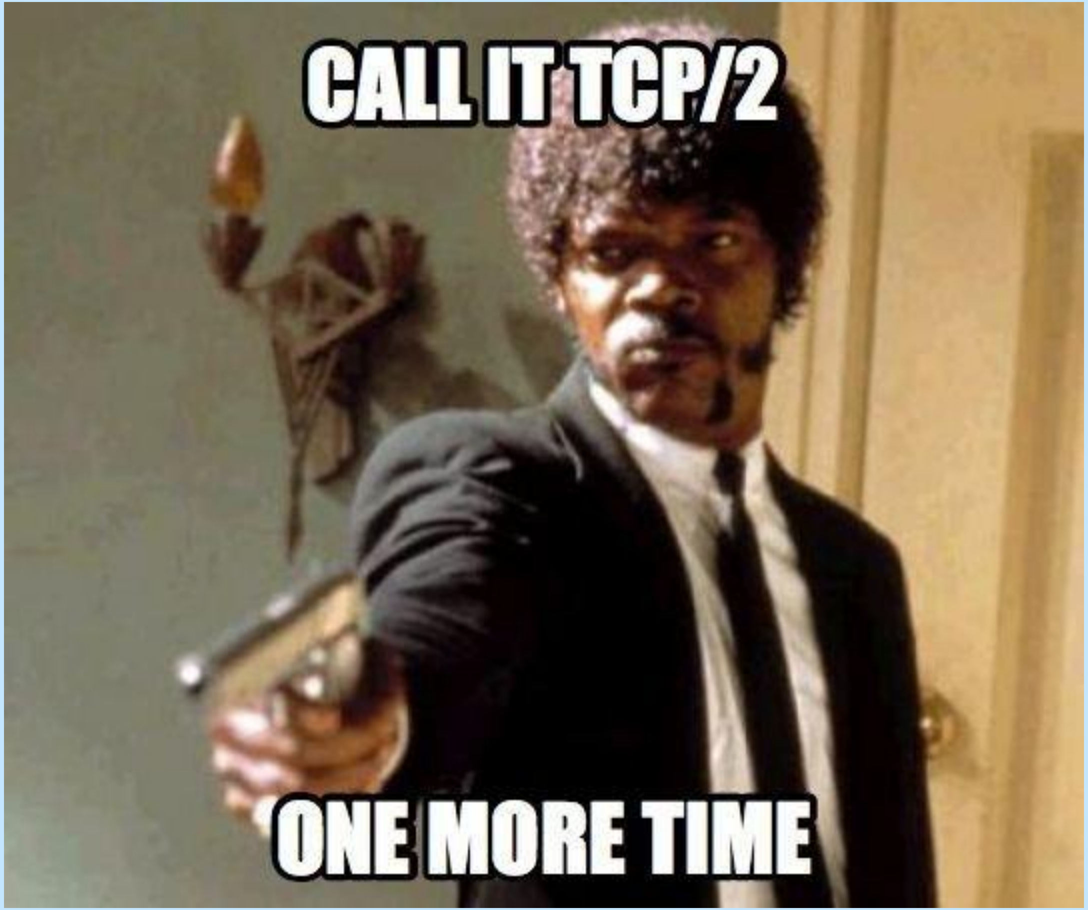
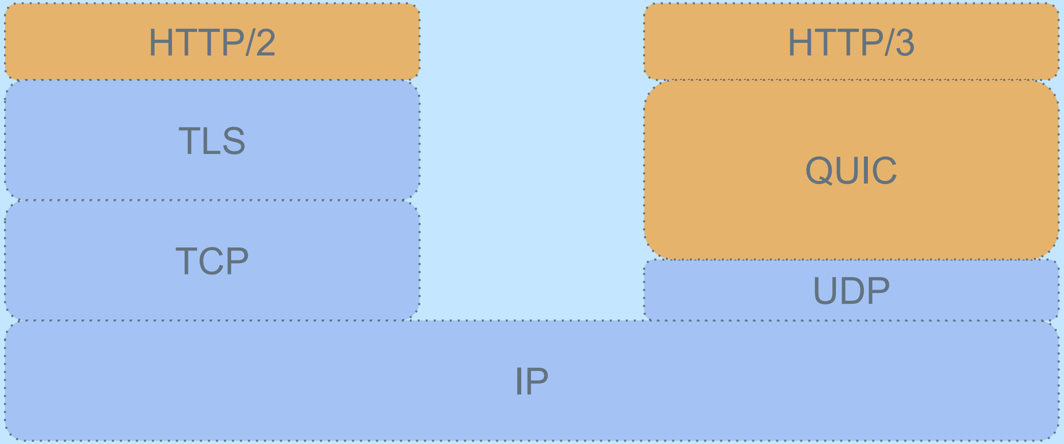
Fast QUIC sockets with vector packet processing

Aloys Augustin, Nathan Skrzypczak,
Mathias Raoul, Dave Wallace

What is QUIC ?


