

#WLPC Prague


STUDIO

Troy Martin

Solution Guy, Wireless Arts & Science





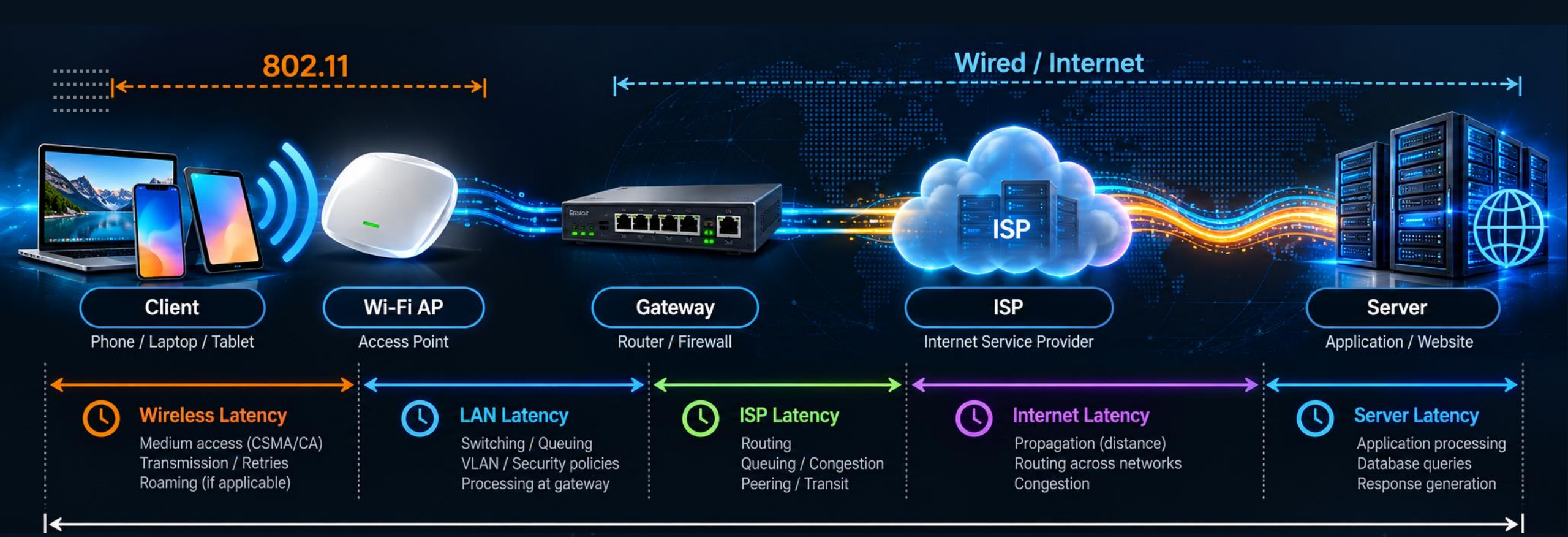
#WLPC

L4S

Low Latency, Low Loss, Scalable Throughput

#WLPC

EDCA



- Processing delay — Time required for devices to inspect and process packets.
- Queuing delay — Time spent waiting for an opportunity to transmit.
- Transmission (serialization) delay — Time required to place all bits of a frame or packet onto a link.
- Propagation delay — Time required for a signal to travel across a physical medium.

THE WI-FI GAME: HOW DEVICES TAKE TURNS TALKING

Clear Channel Assessment (CCA) a.k.a. "The Game" – Avoid Collisions, Get Acked, Win the Airtime

1 LISTEN BEFORE YOU TALK (CCA)

A. PHYSICAL CARRIER SENSE

Check the air for activity

Preamble Detect (Wi-Fi) detects other Wi-Fi devices
- BUSY Wait
- CLEAR Proceed

Energy Detect (Non-Wi-Fi) detects interference & other signals
- BUSY Wait
- CLEAR Proceed

B. VIRTUAL CARRIER SENSE (NAV)

Check if airtime is reserved



Devices hear a transmission and set their Network Allocation Vector (NAV) – they wait for the Duration to expire.

2 THE GAME: CONTENTION WINDOW

Everyone ready to talk rolls a dice (random backoff). Smaller number wins!



STA 3 wins the airtime!

Contention Window (CW) = range of slots to roll from
More busy air = larger CW = more waiting

3 TRANSMIT OPPORTUNITY (TxOP)

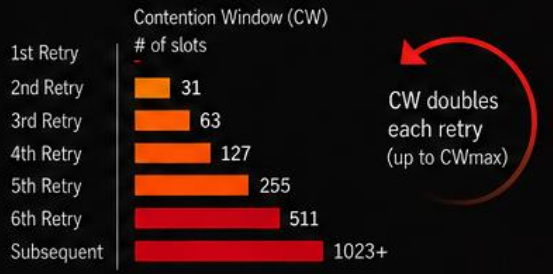
Winner reaches 0 and gets to transmit!



- ACK RECEIVED – Success! Move on.
- NO ACK – Collision or interference. Didn't get it. Retry!

4 RETRY & BACKOFF

If no ACK, the device tries again with a bigger window.



