

End-system controlled, dynamic multihoming and multipath transport

Saleem Bhatti



Acknowledgements

- Current team:
 - Rodney Grimes (NetDEF and FreeBSD).
 - Alistair Woodman (NetDEF).
 - **Saleem Bhatti (University of St Andrews).**
- With support from the ICANN Grant Program:
 - <https://ilnp.cs.st-andrews.ac.uk/digs/>
- Thanks to the IETF NOC team 😊



- 1. Motivation and Problem Statement**
2. Technical approach
3. Testing and Experiments

Motivation and Problem Statement

- Dynamic, flexible use of **multiple network paths**, e.g.:
 - Load distribution / load balancing.
 - Resilience / failover.
 - Mobile nodes and mobile networks.
 - Security and privacy.
- Limited options currently:
 - MPTCP, SCTP, QUIC multipath is work-in-progress.
- **Can we provide a **general** multipath capability for **any** transport protocol (including existing ones)?**

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Identifier Locator Network Protocol (ILNP)

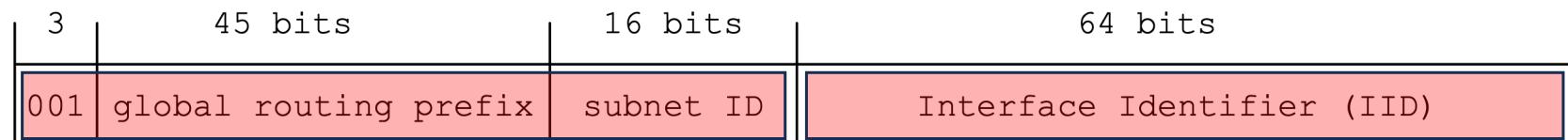
- Ongoing research project on Internet architecture:
 - **Addressing architecture with end-to-end semantics over IPv6.**
- RFCs 6740-6748 (E).
- No tunnels.
- No proxies.
- No NAT.
- No changes to routing or switching.
- No changes to existing applications.
- <https://ilnp.cs.st-andrews.ac.uk/>



ILNP

ILNP addressing semantics (RFC6740/1)

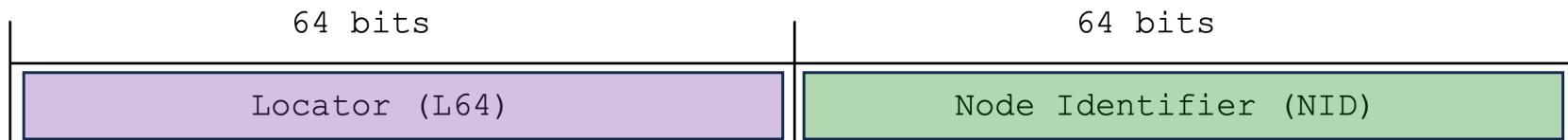
IPv6 (RFC8200(S)) – general IPv6 global address format:



IPv6 routing (address) prefix.

Same syntax as IPv6, different semantics.

ILNP (RFC6741(E)) – Identifier Locator Vector (I-LV):



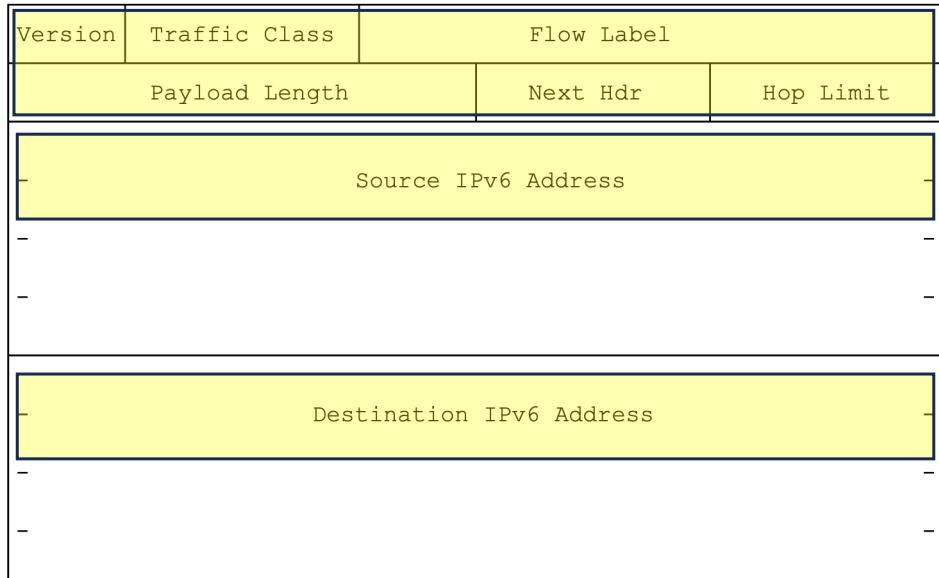
Same syntax and semantics as
IPv6 routing (address) prefix,
so IPv6 routers work as today.