CALL IT TCP/2
ONE MORE TIME

The stack



Nice properties

- Encryption by default ~ TLS 1.3 handshake
- No ossification
- Built-in multiplexing
  - Very common application requirement
  - Independent streams in each connection
  - Addresses head-of-line blocking
  - Stream prioritization support
- Supports mobility
  - 5-tuple may change without breaking the connection

Conns & streams

Why QUIC - pros & cons

Pros

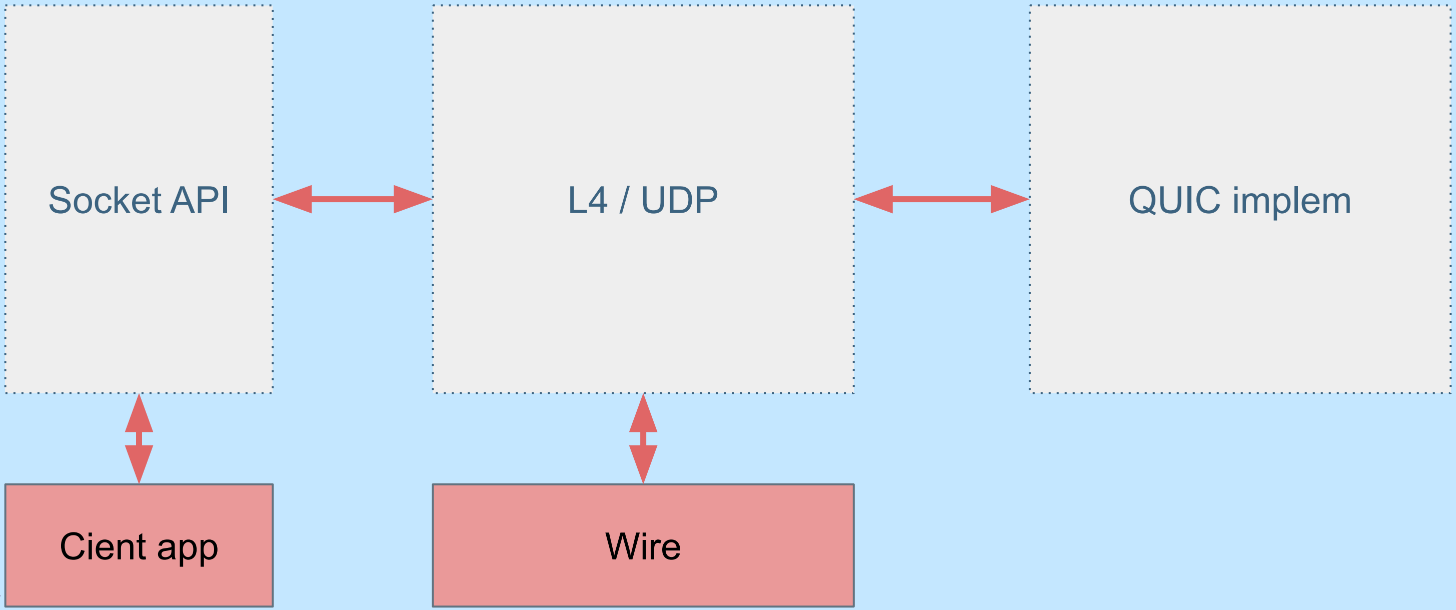
- Runs on UDP, can be implemented out of the kernel
- Addresses head of line blocking
- 5-tuple mobility
- Encryption by default

Cons

- Implementation complexity
- No standard northbound API (for now)
- Still evolving relatively fast, not an IETF standard yet

A quick dive in the code

Building blocks



Building blocks

vpp client lib

vpp

quicly

vectorization

fast L2-3-4

pluggable sessions

few assumptions

very modular

https://github.com/h2o/quicly

What is VPP?

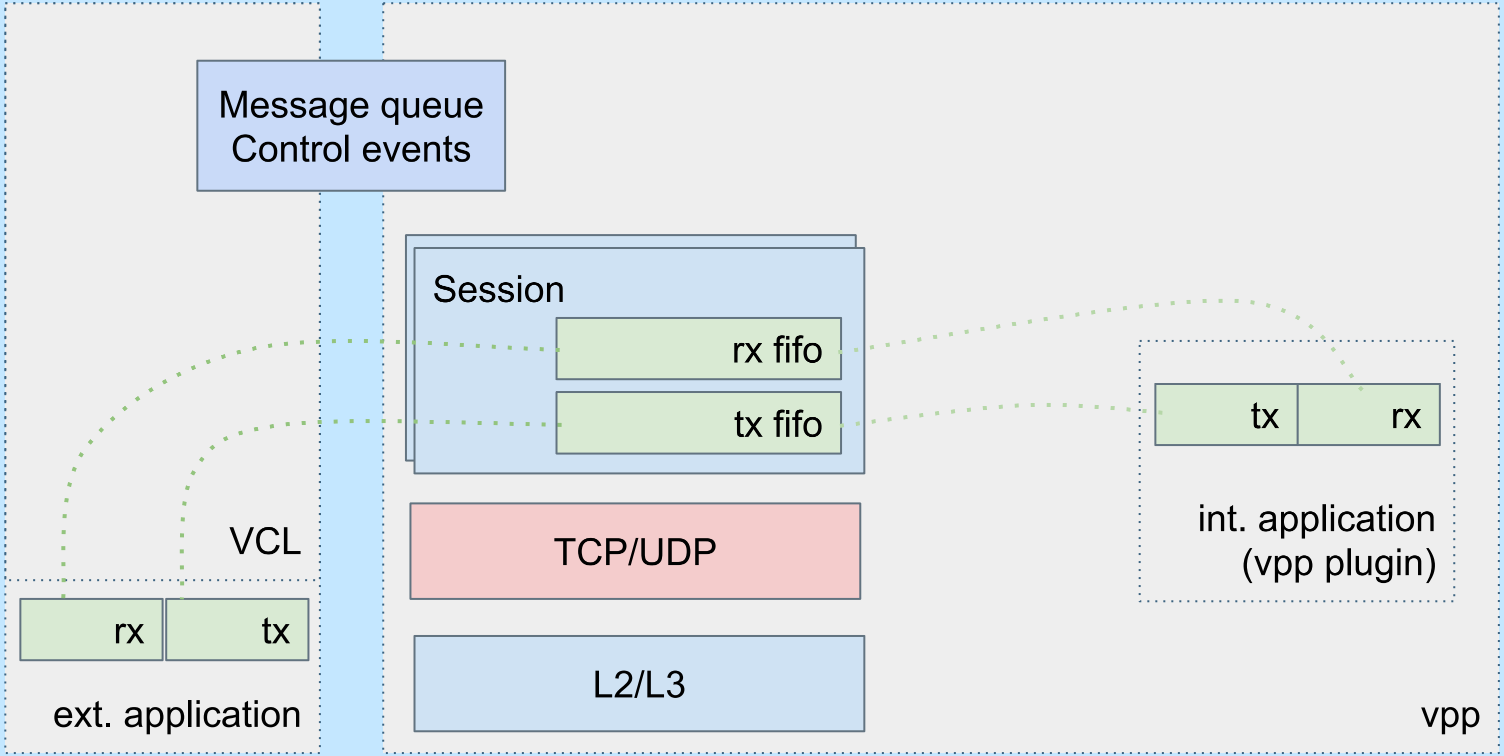
- Fast userspace networking dataplane - https://fd.io/
- Open-source: https://gerrit.fd.io/r/q/project:vpp
- Extensible through plugins
- Multi-architecture (x86, ARM, ...), runs in baremetal / VM / container
- Highly optimized for performance (vector instructions, cache efficiency, DPDK, native crypto, native drivers)
- Feature-rich L2-3-4 networking (switching, routing, IPsec, …)
- Includes a host stack with L4 (TCP, UDP) protocols

