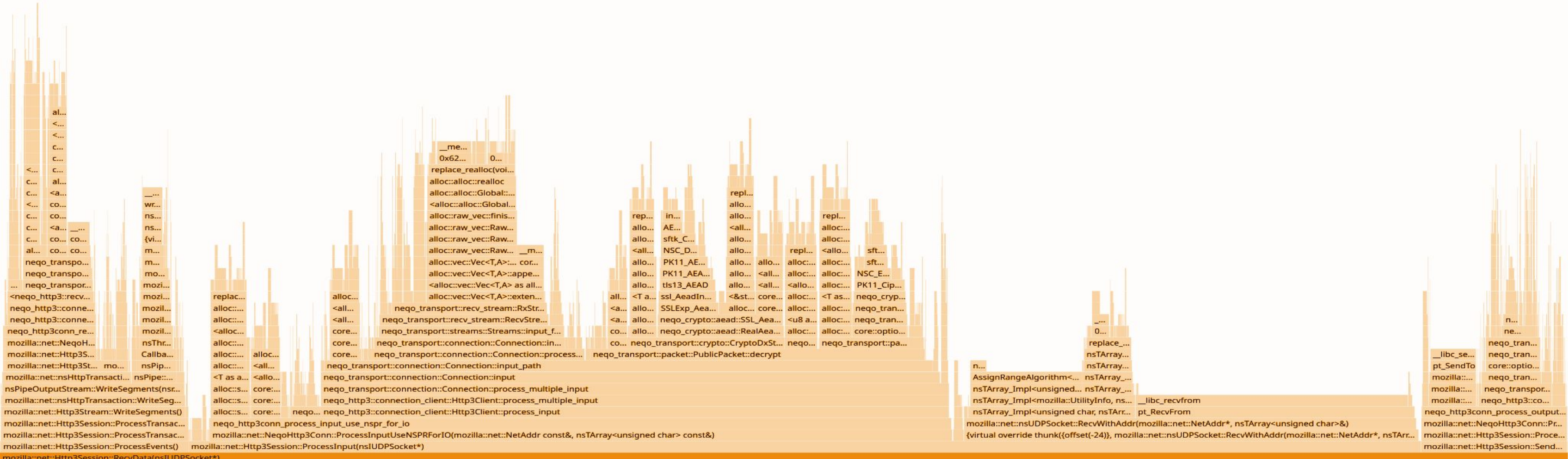
Fast UDP makes QUIC quicker

optimizing Firefox’s HTTP3 IO stack

FOSDEM 2025 - Max Inden



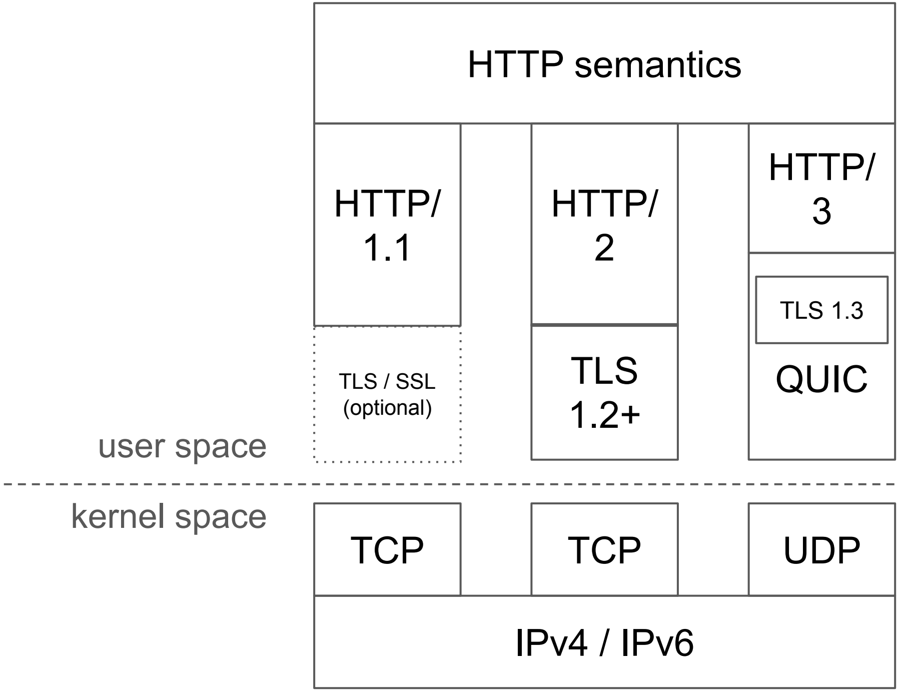
Max Inden

- Software engineer at Mozilla
- Working on HTTP3 and QUIC in Firefox
- mail@max-inden.de
- @mxinden
- Previously p2p, Kubernetes and Prometheus

What is Firefox?