These bits only examined and
acted upon by end systems.

Packet view (the “wire image”)

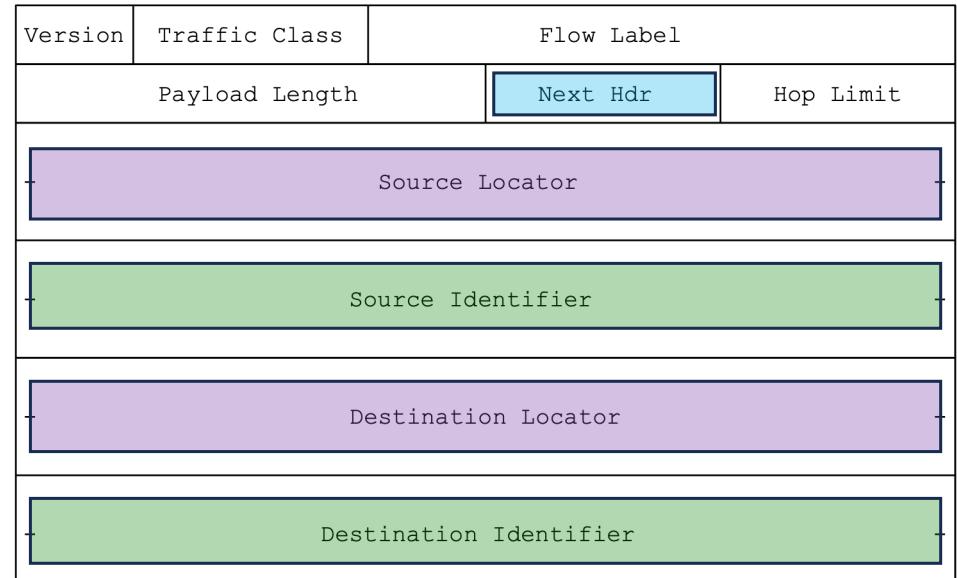
View from an IPv6 **router**

0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1



View from an ILNP **end-system**

0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1



ILNP addressing – architecture

Protocol Layer	IP	ILNP
Application	FQDN (or app specific) IP address	FQDN (or app specific) (RFC1958)
Transport	IP address (+ port number)	Node Identifier (+ port number)
Network	IP address	Locator
(Interface)	IP address	(dynamic mapping)

Entanglement ☹ **Separation ☺**

FQDN fully qualified domain name (DNS)

ILNP addressing – transport state

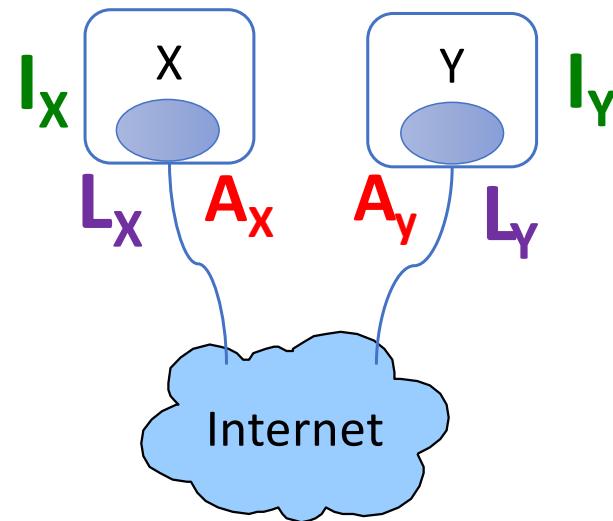
A = IP address (“fixed”)
P = port number

At X:

$\langle \text{TCP: } A_x, P_x, A_y, P_y \rangle < \text{IP: } A_x, A_y \rangle$

At Y:

$\langle \text{TCP: } A_y, P_y, A_x, P_x \rangle < \text{IP: } A_y, A_x \rangle$



I = Node **Identifier** (“stable”)
L = **Locator** (mutable)
(I-LV = Identifier-Locator Vector)
P = port number

At X:

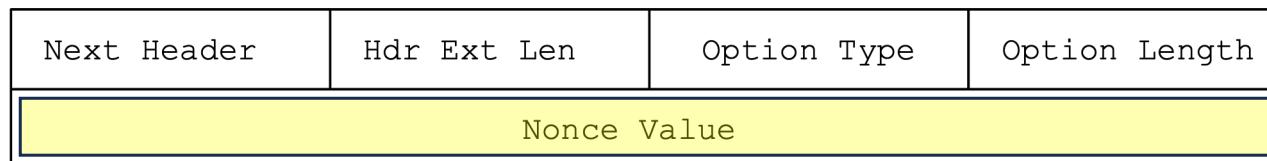
$\langle \text{TCP: } I_x, P_x, I_y, P_y \rangle \# < \text{IP: } L_x, L_y \rangle$

At Y:

$\langle \text{TCP: } I_y, P_y, I_x, P_x \rangle \# < \text{IP: } L_y, L_x \rangle$

ILNP Nonce header (RFC6744)