→ Great platform for a fast userspace QUIC stack

VPP Host stack (1/2)

- Generic session layer exposing L4 protocols
  - Socket-like APIs
- Fifos used to pass data between apps and protocols
- Internal API for VPP plugins
- Similar external API for independent processes available through a message queue
- Designed for high performance
  - Saturates 40G link with 1 TCP flow or 1 UDP flow
  - Performance scales linearly with number of threads

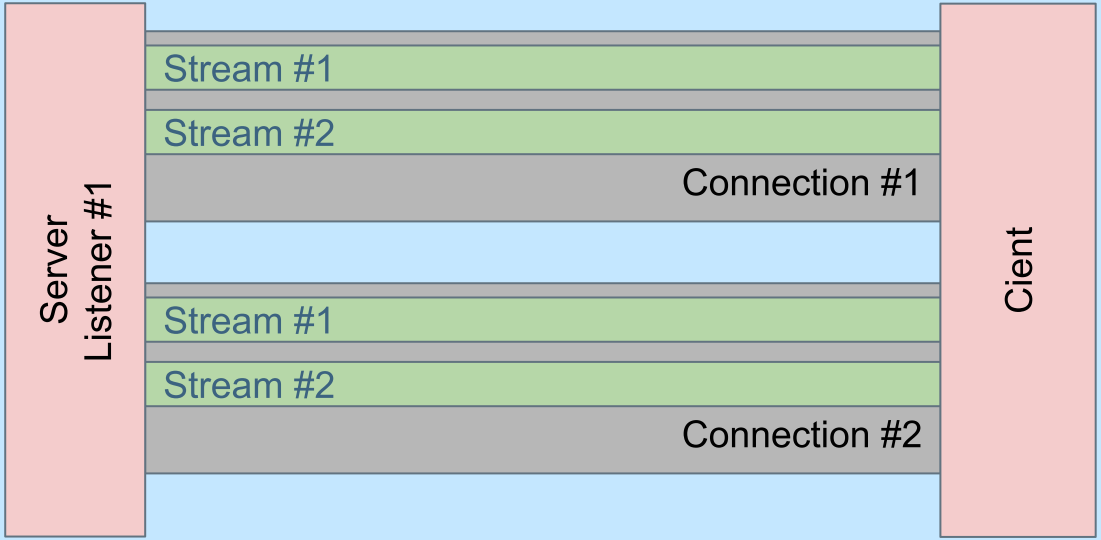
VPP Host stack (2/2)