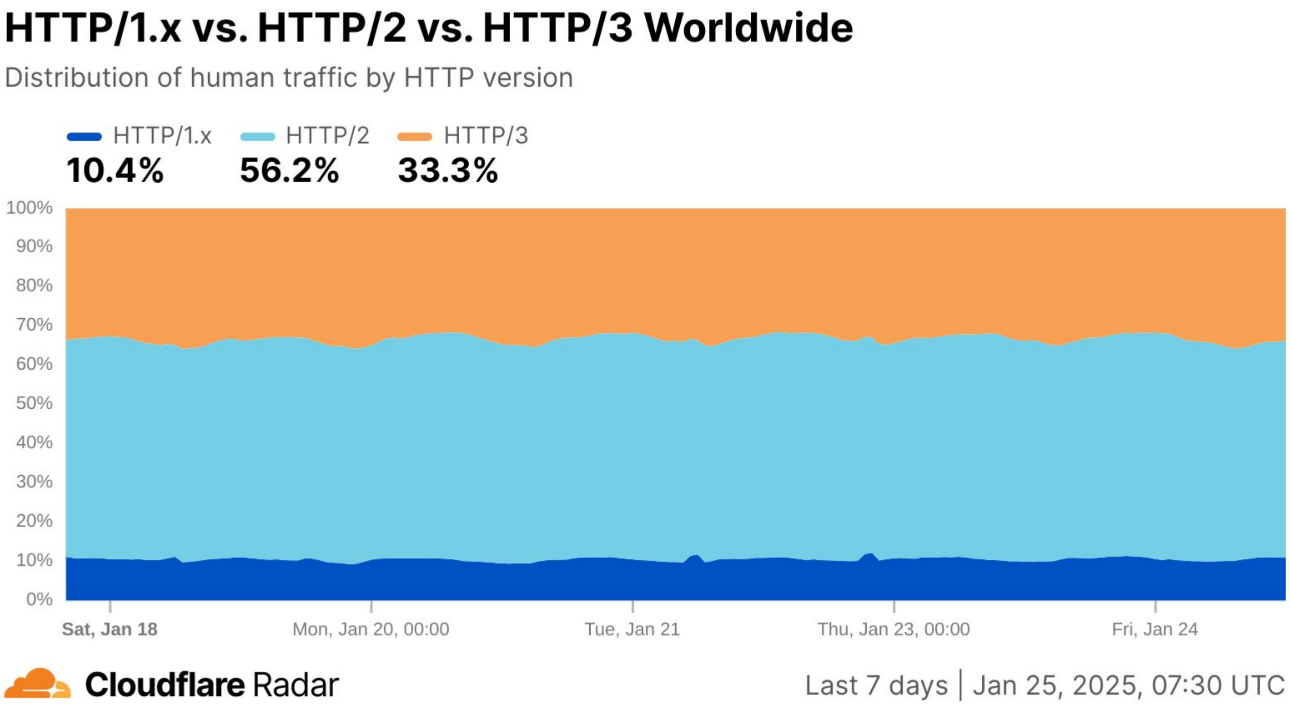
What is QUIC?

