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MPLS Network Actions: A Technological Overview

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Agenda

- Motivation
- The MNA Framework
  - Encoding
  - The Network Action sub-stack
  - Scopes and placement
  - The readable label depth
- Use Cases for MNA
  - Link-specific packet loss measurement
  - Network slicing
  - Stateless MNA-based egress protection
- P4-MNA Prototype
- Conclusion

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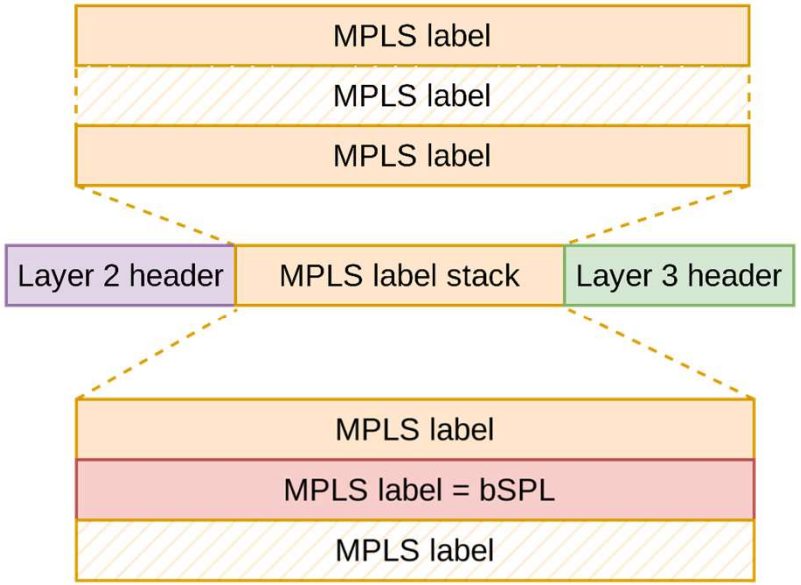
Motivation

- MPLS is a predominant WAN technology
  - Packets are switched based on assigned labels
- New applications require not only forwarding information in labels
  - Entropy labels for ECMP, OAM, Service Function Chaining (SFC), …
- → Special Purpose Labels (SPLs) are well-established to provide special processing
  - Reserved label range
  - Available label space is limited



- The MPLS Network Actions (MNA) framework introduces a mechanism for transmitting and processing predefined network actions
  - Facilitates extensions to MPLS
  - MNA is to MPLS what IPv6 extension headers are to IPv6
  - Under standardization by the IETF MPLS WG
    - Disclaimer: the presented concepts are not yet finalized and may change

https://www.ietf.org/archive/id/draft-ietf-mpls-mna-fwk-15.html

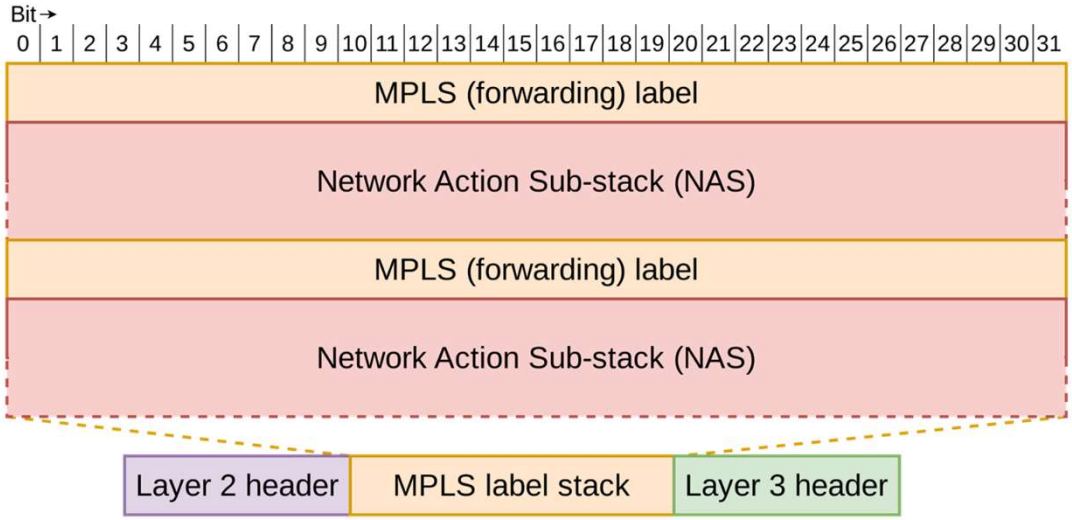
The MNA Framework

The MNA Encoding

- New MPLS header encoding to specify network actions and their data
  - Encoded into label stack entries (LSE)