ILNP Destination Option (RFC6744 (E)):



IPv6 Destination Option Type = 139 / 0x8b

At X:

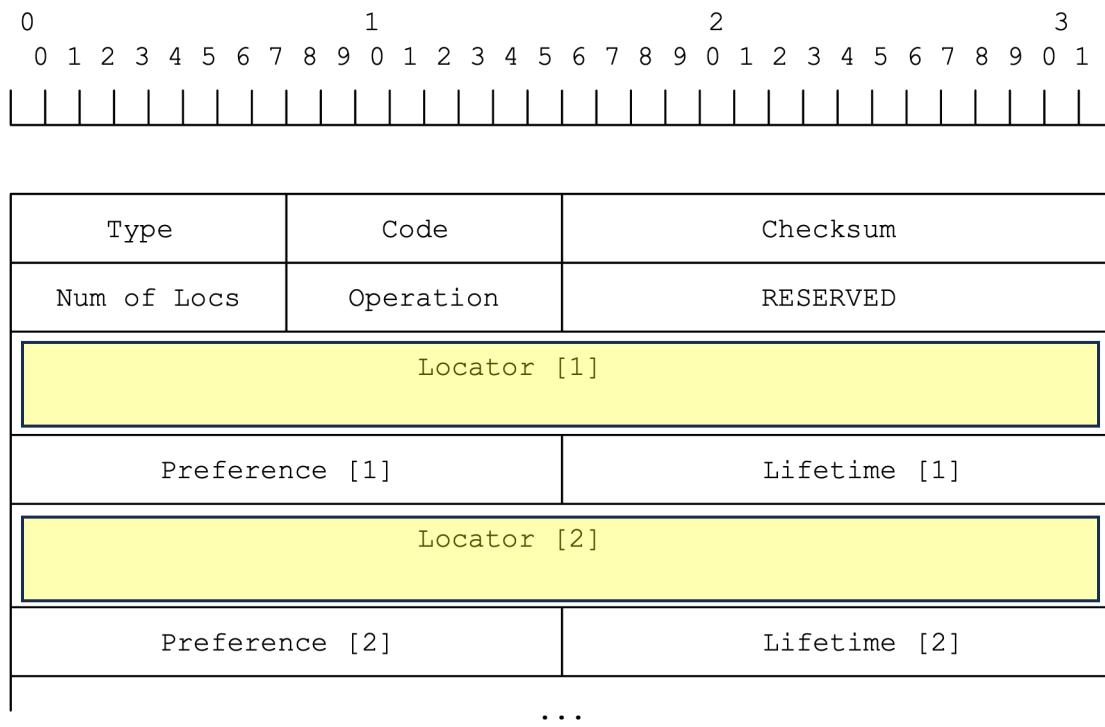
<TCP: I_x, P_x, I_y, P_y, N >#<IP: L_x, L_y >

At Y:

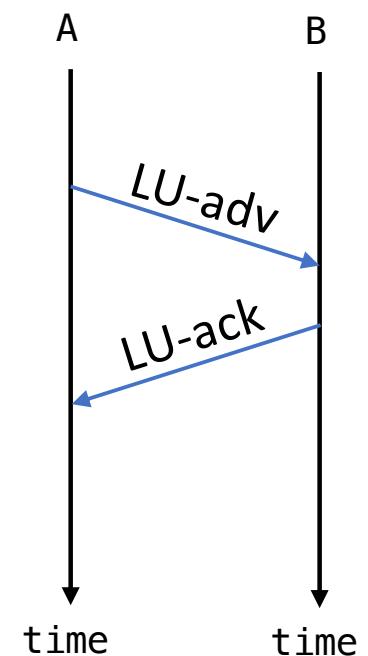
<TCP: I_y, P_y, I_x, P_x, N >#<IP: L_y, L_x >

ILNP Locator Update (LU) (RFC6743)

ICMPv6 Locator Update Message (RFC6743(E)):