- general purpose transport protocol
- on top of UDP
- encrypted (meta) data
- 1 RTT connection establishment
- 0 RTT on consecutive connections
- stream based
- no head-of-line blocking
- connection migration
- easy to evolve
- often in user space
- …



https://en.wikipedia.org/wiki/File:HTTP-1.1_vs._HTTP-2_vs._HTTP-3_Protocol_Stack.svg

QUIC on the Internet today



HTTP/1.x vs. HTTP/2 vs. HTTP/3 Worldwide

Distribution of human traffic by HTTP version

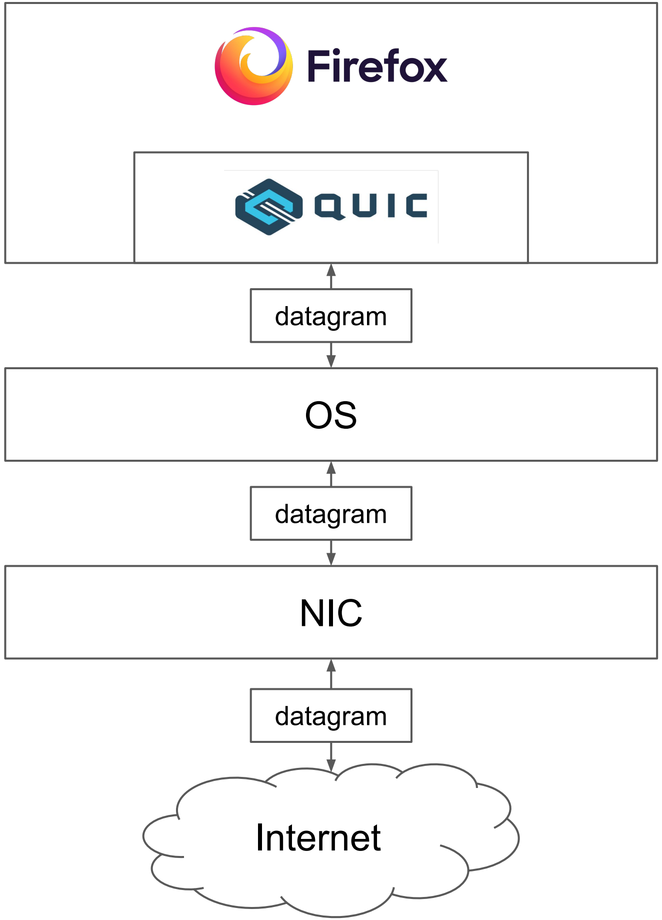
Last 7 days | Jan 25, 2025, 07:30 UTC

QUIC in userspace

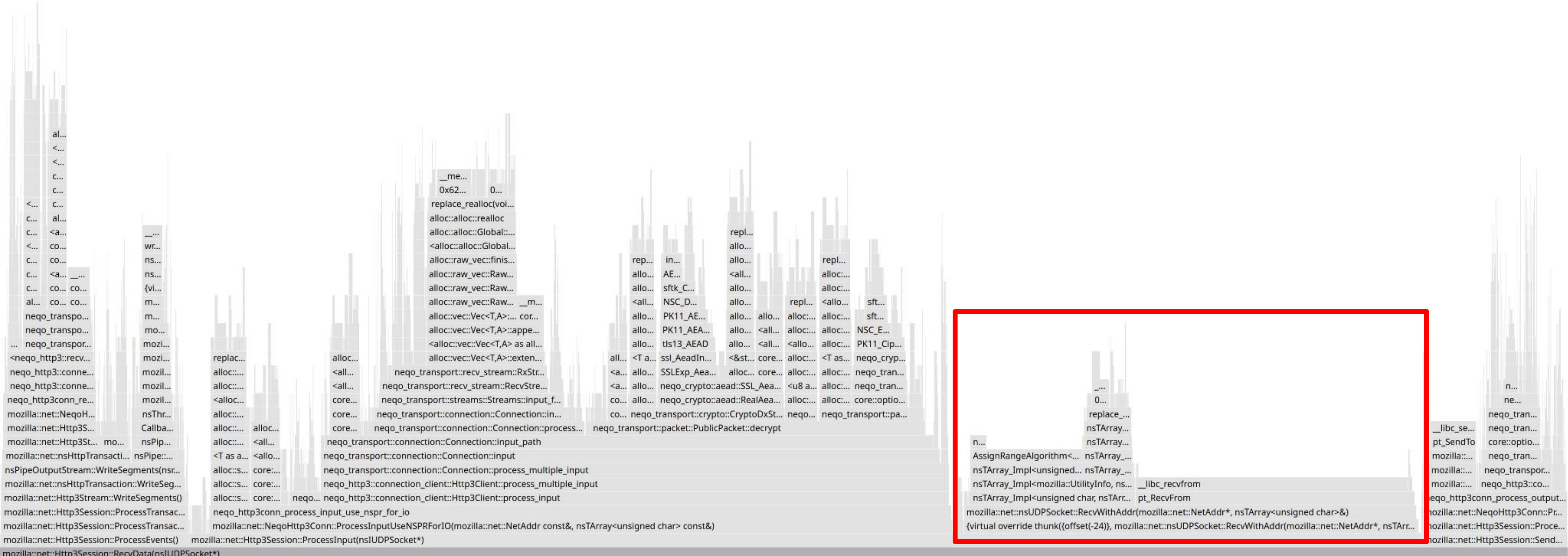
Unsurprisingly an un-optimized userspace transport protocol on top of UDP is not as fast as heavily optimized TCP in kernel space.