- The Network Action Sub-stack (NAS)
  - A stack of related LSE
    - containing network actions and their data
  - Inserted into the MPLS stack
    - in-stack data, ISD
  - Added after the MPLS stack
    - post-stack data, PSD

- A NAS must never be at the top-of-stack
  - Ensures backward compatibility
  - NAS at the top-of-stack must be popped

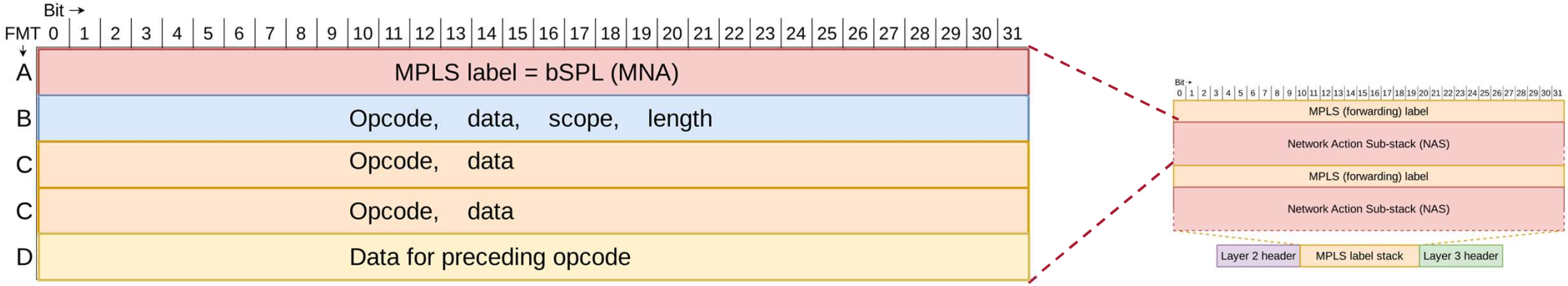


https://www.ietf.org/archive/id/draft-ietf-mpls-mna-hdr-11.html

The Network Action Sub-stack (NAS)

- What does a NAS look like?
  - → Special label value (bSPL) followed by network actions and their data
    - = NAS indicator

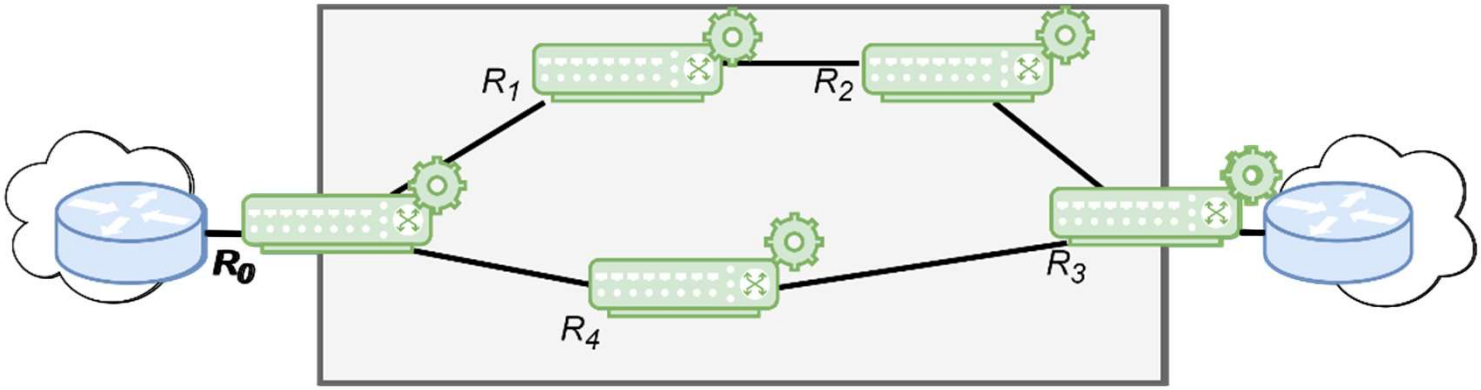
- LSE encoding redefined for network actions and ancillary data in a NAS
  - Initial opcode (mandatory, Format B)
  - Subsequent opcode (optional, Format C)
  - Ancillary data (optional, Format D)
- Up to 17 LSEs large