Type = 156 / 0x9c, Code = 0

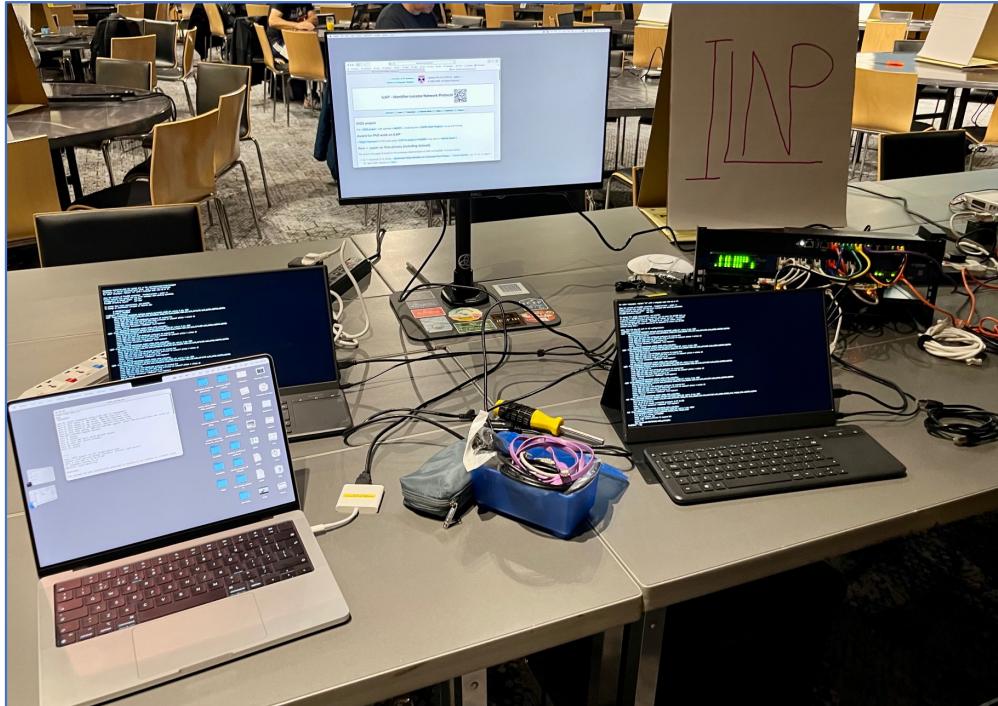


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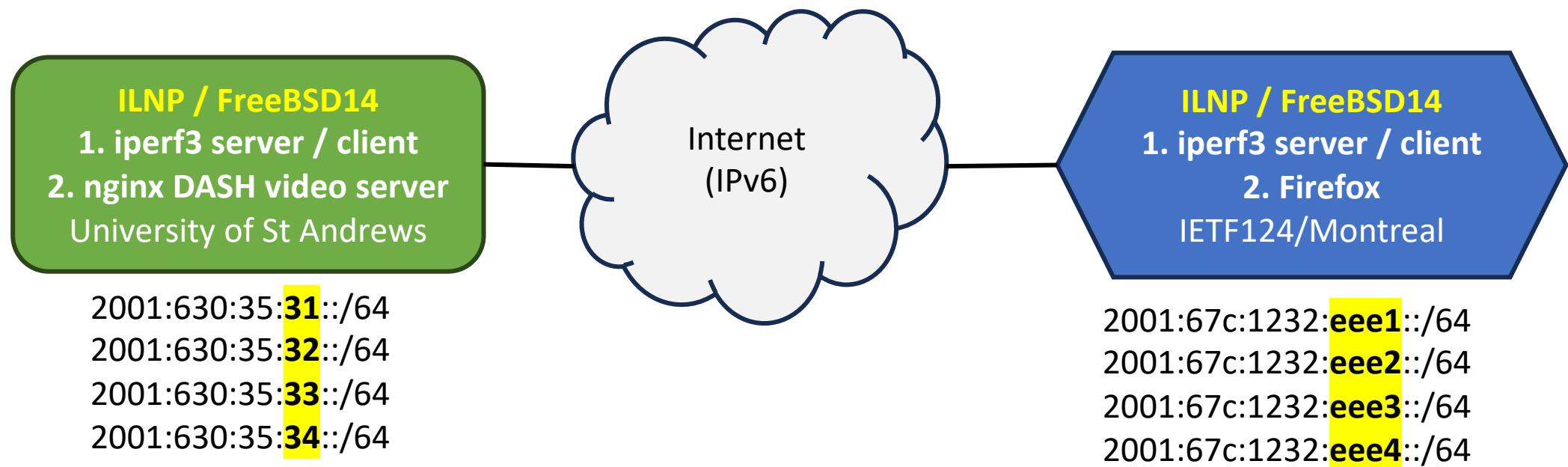
Experiment configuration

- **Test: end-to-end multipath control via ICMPv6 signalling.**
- Test scenarios using an implementation on FreeBSD14:
 1. Dynamic 4-way multipath with TCP, [iperf3](#):
 - [TCP CUBIC](#) / ILNP.
 2. Video streaming over TCP with 3-way multipath, [nginx](#) + [Firefox](#):
 - DASH / HTTP / TLS / [TCP CUBIC](#) / ILNP.
- **Standard program libraries and binaries** from repos:
 - [iperf3](#), [nginx](#), [Firefox](#).
- Code-base is in development, so surprises were expected:
 - **Preliminary results look promising** ☺