Userspace QUIC might do:

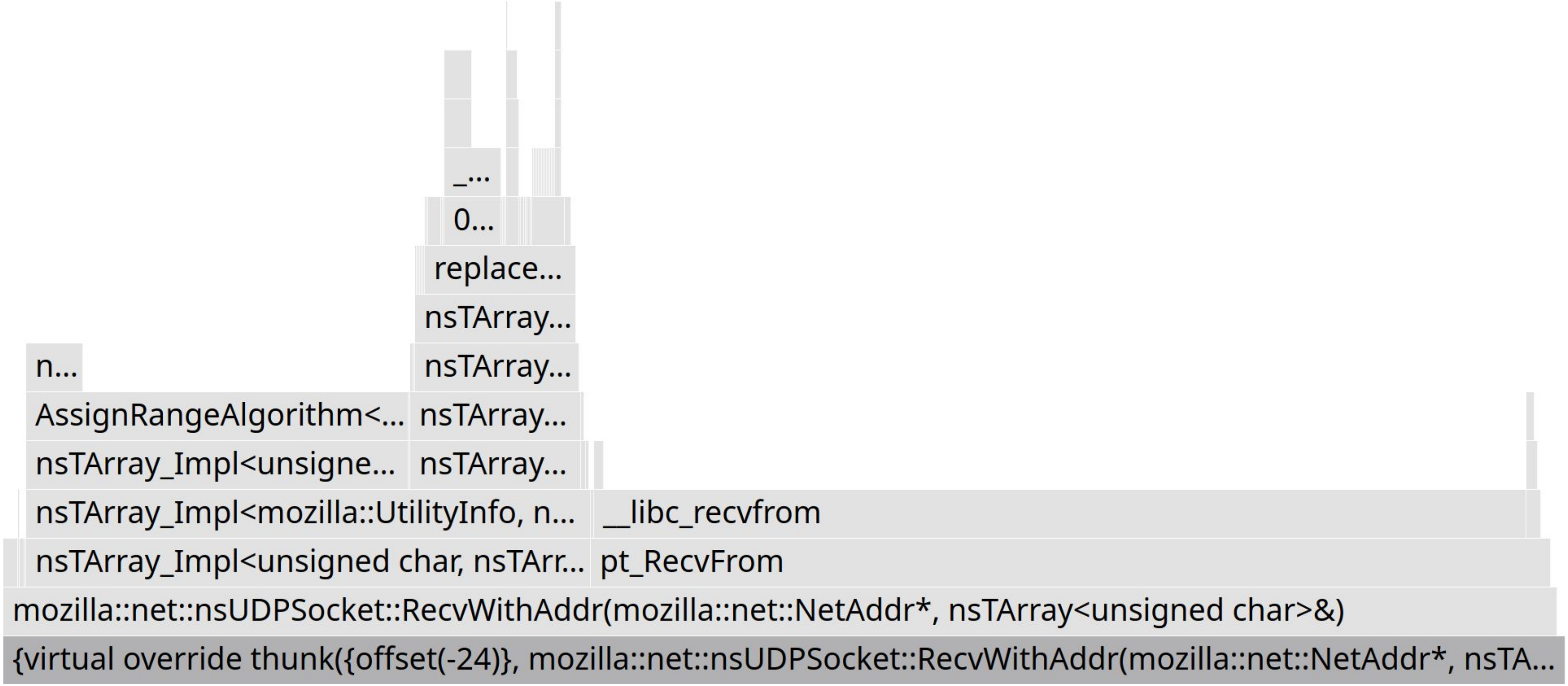
- one syscall per UDP datagram
- < 1500 byte MTU for Internet traffic
- ACK of up to every second packet
- de Bruijn et al. “3.5x the CPU cycles per byte”