https://www.ietf.org/archive/id/draft-ietf-mpls-mna-hdr-11.html

Scopes in the MNA Framework

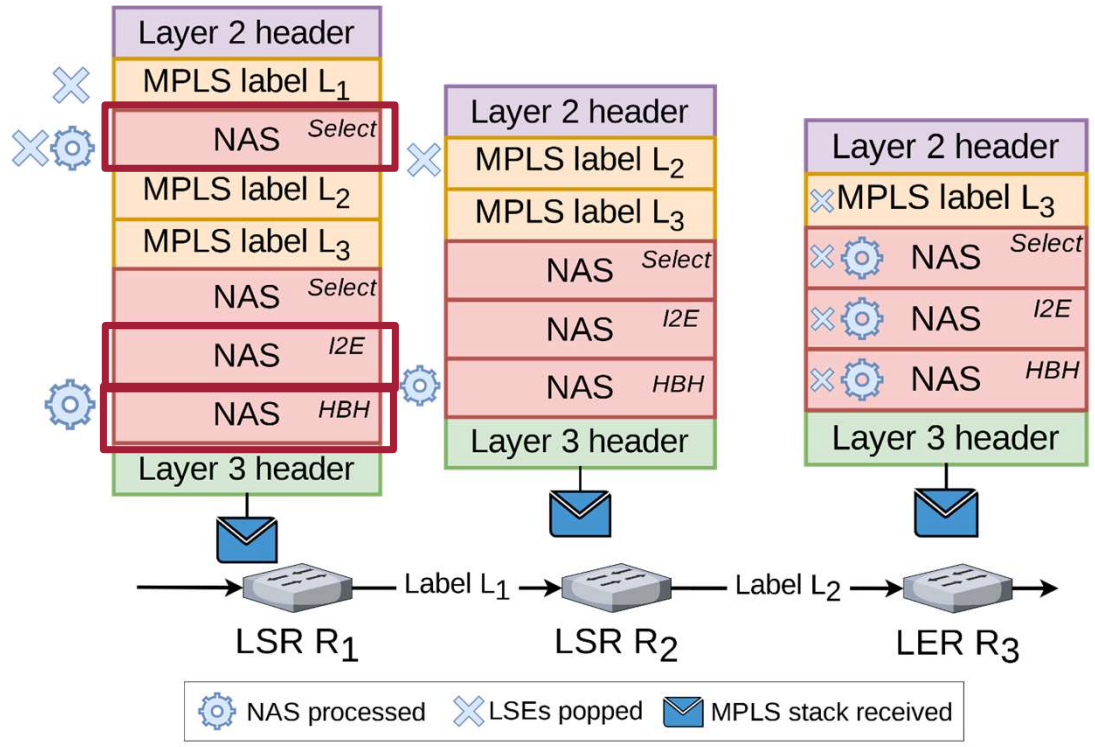
- On which nodes in a network should network actions be processed?
  - Only on **select**ed nodes
  - Only on the egress node (Ingress-to-Egress, **I2E**)
  - On all nodes (hop-by-hop, **HBH**)
- Indicated in Format B LSE of NAS
- MPLS stack including actions is pushed by ingress node



Placement of NAS in the Stack

- Placement per scope
  - *Select*-scoped NAS are located below the forwarding label for the node
  - *I2E*-scoped NAS are placed at the bottom of stack
  - *HBH*-scoped NAS must be readable by each node
    - Here: Located at the bottom of stack

- A transit node must…
  1. Process and pop a select-scoped NAS if it is exposed to the top
  2. Search through the stack to find a HBH-scoped NAS