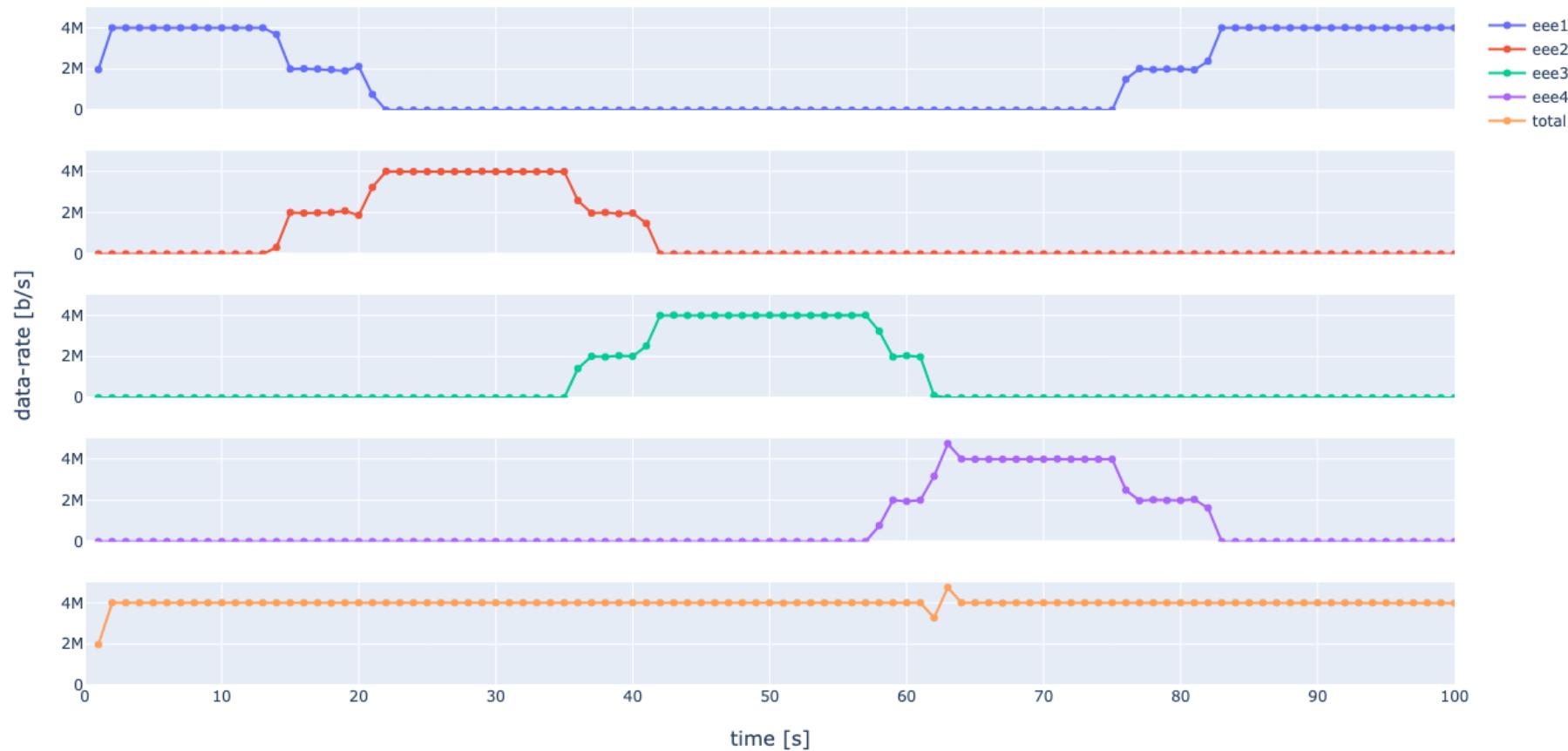
IETF124/Montreal, 01-07 November 2025



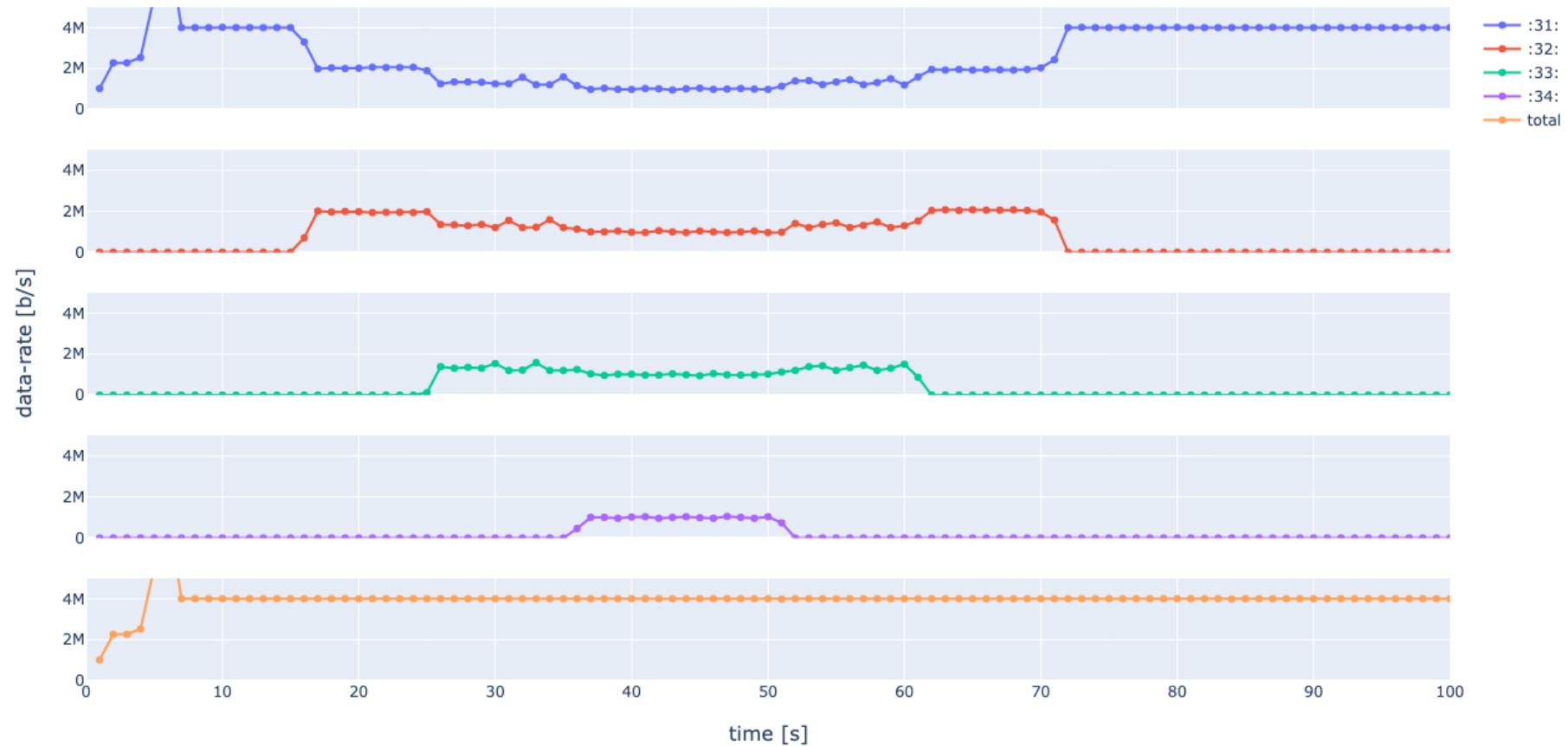
Network configuration