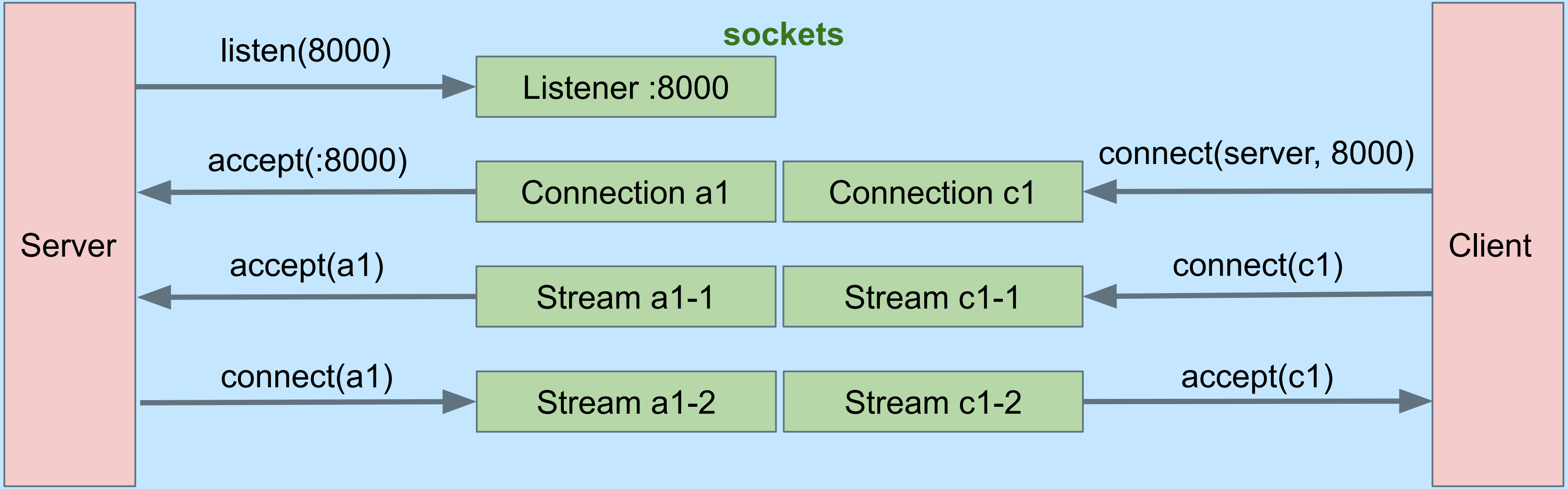
QUIC App Requirements

Three types of objects:

