

- Constantly advancing packet numbers helps!
  - Congestion/receive window limits outstanding numbers

Results: IETF QUIC emerged as HTTP/3

- Google QUIC supported 90% of all Chrome traffic
  - Years of testing worldwide
  - AWS, Google, and others implement IETF QUIC standards
- Faster connection, reduced latency variance
  - Customers around the world benefit

Summary of QUIC, and now HTTP/3

What is HTTP/3?

- Next generation HTTP protocol and more
  - Replaces TCP+TLS+HTTP/2 using UDP packets
- Provides guaranteed delivery
- Faster cryptographic connection establishment
- Multiplexing of streams
  - One congestion-controlled flow
  - Improved latency with reduced variance
- Evolving congestion control
- Amazon CloudFront supports IETF QUIC, as do browsers!

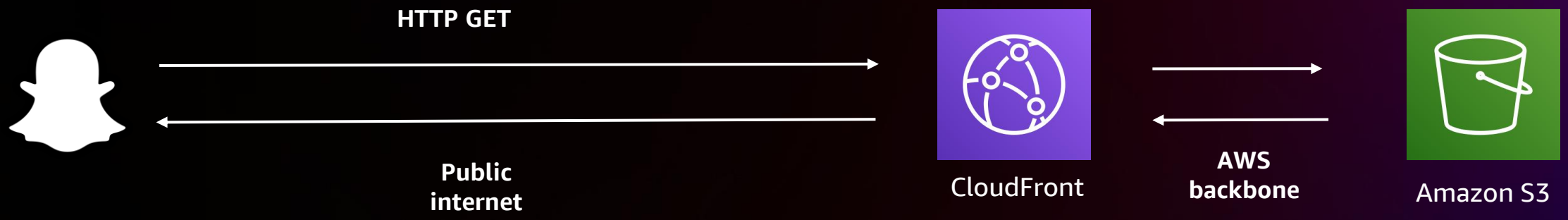
Snap deployment

- Snap content delivery
- Snap and QUIC
- Testing at scale
- Challenges
- Results
- Snap lessons learned and next steps

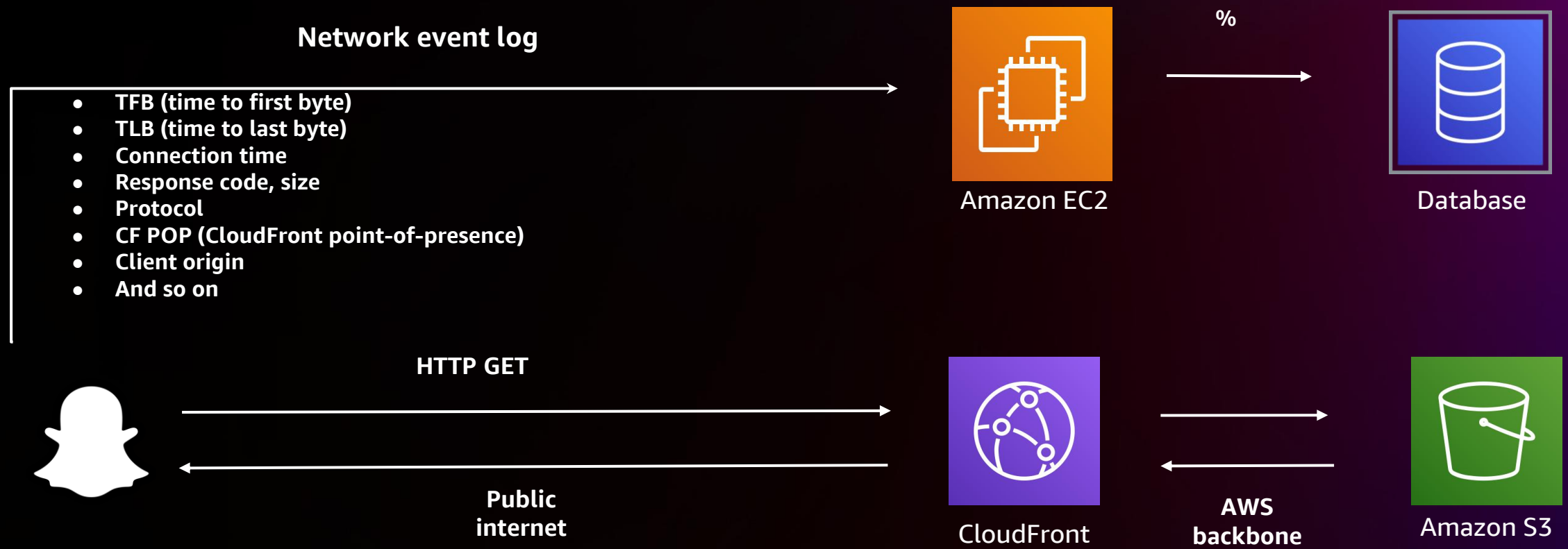
Snap background

- Snapchat aspires to be the fastest way to communicate
- Snap has a long term investment in QUIC
- Amazon CloudFront is a core infrastructure to Snap
- Amazon CloudFront HTTP/3?
  - Yes, please!
- 330M+ use Snapchat every day
- New technology needs validation