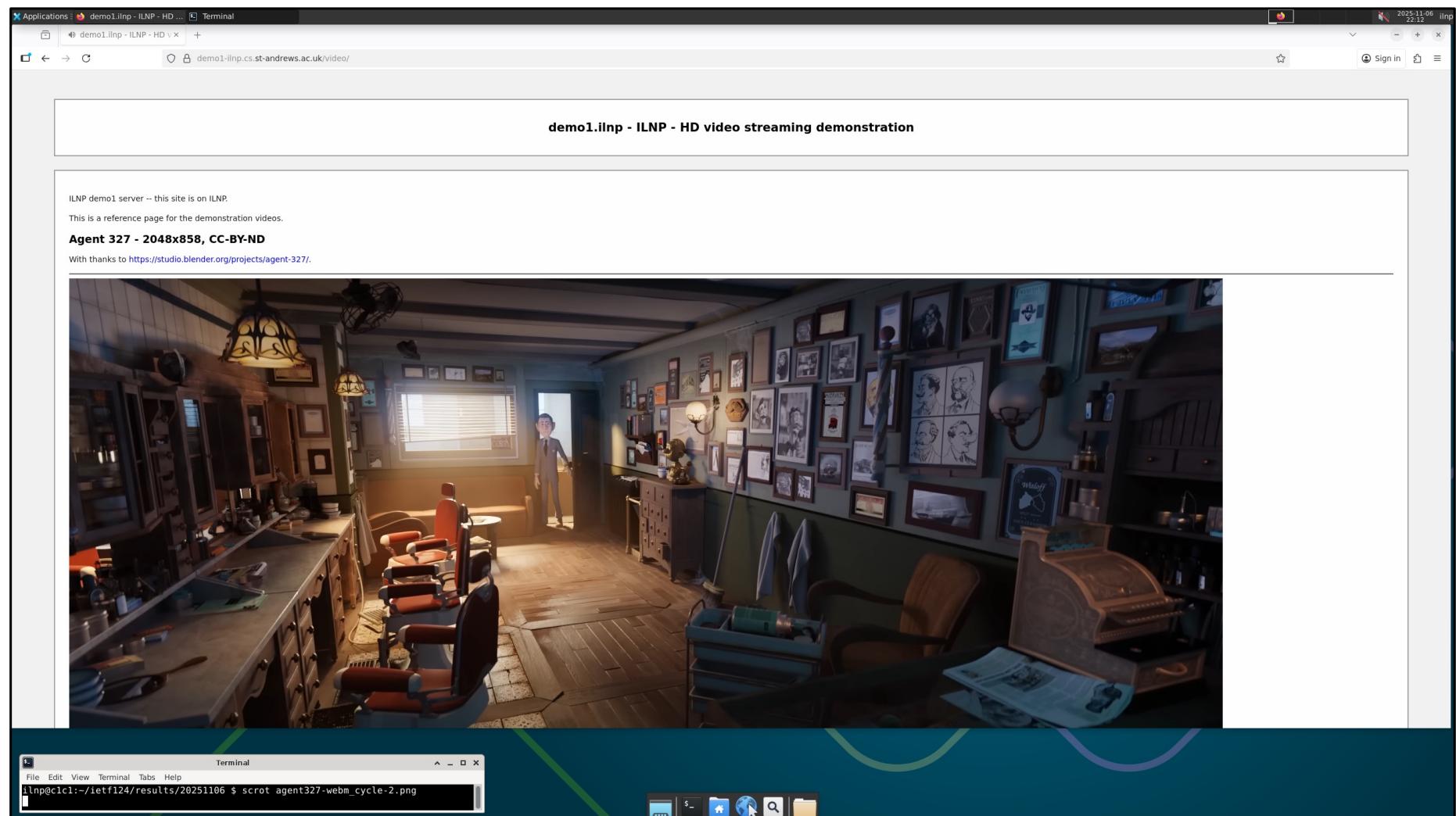


TCP c1c1 (IETF124/Montreal) to demo1 (St Andrews, UK), iperf3 4Mb/s flow, 4-way dynamic multipath