- Listeners
- Connections
- Streams

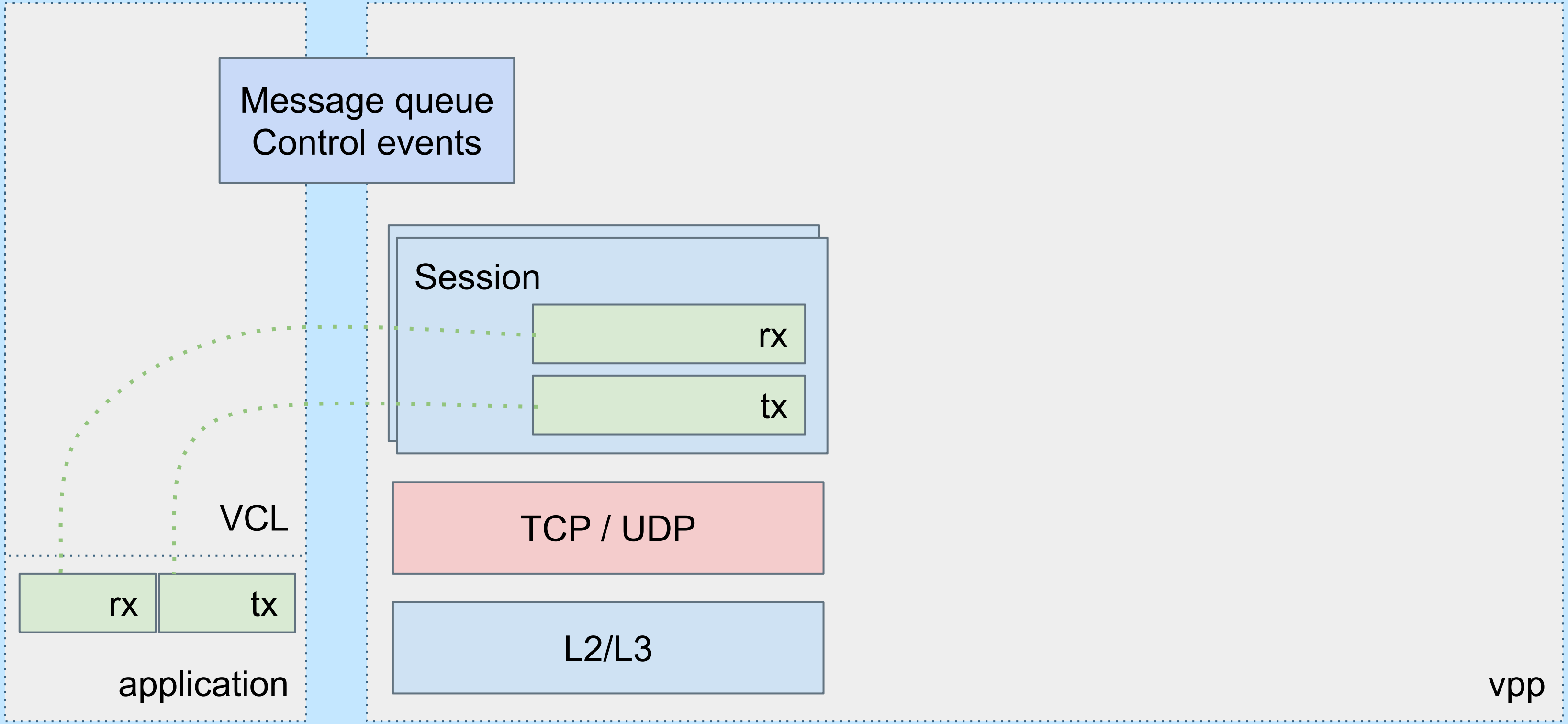


Socket-like API for QUIC

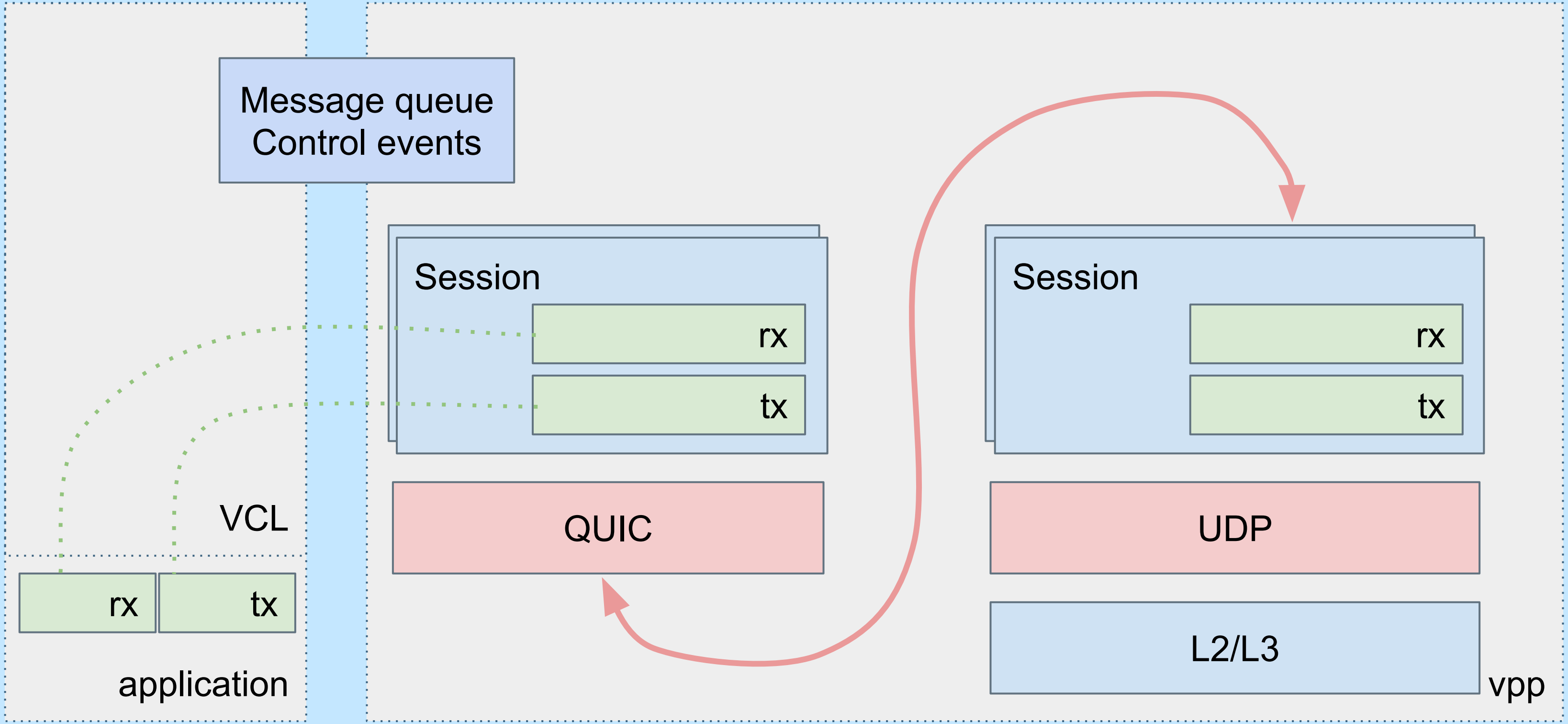


Three types of sockets for listeners, connections and streams
Connection sockets are only used to connect and accept streams
Connection sockets cannot send or receive data