5 NOT ALL TRAFFIC WAITS THE SAME

EDCA / Wi-Fi QoS gives different traffic different priority.

ACCESS CATEGORY	EXAMPLE	CW RANGE
AC_VO (Voice)	Voice	CW 0 – 3
AC_VI (Video)	Video	CW 0 – 7
AC_BE (Best Effort)	Data	CW 0 – 15
AC_BK (Background)	Background	CW 0 – 15

HIGH PRIORITY – Smaller CW = faster access
LOW PRIORITY – Larger CW = more waiting

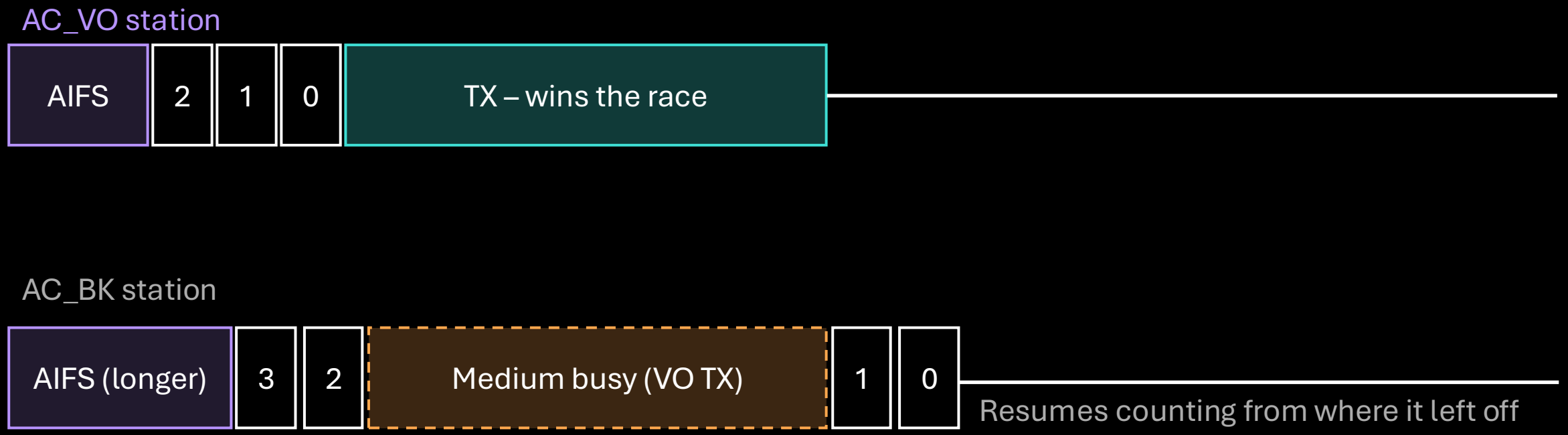
KEY TAKEAWAY

Wi-Fi tries to avoid collisions by listening, waiting, and taking turns. Sometimes collisions still happen (same roll, interference, etc.), but this is how Wi-Fi works and tries to behave.

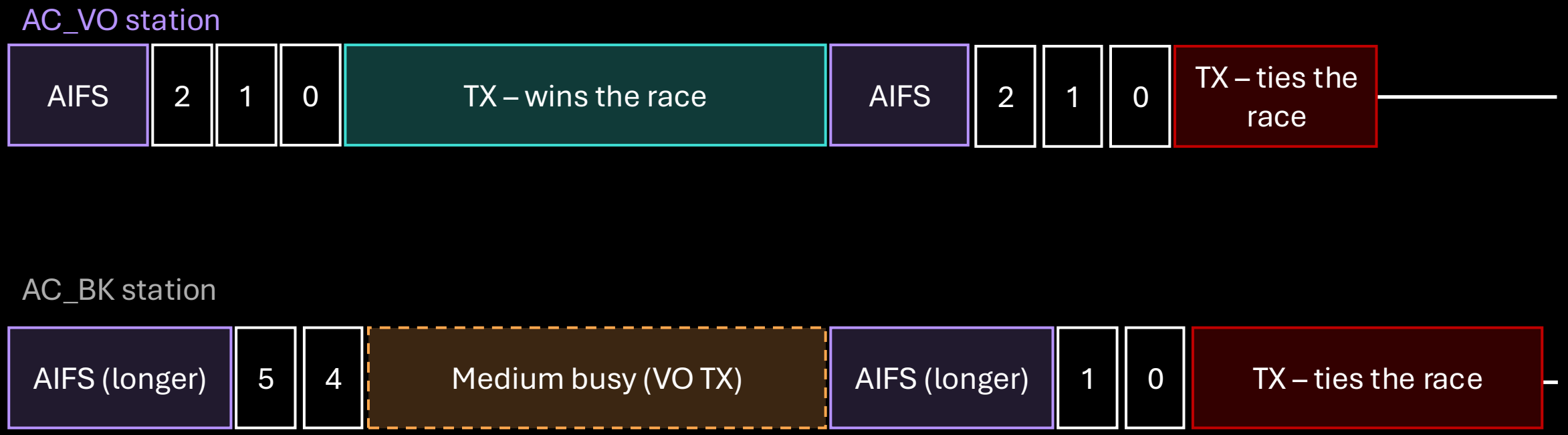
More Devices = More Waiting = Less Throughput