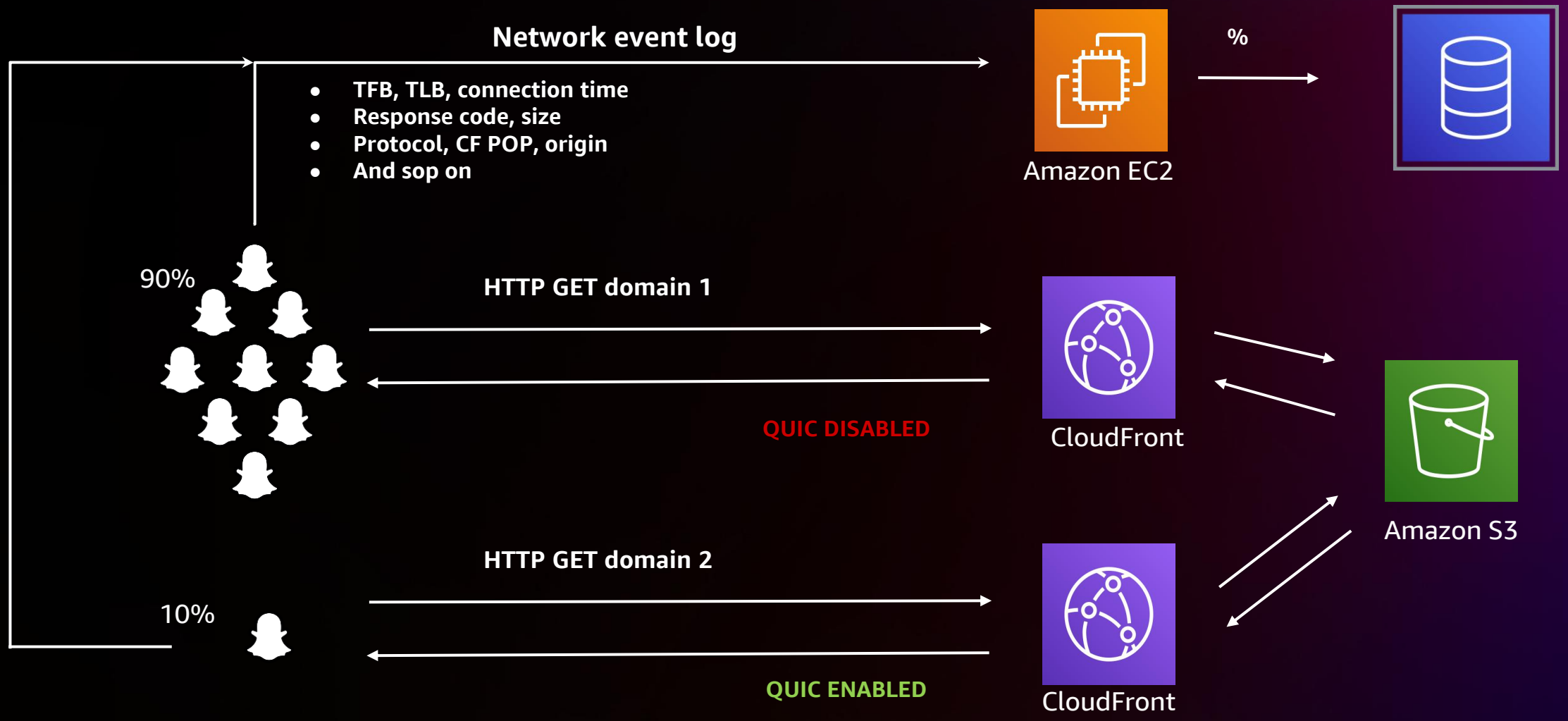
Snap media download



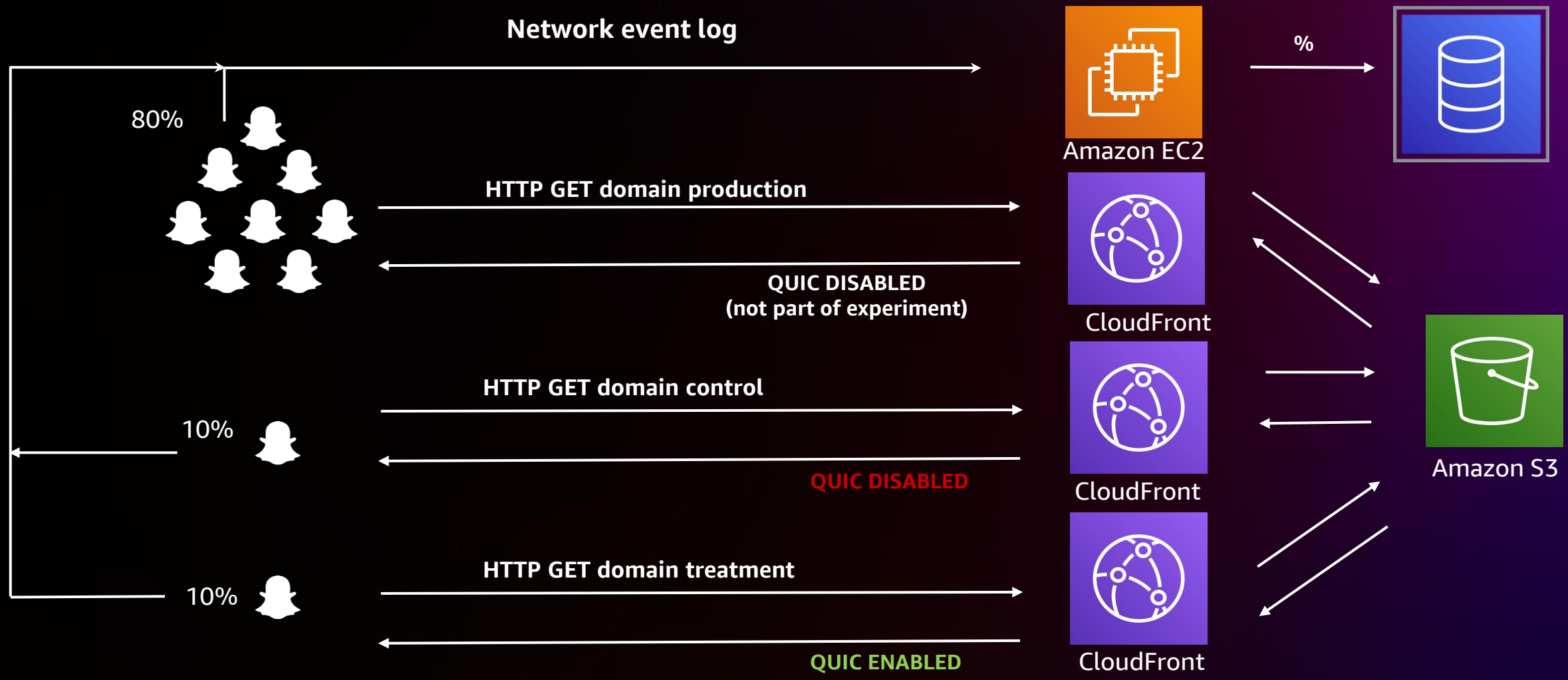
Snap media download



How to test QUIC (production mirroring)



How to test QUIC (counterfactual)



It’s not that simple!

- Autonomous service networks
  - ~10k ASNs
- Customer platforms
  - Android?
  - iPhone?
- Client libraries
  - NSURL?
  - Cronet?
  - OkHttp?

Results for Snap’s test

- Trimmed mean (99%) [average, excluding worst 1%, which is just noise]
  - Time to first byte 6–10% faster
  - Time to last byte is 6% faster

Lessons learned

- New technology is cool, but always be careful
- Slice and dice carefully
  - iOS versus Android?
  - High end versus low end?
  - ISP1 versus ISP2
  - Object size
- Representative sampling
- Iterate!

For more information

- HTTP/3 Support in Amazon CloudFront:
  - https://go.aws/3UJX0YX
- “QUIC: Design Document and Specification Rationale” by Jim Roskind
  - 70-page design spec, cut down to a mere 40 pages for publication in 2012
- Search for “IETF QUIC” and read latest RFC and standardization documents
- For more info on “trimmed mean” and better latency metrics to improve your latency – attend/view AMZ302 this Wednesday

Thank you!

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