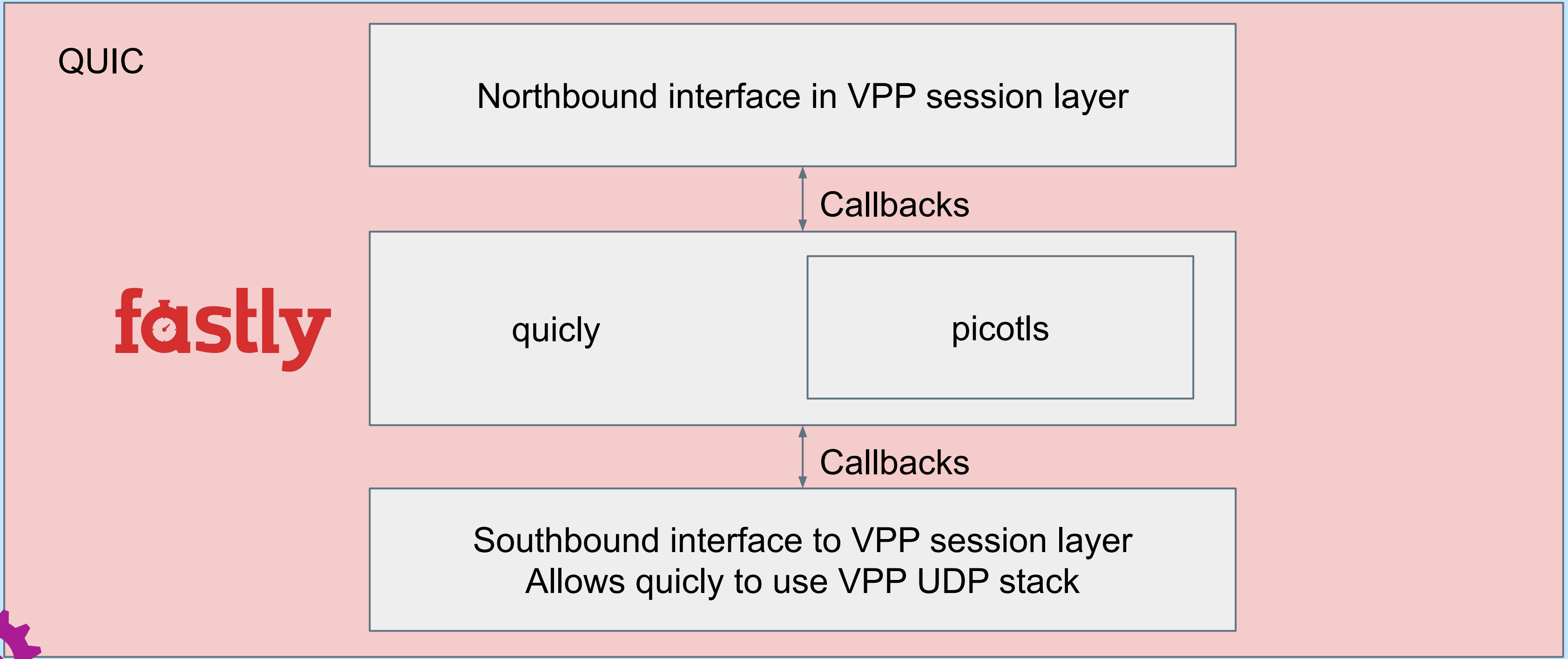
Building a QUIC stack in VPP



Building a QUIC stack in VPP

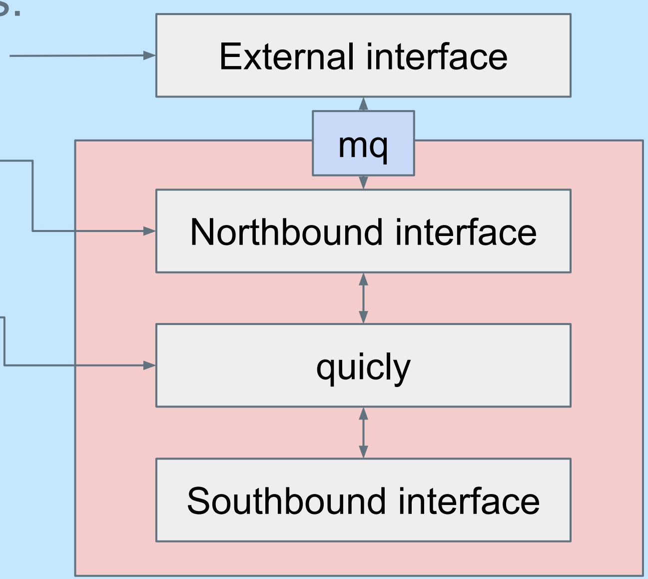


Zooming in


QUIC
Northbound interface in VPP session layer
Callbacks
quicly
picotls
Callbacks
Southbound interface to VPP session layer
Allows quicly to use VPP UDP stack

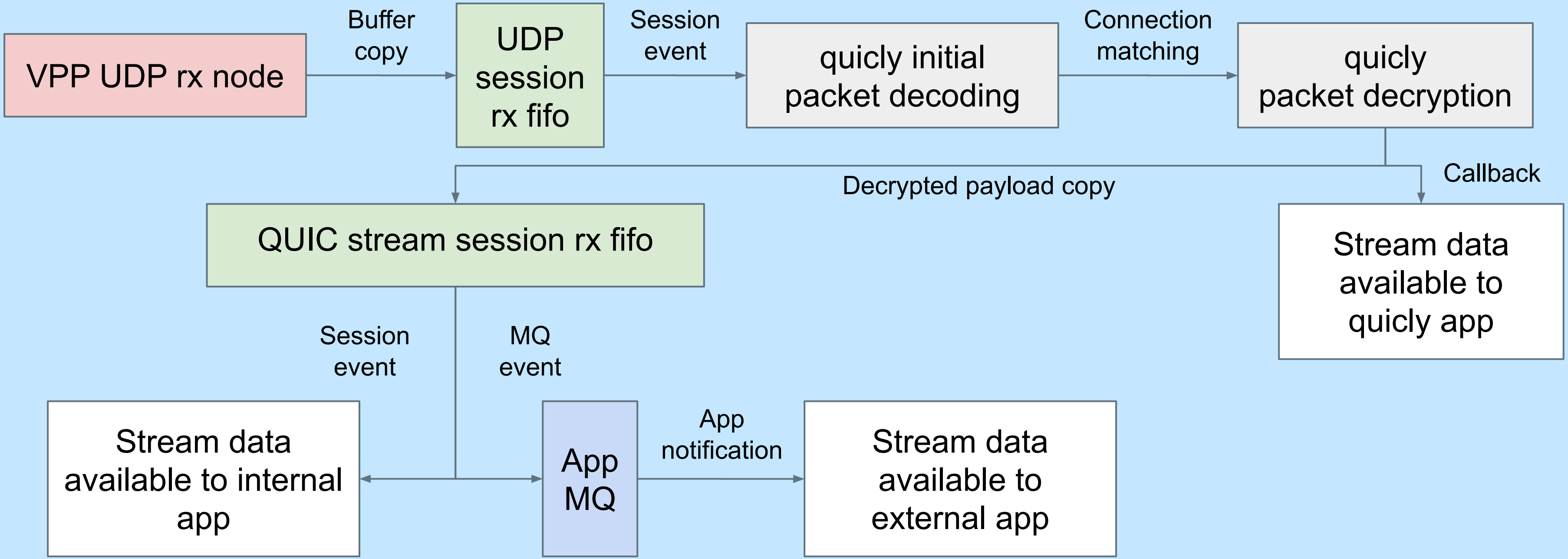
QUIC Consumption models in VPP

- The VPP QUIC stack offers 3 consumption models:
  - External apps: independent, use the external (socket) API
  - Internal apps: shared library loaded by VPP, use the internal API
  - Apps can use the quicly northbound API directly
    → As long as they use the VPP threading model



Northbound interface in the host stack is optional!