BEASTIE
BOYS
FIGHT FOR YOUR RIGHT

Two devices, one race

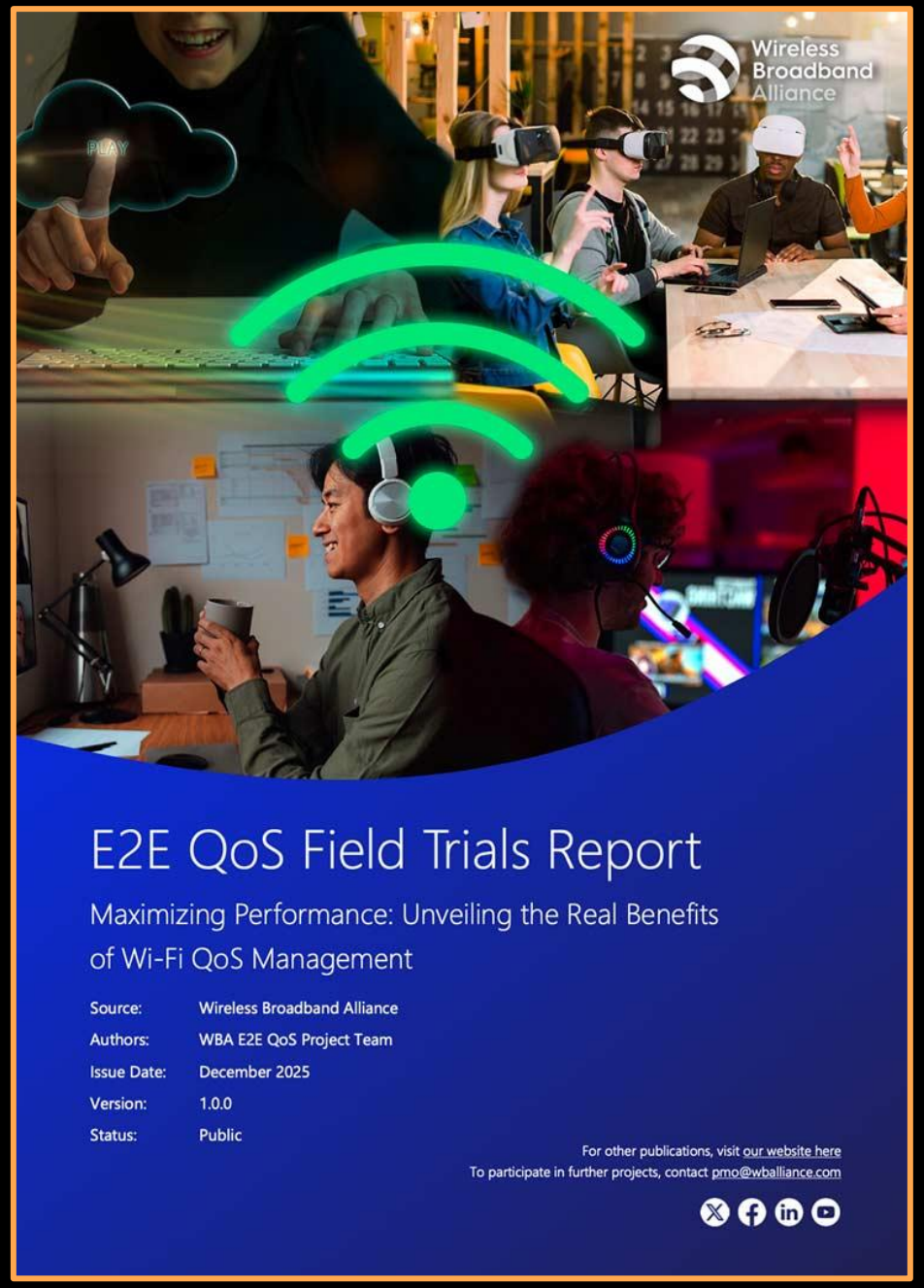


Two devices, one race, one collision



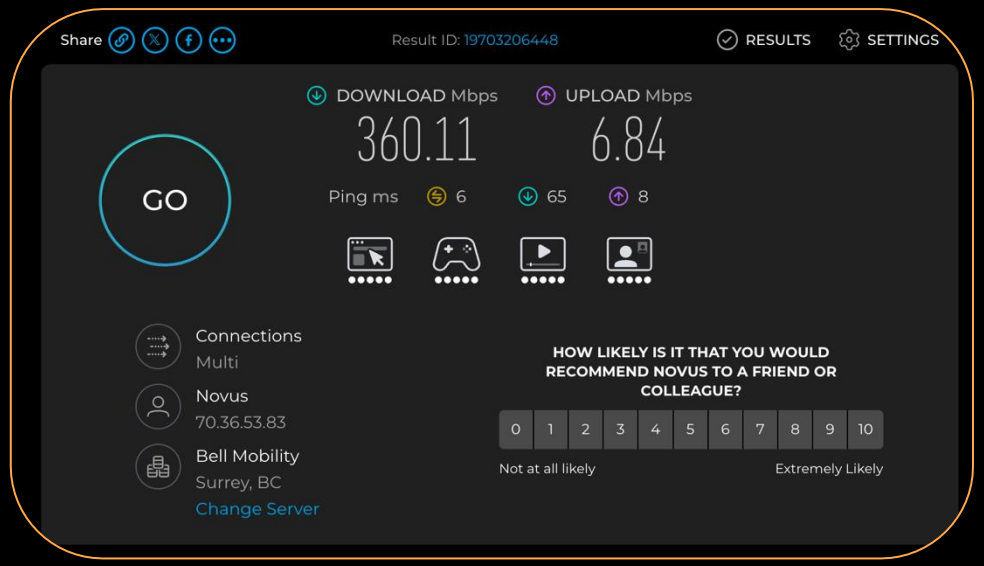
Resumes counting from where it left off

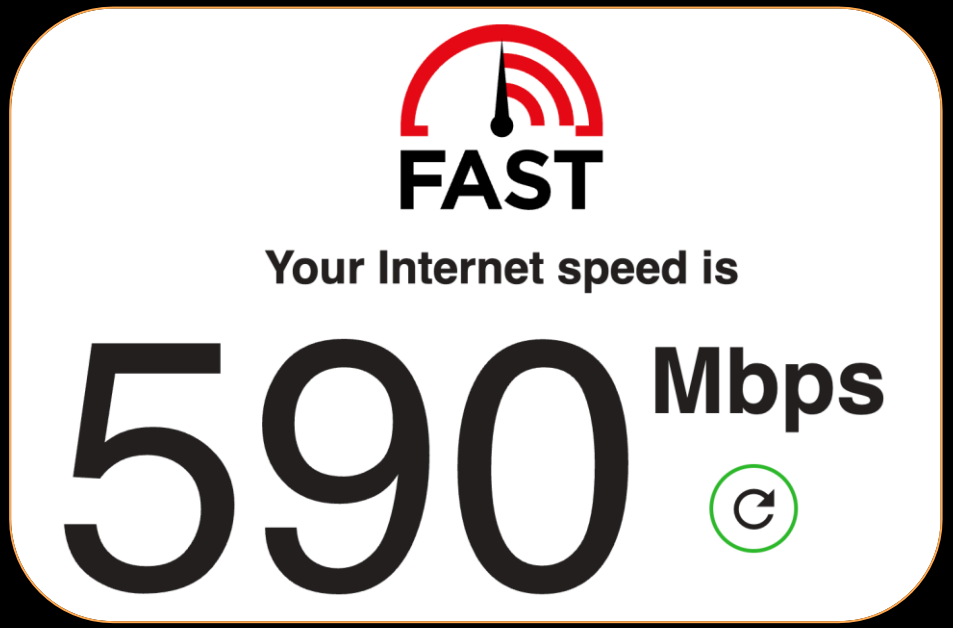




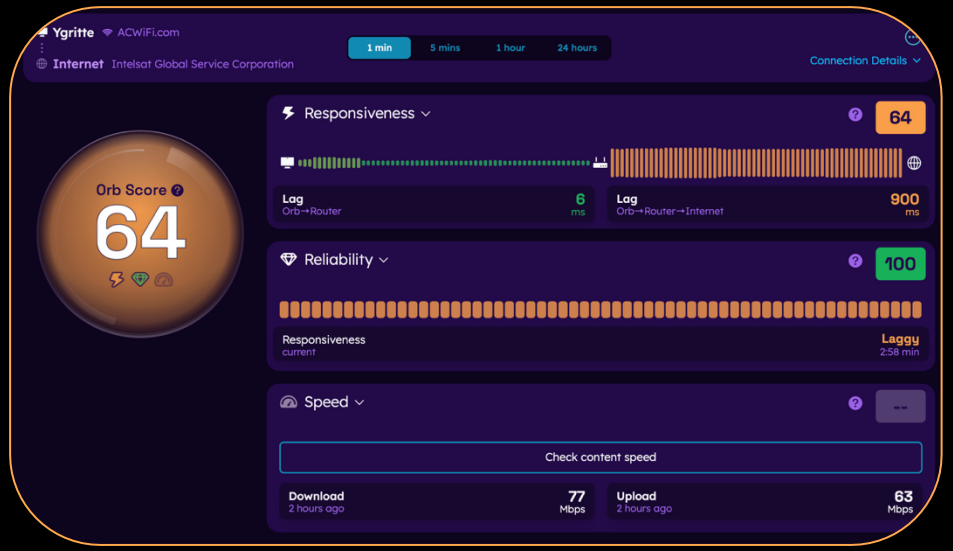
https://wballiance.com/e2e-qos-field-trials-report/

Packet Blasting


Share
Result ID: 19703206448
RESULTS
SETTINGS
DOWNLOAD Mbps
UPLOAD Mbps
360.11
6.84
GO
Ping ms 6
65
8
Connections
Multi
Novus
70.36.53.83
Bell Mobility
Surrey, BC
Change Server
HOW LIKELY IS IT THAT YOU WOULD RECOMMEND NOVUS TO A FRIEND OR COLLEAGUE?
0 1 2 3 4 5 6 7 8 9 10
Not at all likely
Extremely Likely


FAST
Your Internet speed is
590
Mbps


Your Wi-Fi and internet both look fine.
Run again
Wi-Fi: Moderate
Internet: Weak
Measured over Wi-Fi (en0).
Both your Wi-Fi and your internet are keeping up.
Your Wi-Fi link is 132% faster than your internet connection.
Walk to another spot and run it again. This answer often changes when you move.