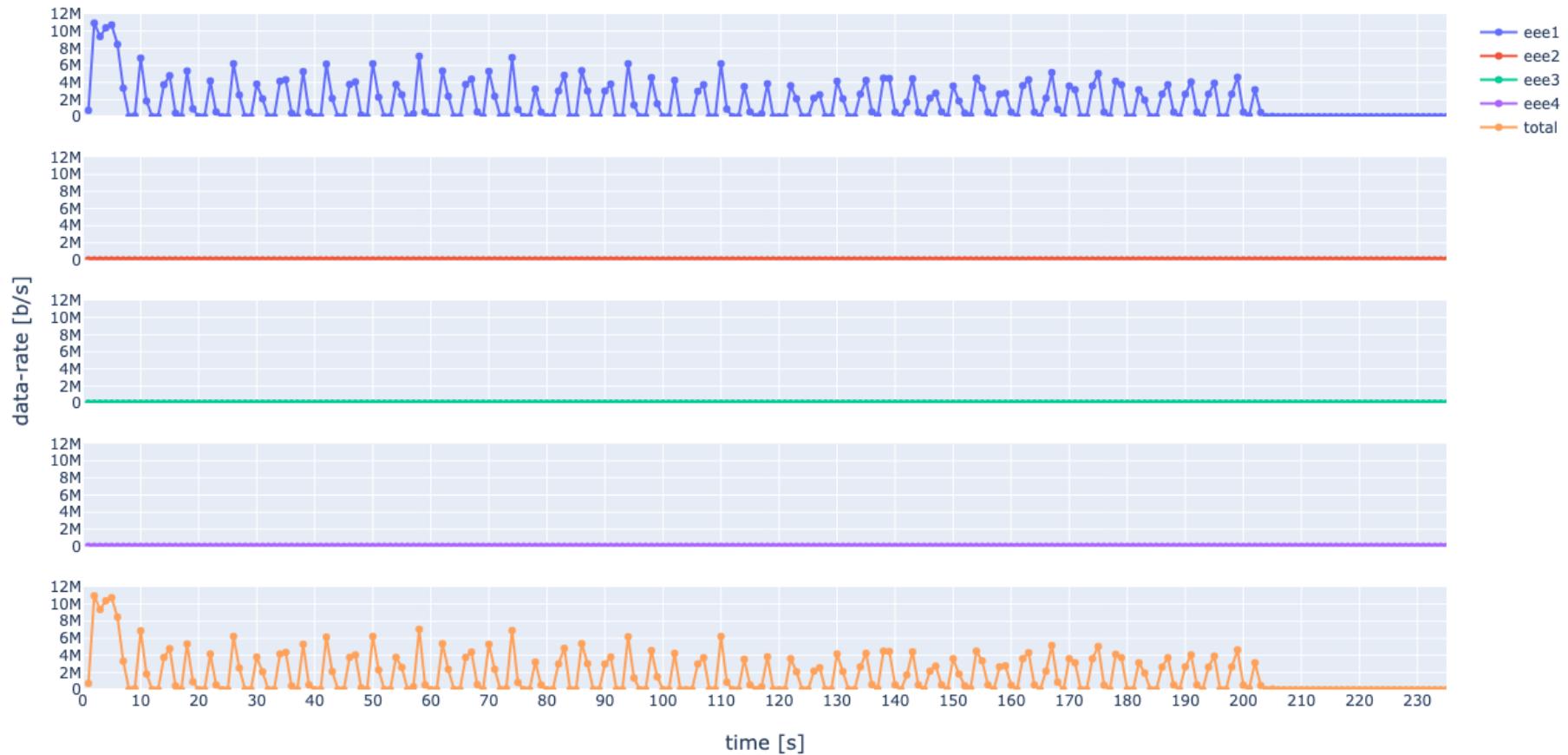


TCP demo1 (St Andrews, UK) to c1c1 (IETF124/Montreal), iperf3 4Mb/s flow, 4-way dynamic multipath