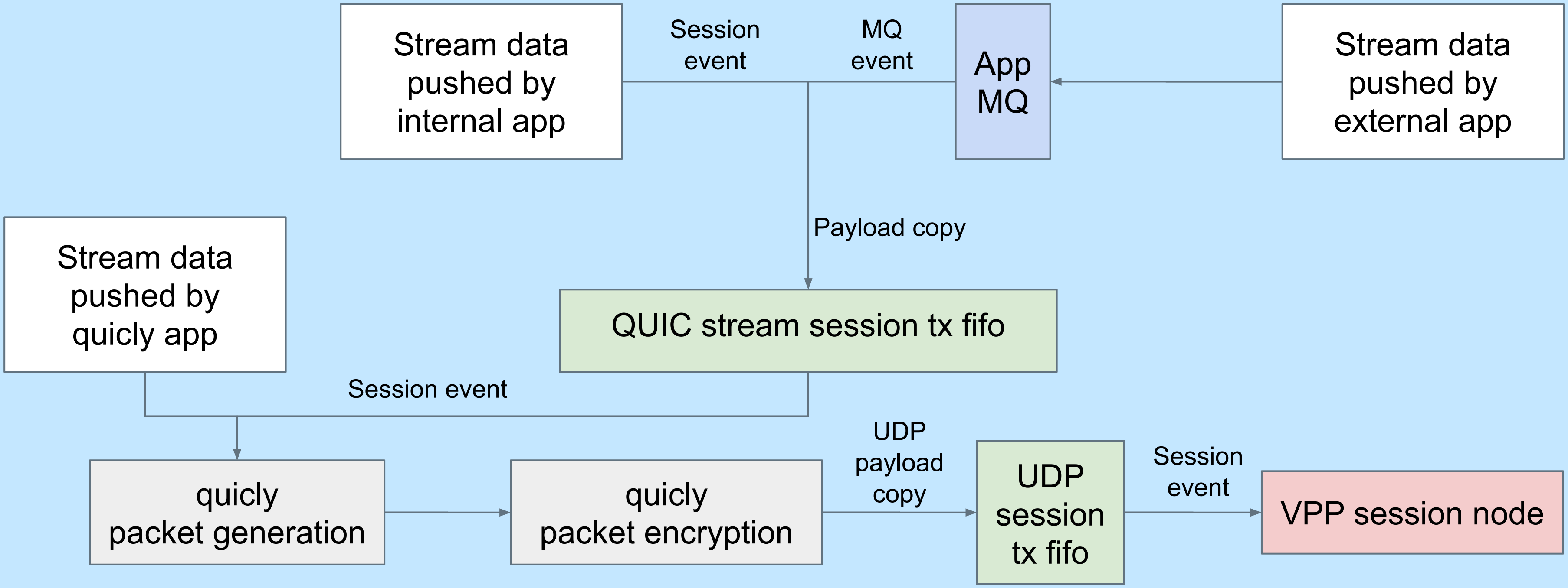
RX path


VPP UDP rx node
Buffer copy
UDP session rx fifo
Session event
quicly initial packet decoding
Connection matching
quicly packet decryption
Decrypted payload copy
Callback
QUIC stream session rx fifo
Stream data available to quicly app
Session event
MQ event
Stream data available to internal app
App MQ
App notification
Stream data available to external app

Memory management and ACKs

- VPP fifos are fixed size. What if a sender sends more data than fifo size ?
  - Before a packet is decrypted, we have no way to know which stream(s) it contains data for → We cannot check the available space in the receiving fifo
  - Once a packet is decrypted, Quicly does not allow us to drop it otherwise it will never be retransmitted
  - Fortunately, QUIC has a connection parameter called *max_stream_data*, which limits the in-flight (un-acked) data per stream sent by peer.
  - Setting this parameter to the fifo size solves this problem, as long as we ACK data only when it is removed from the fifo
- QUIC has several other connection-level settings to control memory usage:
  - Max number of streams
  - Total un-acked data for the connection

TX path

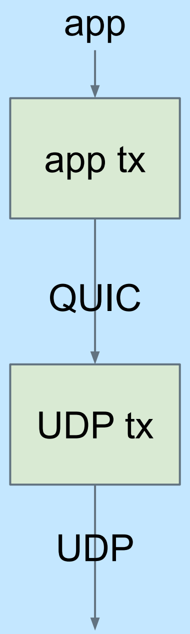


Stream data pushed by internal app
Session event
MQ event
App MQ
Stream data pushed by external app
Payload copy
Stream data pushed by quicly app
QUIC stream session tx fifo
Session event
quicly packet generation
quicly packet encryption
UDP payload copy
UDP session tx fifo
Session event
VPP session node

Backpressure

- UDP backpressure: we limit the amount of packets generated by quicly so as not to overflow the UDP tx fifo

- How does an app know it should wait before sending more data?
    - When Quicly cannot send data as fast as the app provides it, it stops reading from the QUIC streams tx fifos
    - The app needs to check the amount of space available in the fifo before sending data
    - The app can subscribe to notifications when data is dequeued from its fifos



Threading model

- VPP runs either with one thread, or one main thread + n worker threads
- UDP packets assignment to threads is dependent on RSS
  - The receiving thread is unknown when the first packet is sent
  - UDP connections start on one thread and migrate when the first reply is received
  - The VPP host stack sends notifications when this happens
- QUIC sessions are opened only when the handshake completes, and thus do not migrate (as long as there are no mobility events - not yet supported)
- All QUIC streams are placed in the thread where their connection exists

How quick is it ?