Ygritte
ACWiFi.com
Internet
Intelsat Global Service Corporation
1 min
5 mins
1 hour
24 hours
Connection Details
Orb Score
64
Responsiveness
64
Lag
Orb→Router
6
ms
Lag
Orb→Router→Internet
900
ms
Reliability
100
Responsiveness
current
Laggy
2:58 min
Speed
--
Check content speed
Download
2 hours ago
77
Mbps
Upload
2 hours ago
63
Mbps

4:22

RESULTS

2026-10-14, 4:21 PM
Test ID: 7272093597

SPEED

Download
28.5
Mbps

Data used 31.7MB

Upload
26.7
Mbps

Data used 19.1MB

RESPONSIVENESS

PING ms

Idle	Download	Upload
9	84	69
Low 8	Low 12	Low 9
High 10	High 548	High 447
Jitter 1	Jitter 33	Jitter 26

PACKET LOSS %
0.00

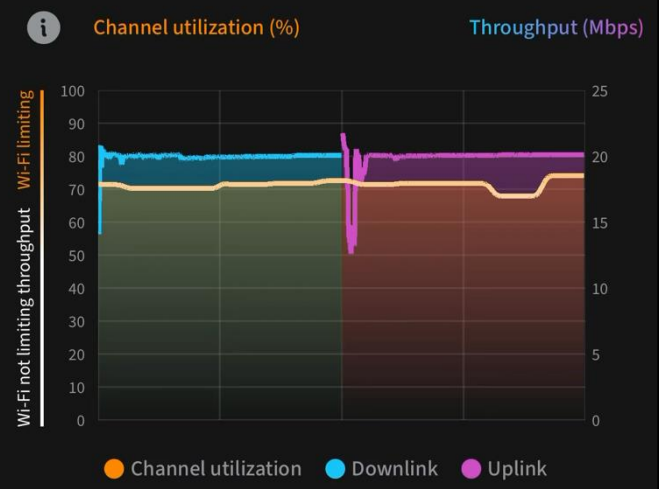
8:22

Speedtest

GO
Test again

Download	Upload
19.60 Mbps	19.70 Mbps

Ping	Jitter
8 ms	16 ms




HOONIGAN
PIRELLI
SHOWDOWN
Snap-on





What the packet blast actually samples

What it measures

- Peak throughput of **one or a few parallel flows**
- A short window — typically 10–15 seconds
- Best-case path: your device straight to a nearby test server
- A single moment, usually when nothing else is happening

What is [often] never asked

- What happens to **ping while that flow is saturating the link**
- Behaviour with **many concurrent flows** (your actual environment)
- Jitter, packet reordering, retry storms on the radio hop
- Sustained load: minutes into a call or cloud backup, not seconds

DATE	TIME	IP VERSION	BASELINE	PEERING	SERVER	ASN	ISP
Oct 11, 2026	6:19 PM	IPv4	8.2 ms	18.5 ms	Vienna, AT	AS8412	Realotel W Ein...

BROWSER
Safari

Total Bufferbloat Grade

AQ EVIDENCE: USABLE

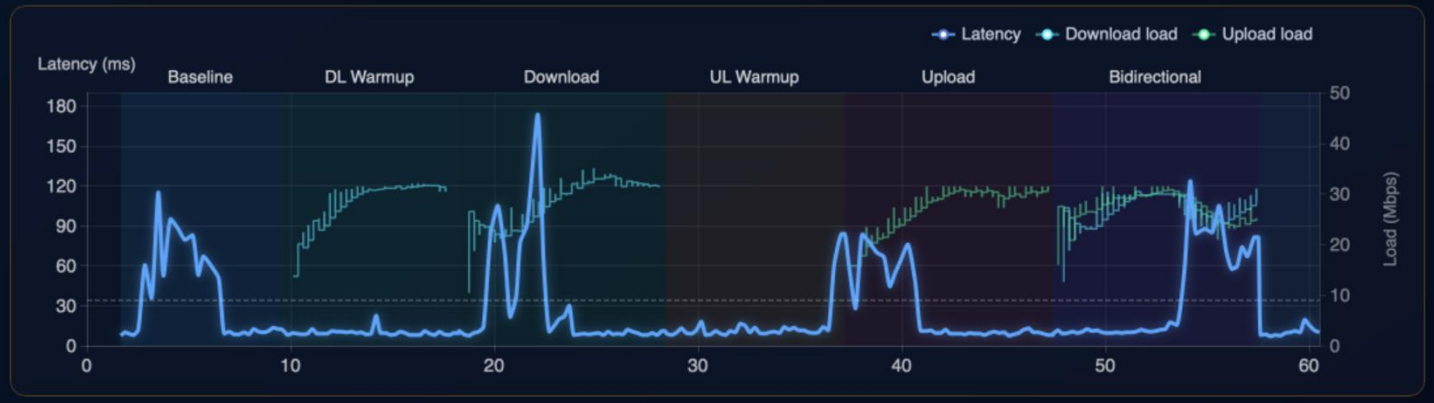
C +70.6 ms

VERDICT

Noticeable bufferbloat that affects performance. You'll likely experience lag during video calls, choppy streaming, and delayed responses in online games when your connection is busy.