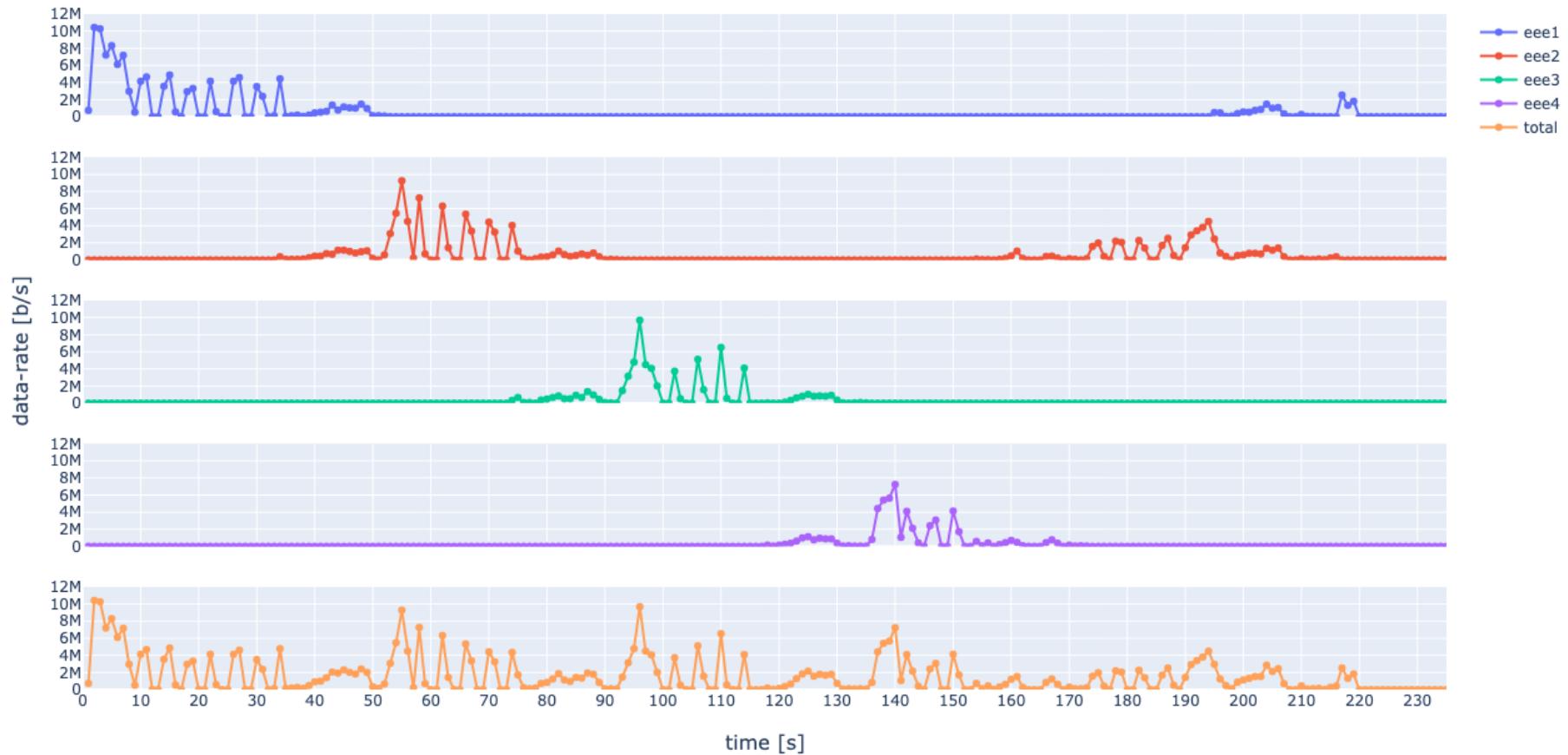




TCP video streaming single stream c1c1 (IETF124/Montreal) streaming from demo1 (St Andrews, UK)



TCP video streaming 4-way dynamic multipath c1c1 (IETF124/Montreal) streaming from demo1 (St Andrews, UK)



Thank you for your attention!

- End-to-end signaling for multihoming and multipath works as expected between the US and the UK. ☺
- Other work in progress for ILNP:
 - “Assistance” for transport protocol operation, e.g., **congestion control**, real-time applications, QUIC, multipath APIs, ...
 - DNS (RFC6742 support exists in BIND, Unbound, and KnotDNS).
 - {wire,t}shark dissector for ILNP updated Q4/2025, v4.6+.
- More information on ILNP:
 - RFCs, papers, and datasets.
 - FreeBSD 14.3 amd64 binaries.
 - <https://ilnp.cs.st-andrews.ac.uk/>