Un-optimized Firefox QUIC UDP IO

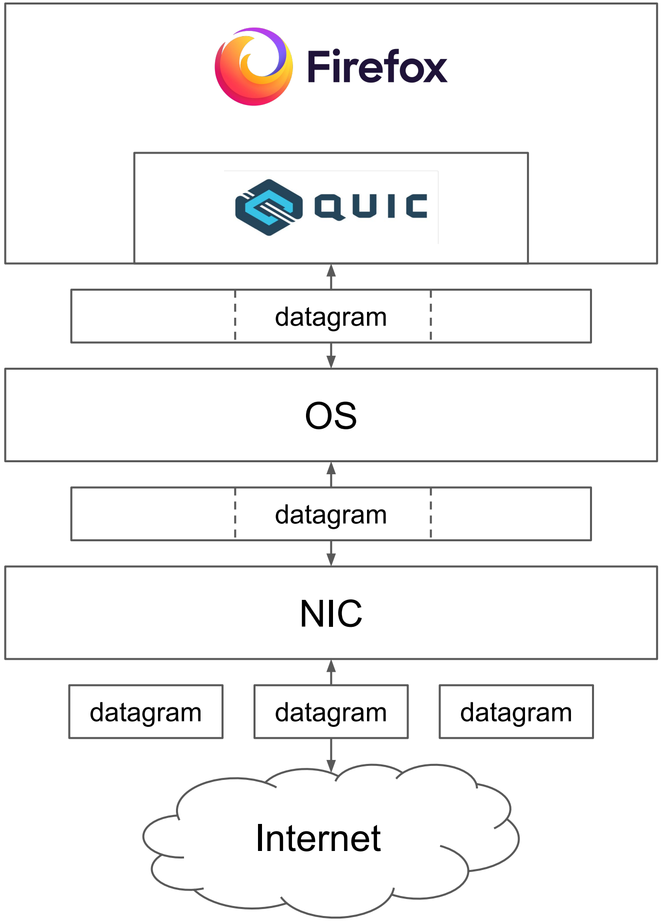


Un-optimized Firefox QUIC UDP IO



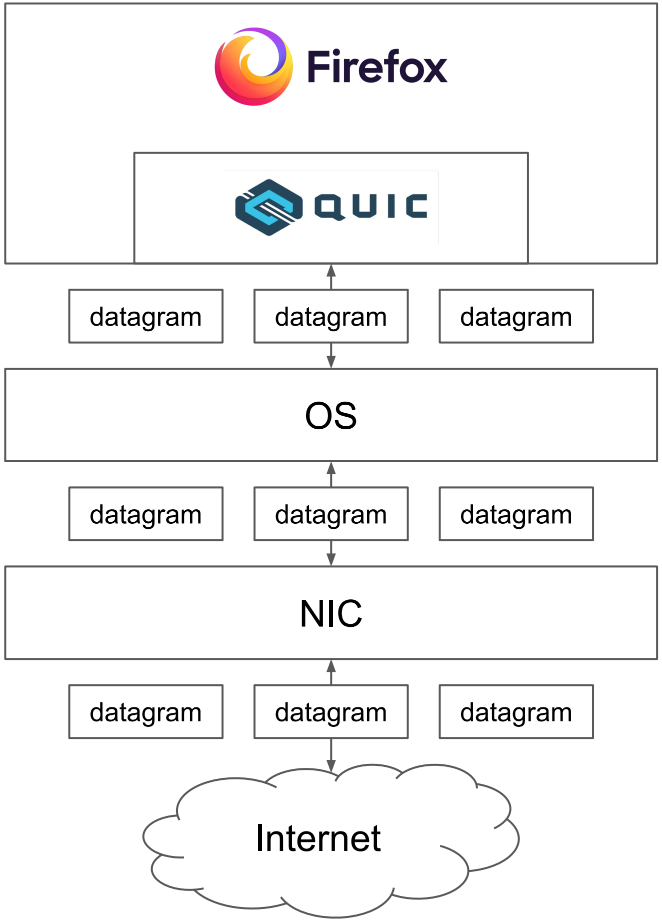
Segmentation offloading

- Linux's GSO/GRO
- Windows' USO/URO
- measurements on Firefox Nightly Linux GRO
  - 75th of read syscalls read 2 or more packets, 95th read 10 or more packets.
  - 75th of read syscalls read 2.4 KiB total, 95th read 12 KiB total.
- close to the 1 Gbit/s on loopback benchmark