Download	Upload	Bidirectional
+70.6 ms C 27.0 Mbps	+59.3 ms B 26.2 Mbps	+76.1 ms C -- Mbps
8.0 ↔ 91.9 ms	8.0 ↔ 76.2 ms	9.4 ↔ 90.1 ms

Browsing	Streaming	Video Calls	Audio Calls	Backup	Gaming
QoO 94%	QoO 100%	QoO 83%	QoO 99%	QoO 100%	QoO 57%



LibreQoS test.libreqos.com

Advanced Details (Tables, ΔQ)

LibreQoS (Advanced)

https://test.libreqos.com/advanced/

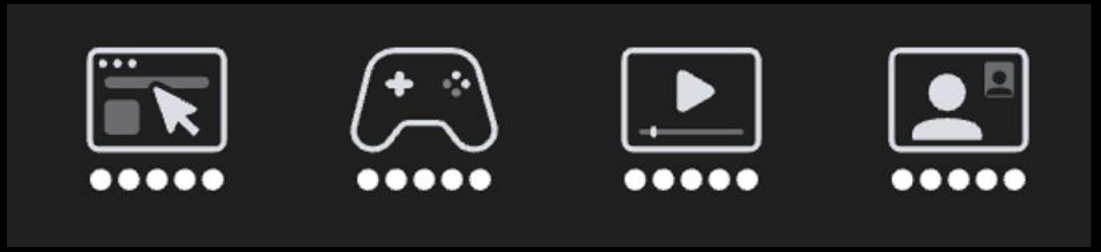
The metric: loaded vs. unloaded latency

A

- unloaded & loaded RTT both stay near baseline

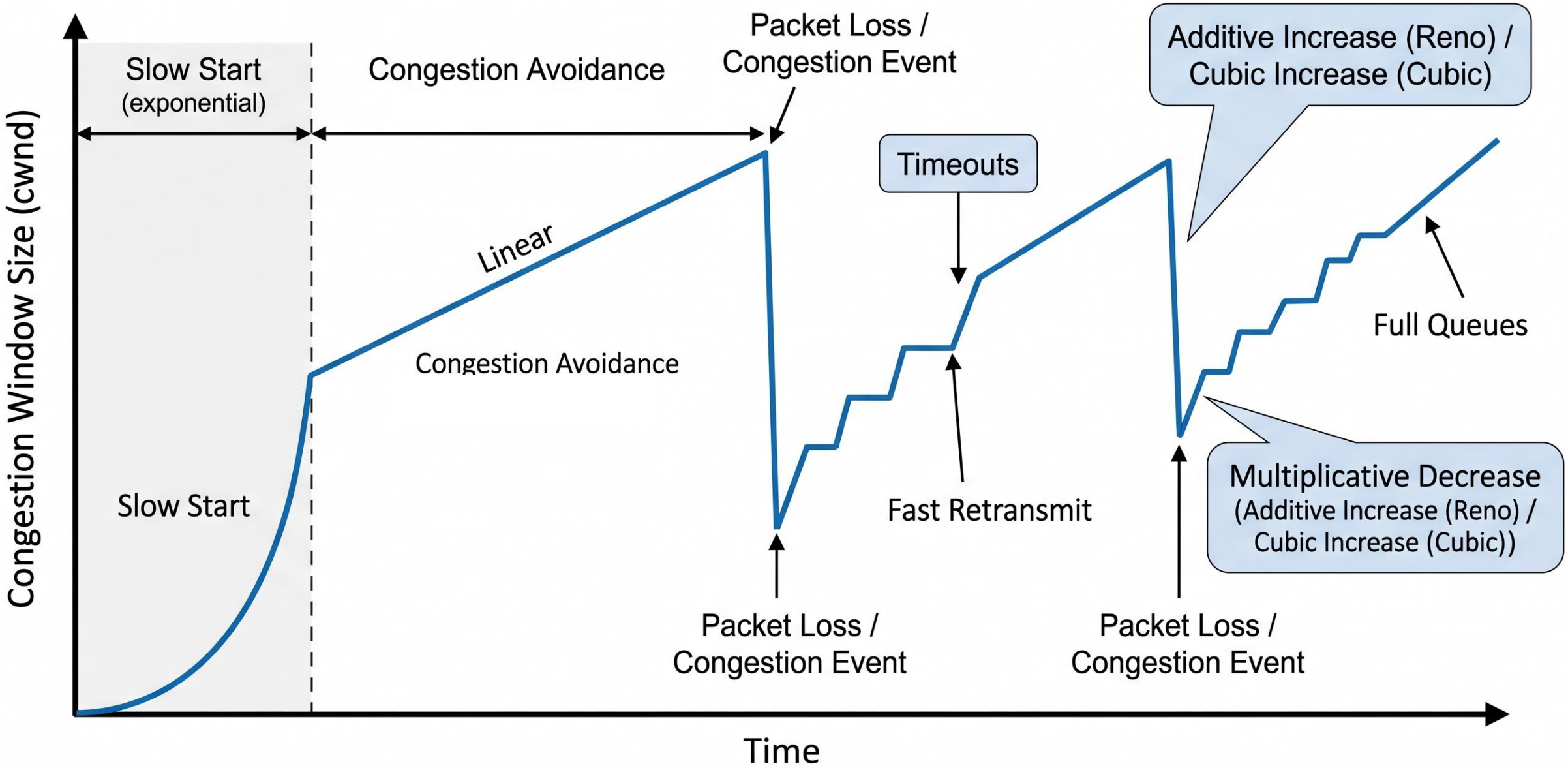
F