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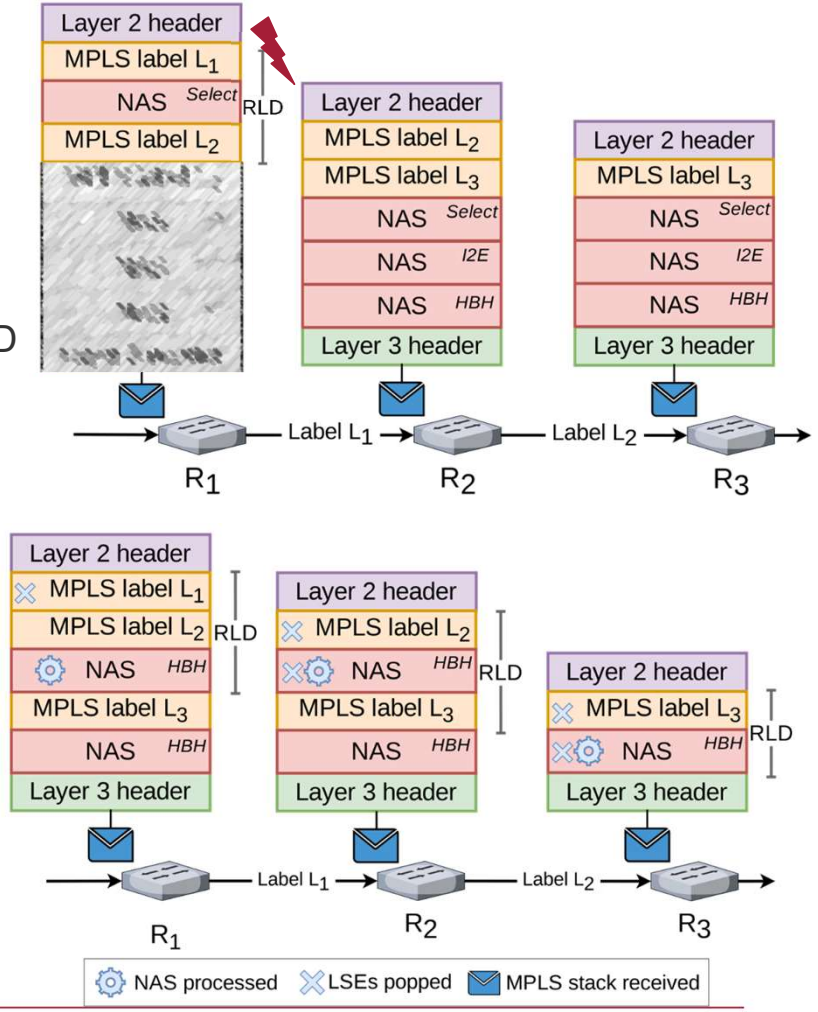
The Readable Label Depth (RLD)

- Hardware devices can only read a limited number of LSEs
  - = The readable label depth (RLD)
  - Network actions must be within RLD to process them
- Difficult for HBH-scoped NAS: must be readable by every node
  - Placing the NAS at the bottom works if the entire MPLS stack is in RLD
  - This is typically not the case
    - A single NAS may be up to 17 LSEs large
- Ingress node must ensure that a NAS is readable once it reaches a node
  - All nodes signal their RLD to the ingress node
  - Places copies of the HBH NAS in the stack
    - A node only processes the top copy of a HBH NAS
- → The RLD is a critical parameter