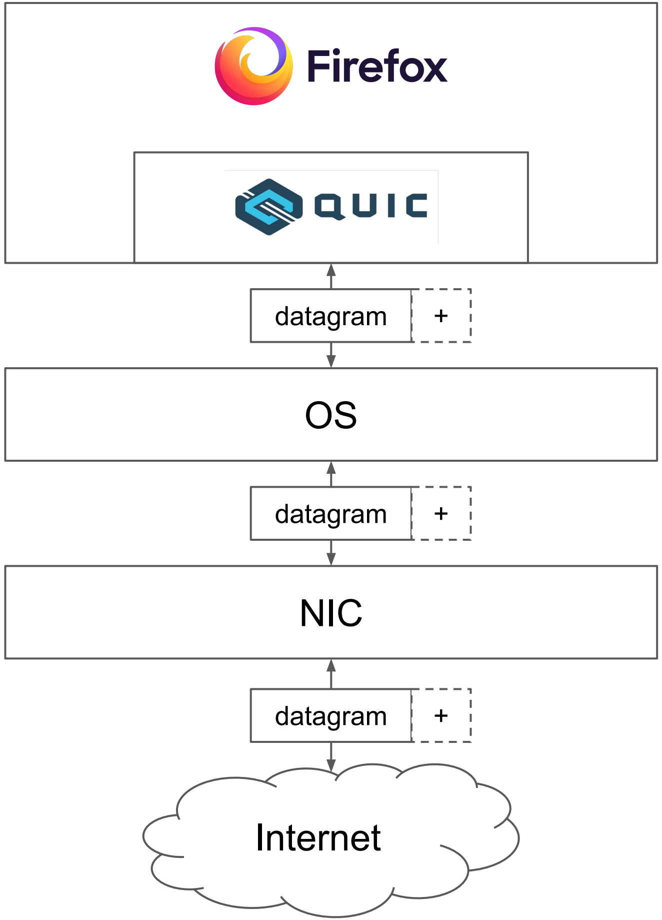
Multi-message syscalls

- MacOS sendmsg_x and recvmsg_x
- Similar to Linux's sendmmsg and recvmmsg
- 11% performance improvement on loopback transfer



PLPMTUD

- Packetization Layer Path MTU Discovery for Datagram Transports (RFC 8899)
- probe maximum MTU on path
- 1280 bytes vs 1472 bytes makes a difference
- See also
  - Firefox QUIC implementation
  - Custura, A., Fairhurst, G., & Learmonth, I.: **“Exploring usable Path MTU in the Internet”**



QUIC ACK frequency

- QUIC Acknowledgment Frequency IETF draft
- say a QUIC receiver ACKs every second packet on a 1 Gbit/s transfer
- 1 Gbit/s / 8 / 1500 / 2 ~= 40k ACK / s
- instead have the sender propose an ACK rate to the receiver

Additional wins

- QUIC UDP IO in Rust using quinn-udp
- Explicit Congestion Notification (ECN)
    - with modern syscalls, we can now read auxiliary IP metadata, e.g. ECN.
    - on Firefox Nightly we see
        - ~50% of paths being ECN capable
        - 75th percentile of QUIC connections see >= 0.6% CE marks on receive path.
- optimized memory management
    - we use a single long-lived 64k receive buffer for all QUIC connections
    - soundness check at compile time via Rust’s borrow checker
    - significant reduction in CPU time on large transfers

What is next?

- rolling out
  - PMTUD
  - ECN
  - ACK frequency
- send-path optimizations
  - GSO, USO, sendmsg_x, …
  - long lived send buffer

Get involved!

- try it yourself on Firefox Nightly, soon Beta and Release then after
- contribute to https://github.com/mozilla/neqo
  - Rust codebase
  - modern transport protocol
  - help make Firefox faster
- reach out:
  - https://matrix.to/#/#neqo:mozilla.org
  - mail@max-inden.de