- loaded RTT balloons hundreds of ms under a saturating flow



- Measure **with the link idle** — that's your baseline.
- Then saturate the link (big download/upload) and measure **again, at the same time**.
- The gap between the two numbers *is* your buffer bloat, in milliseconds.
- How quickly latency recovers after traffic stops.

Visualizing Traditional TCP (Cubic/Reno) Saw-Tooth Behavior

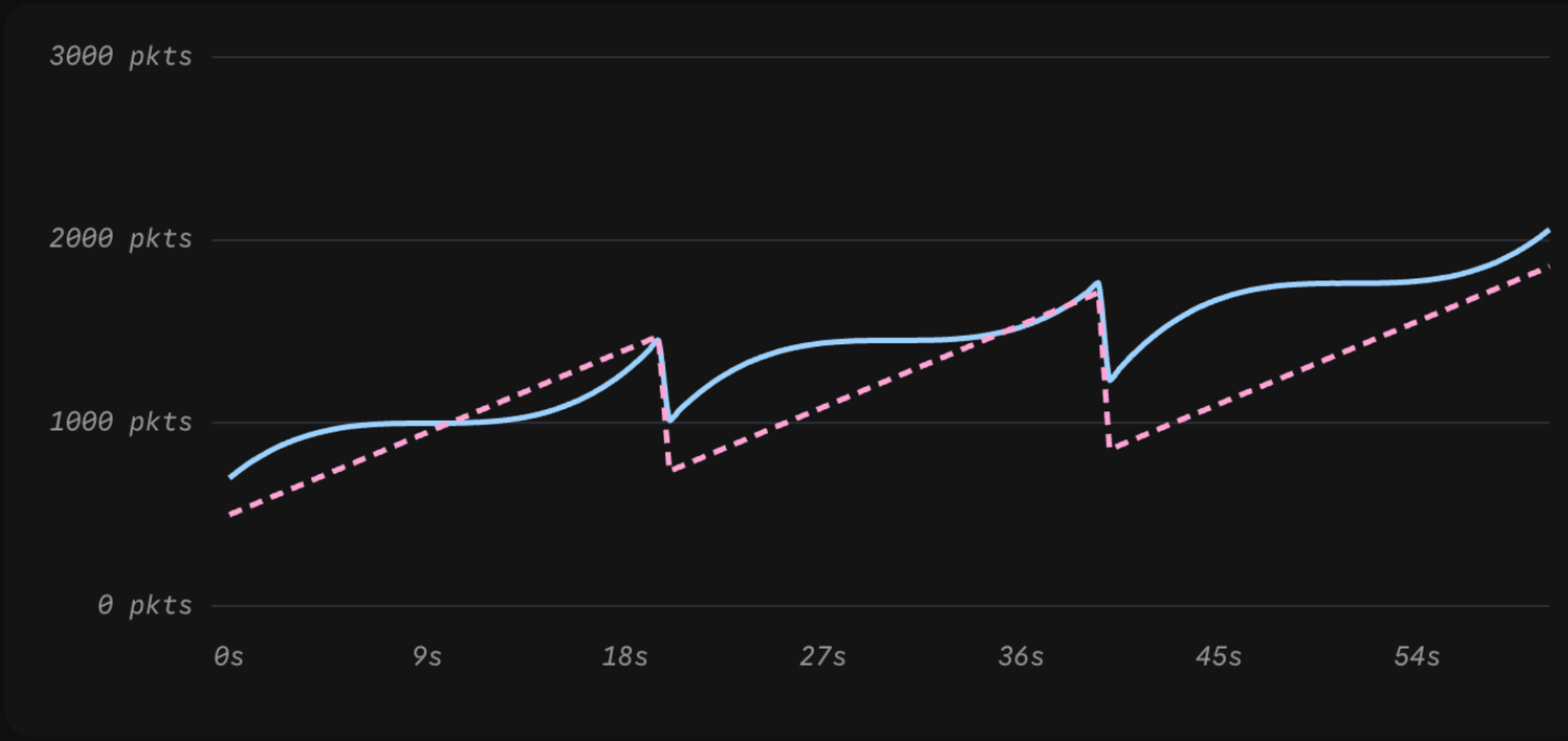


TCP Reno Avg cwnd

1,191 pkts

TCP CUBIC Avg cwnd

1,396 pkts



Bandwidth vs Latency

how wide the pipe is?