https://www.ietf.org/archive/id/draft-ietf-mpls-mna-hdr-11.html

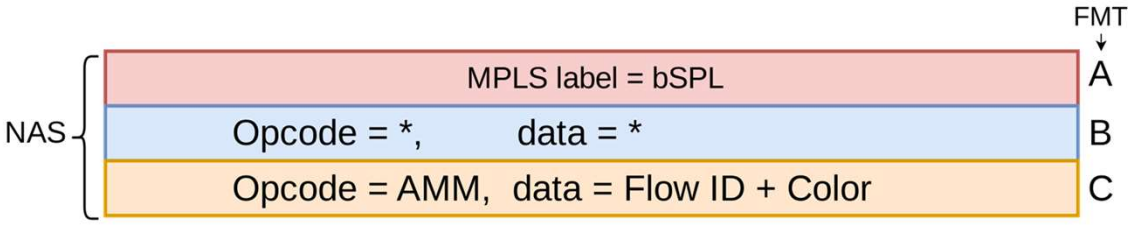


Use Cases

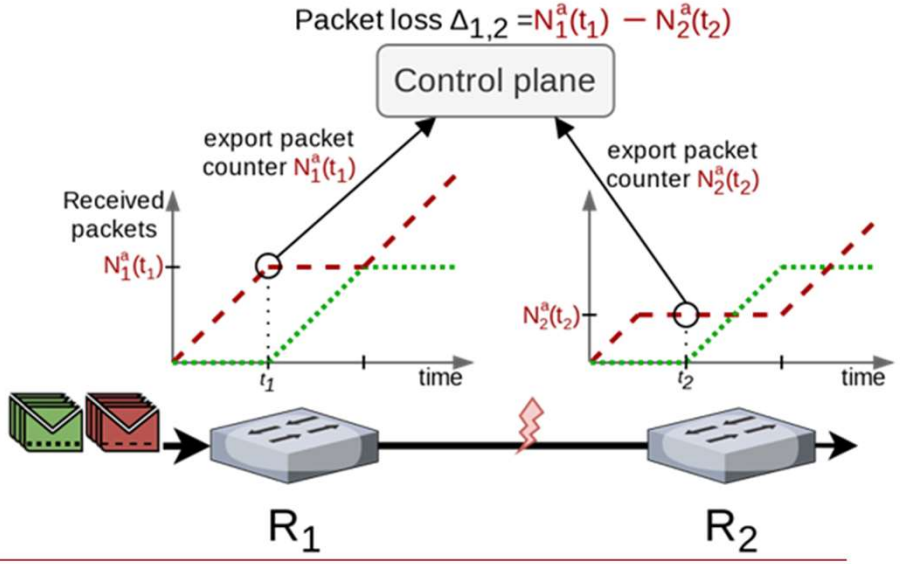
Use Cases – AMM

- Performance measurement using the alternate marking method (AMM)
  - Measure packet loss between two points without sequence numbers

- Measuring per-link packet loss
  1. Send packets in colored batches
     - Color is contained in network action
  2. Alternate color between batches
  3. Count packets per color per batch at nodes
  4. On color change, export per-node counters to control plane
  5. → Calculate packet loss



https://datatracker.ietf.org/doc/draft-cx-mpls-mna-inband-pm/

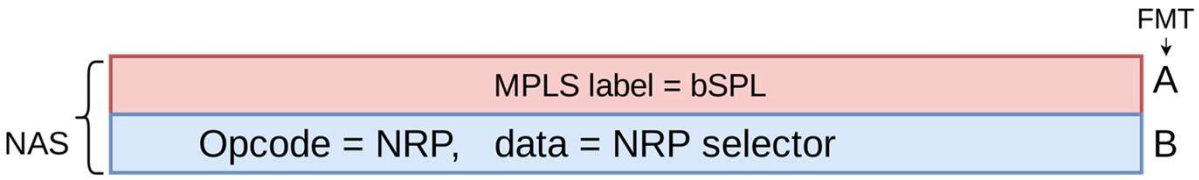


Use Cases – Network Slicing

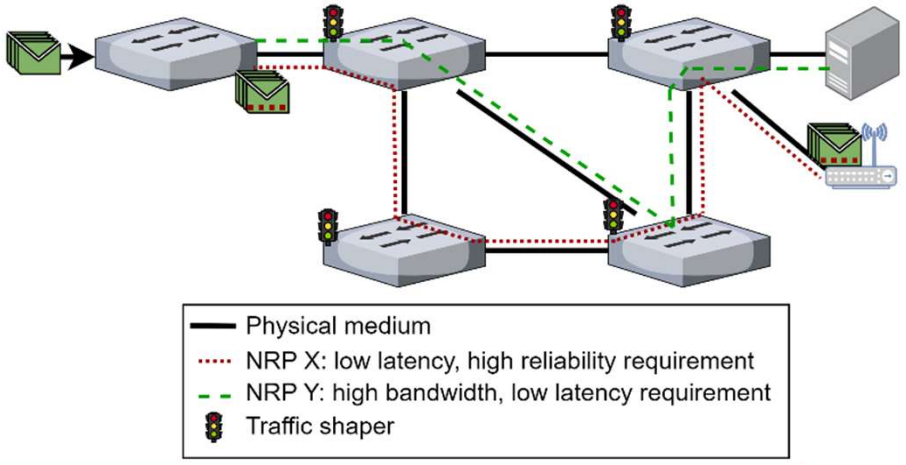
- Network slicing
  - End-to-end logical network over a shared physical infrastructure
  - Connectivity coupled with a set of network resource commitments
    - Bandwidth, latency, …
    - = Network Resource Partition (NRP)