Performance: evaluation

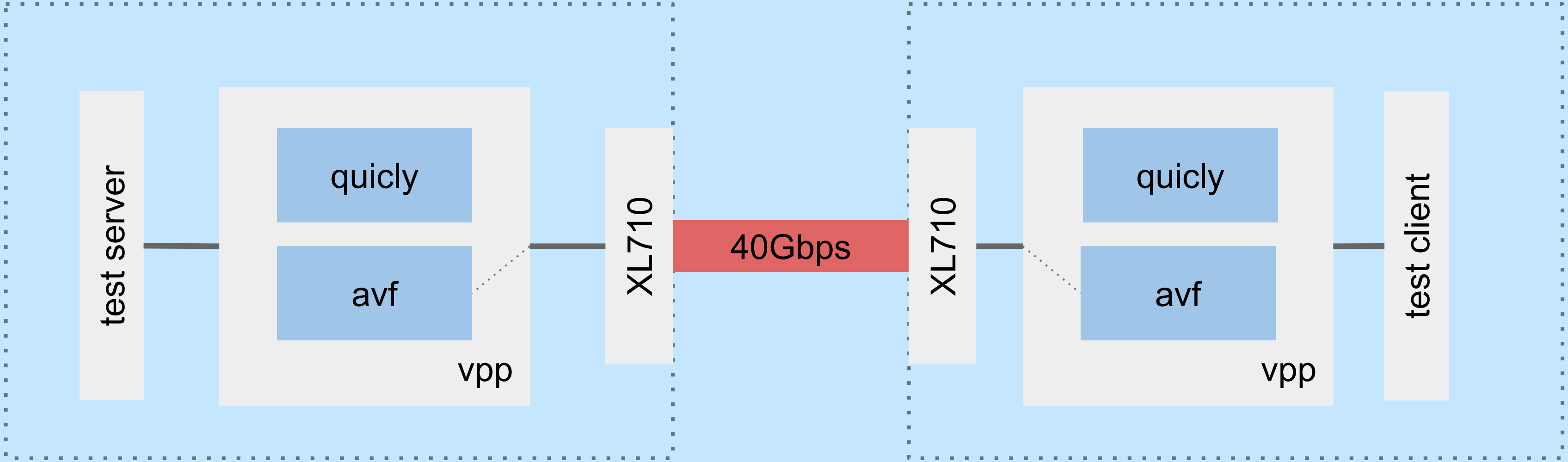
For now : no canonical QUIC perf assessment tool

Custom iperf-like client/server benchmark tool

- Opens N connections
- Then opens n streams in each connection
- Client sends d bytes of data per stream
- Server closes the streams, then the connection

Typical setup N=10 n=10 d=1GB

Performance: test setup



- Core pinning, VPP and test apps on same NUMA node
- 1500 bytes MTU
- 2x Intel Xeon Gold 6146 3.2GHz CPUs

Performance: initial results

10x10	1 worker	3.5 Gbit/s
100x10	4 workers	13.7 Gbit/s

Simultaneous connections

- Scales up to 100k streams / core
- Handshake rate ~1500 / s / core

Performance: optimisations

- Crypto
  - Quicly uses picotls by default for the TLS handshake and the packet encryption / decryption
  - Picotls has a pluggable encryption API, which uses openssl by default for encryption
  - Using the VPP native crypto API yielded better results
  - Further improvements were obtained by batching crypto operations, using the Quicly offload API:
    - N packets are received and decoded
    - These N packets are decrypted at the same time
    - The decrypted packets are passed to quicly for protocol processing
    - The same idea is applied in the TX path as well
- Congestion control
  - The default congestion control (Reno) of quicly doesn’t reach very high throughputs
  - Fortunately, it is pluggable as well :)

Performance: new results

10x10 pre-optimization	1 worker	3.5 Gbit/s
10x10 w/ batching & native crypto	1 worker	4.5 Gbit/s (+28%)

For now, most of the CPU time is spent doing crypto
Intel Ice Lake CPUs will accelerate AES and may move the bottleneck more towards the protocol processing

What's next

Next steps

- Performance optimisation
- Mobility support
- Continuous benchmarking - soon on https://docs.fd.io/csit/master/trending/index.html

If you want to get involved:

https://gerrit.fd.io/r/q/project:vpp - code in src/plugins/quic/

If you want to try it, check out the example code in src/plugins/hs_apps/ (host stack apps)

Use cases

- Scalable HTTP/3 servers
- Scalable gRPC over QUIC servers
- QUIC VPN
  - Better than SSL VPN: mobility support, using one stream per flow allows to get rid of head of line blocking
  - As easy to deploy as an SSL VPN: only a certificate is needed on the server, with an authentication mechanism for clients
- QUIC VPN with transparent proxying
  - Transparently terminating the TCP connections at the VPN gateway and sending only the TCP payloads in QUIC streams allows to get rid of the nested congestion control issues

Takeaways

- Great experience with quicly
- VPP now provides an easy API to use QUIC
- Host stack proved to be extensible for new protocols
- VPP framework gave good performance boost to QUIC
    - Native crypto + vector processing
    - Still some effort required to reach max levels of performance

Thanks for listening

Any questions ?

Backup slides

Building a QUIC stack - a QUIC dive