"how much per second."

Bandwidth

how long any one packet waits its turn?

"how soon."

Latency

IETF - L4S Standards

RFC 9330

- foundational blueprint
- describes the overall architecture, core components, and operational philosophy of L4S, explaining how senders, receivers, and network nodes cooperate
- Used by network architects, engineers, and protocol designers to understand how to deploy end-to-end low-latency services without harming existing internet traffic

RFC 9331

- protocol definition
- specifies how ECN bits in the IP header are used to distinguish L4S traffic from classic traffic and defines how scalable congestion control algorithms must respond to these signals
- Crucial for developers building operating systems, network stacks, and application protocols (like TCP Prague or QUIC) so devices can correctly flag and read L4S packets

RFC 9332

- router implementation guide
- outlines the requirements for network nodes, specifically defining the "DualPI2" algorithm which splits traffic into two queues (L4S and Classic) while coupling them to ensure fair bandwidth sharing
- Aimed at hardware manufacturers, router developers, and ISPs to implement L4S queue management in APs, routers, switches, and cable modems

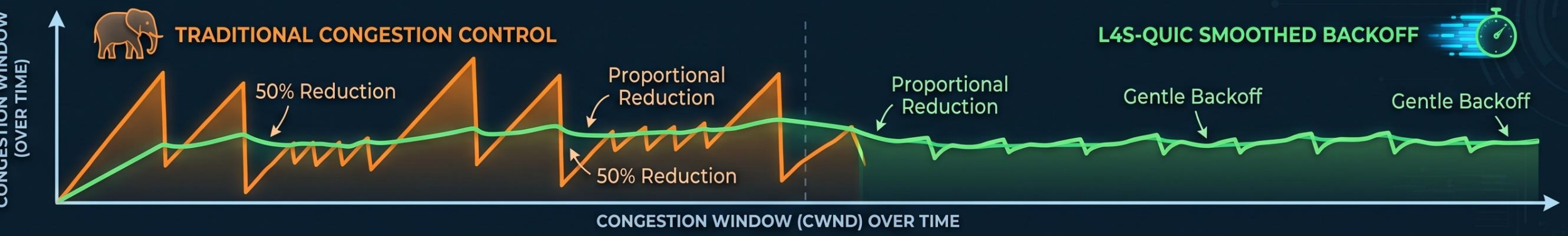
ECN Packet Marking

```
Frame 412: 1214 bytes on wire, 1214 bytes captured
Ethernet II, Src: Cisco_0a:1b:2c, Dst: Apple_3d:4e:5f
Internet Protocol Version 4, Src: 192.0.2.10, Dst: 198.51.100.45
    0100 .... = Version: 4
    .... 0101 = Header Length: 20 bytes (5)
    Differentiated Services Field: 0x03 (DSCP: CS0, ECN: CE)
        0000 00.. = Differentiated Services Codepoint: Default (0)
        .... ..11 = Explicit Congestion Notification: Congestion Experien
                    [Standard: RFC 3168 / L4S reinterpretation RFC 9331]
Transmission Control Protocol, Src Port: 443, Dst Port: 51244, Seq: 4001,
    Source Port: 443
    Destination Port: 51244
    Flags: 0x018 (PSH, ACK)
        0000 0000 0001 1000 = Flags
        .... .... .... .0.. = RST: Not set
        .... ...0 .... .... = Accurate ECN (AE): Not applicable to downst
        [Stream index: 0]
```

ECN bit mapping (L45S reinterpretation)

- 00 Not ECN-capable transport
- 01 Classic ECN-capable transport
- 10 L4S-capable transport
- 11 Congestion experienced

SMOOTHED BACKOFF IN QUIC with L4S and ECN ENABLED



1. NORMAL FLOW

QUIC/IP PACKETS

QUIC/IP

QUIC SENDER

L4S

NETWORK

2. CONGESTION & ECN MARKING

Conceptual *E* or mope traffic

L4S-aware AQM
Mark ECN-CE based on a fine-grained, low-delay threshold

L4S-aware

incipient congestion

L4S-aware queue

ECN-CE (CONGESTION EXPERIENCED)

Precise marking before full queue

ECN-CE (CONGESTION EXPERIENCED)

3. FEEDBACK & SMOOTHED RESPONSE

Gets ECN-marked packets, Generates QUIC ACK with cumulative ECN information (e.g.

ECN-CE (CONGESTION EXPERIENCED)

QUIC ACK
(ECN Echo count)

QUIC RECEIVER

SMOOTHED REDUCTION CALCULATION
Reduction ∝ ECN Marking Rate



Small, proportional reductions lead to smooth performance and low latency.

QUIC ECN-AWARE CONGESTION CONTROLLER



Calculate data, Ecn-aware reduction

KEY PRINCIPLES

1. Precise ECN feedback on incipient queueing.
2. Proportional congestion window adjustment (Smoothed Backoff).
3. Maintaining ultra-low latency while maximizing throughput.

We have battled **beacon bloat**....

...now join the battle against **buffer bloat**.

#WLPC

#WLPC Prague



EST. 1997
802.11
IEEE
wifivitae.com