- NRP selector identifies to which NRP a packet belongs to
  - → Indicated in network action

- Nodes apply traffic shaping based on configured NRP and NRP selector in packet

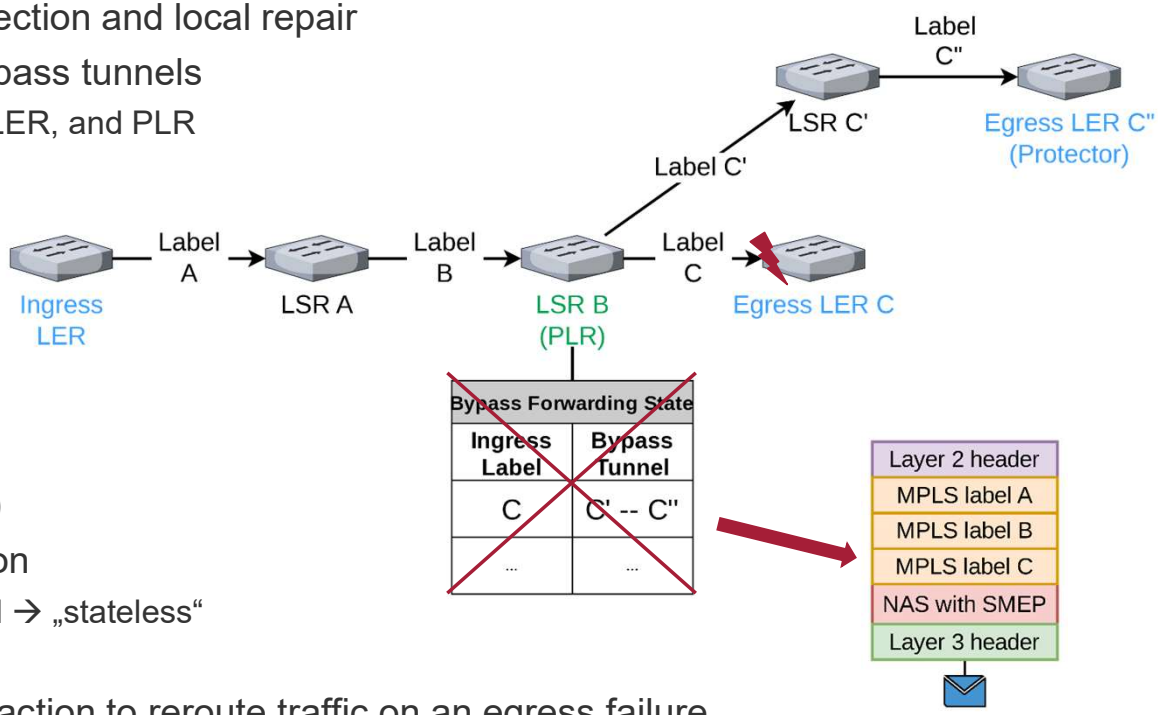


https://www.ietf.org/archive/id/draft-li-mpls-mna-nrp-selector-02.html



Use Cases – SMEP

- MPLS Egress Protection Framework (RFC 8679) establishes bypass tunnels for egress routers on an egress failure
  - Relies on Point of Local Repair (PLR) for failure detection and local repair
  - PLR maintains a mapping of transport tunnels to bypass tunnels
    - Signaled between egress LER, Protector LER, ingress LER, and PLR



- Stateless MNA-based Egress Protection (SMEP)
  - Egress bypass tunnels are carried in a network action
    - No mapping from label to bypass tunnel in PLR required → „stateless“
    - Signaling with the PLR is not required anymore
  - PLR uses the bypass MPLS label from the network action to reroute traffic on an egress failure

https://datatracker.ietf.org/doc/draft-ihle-mpls-mna-stateless-egress-protection/

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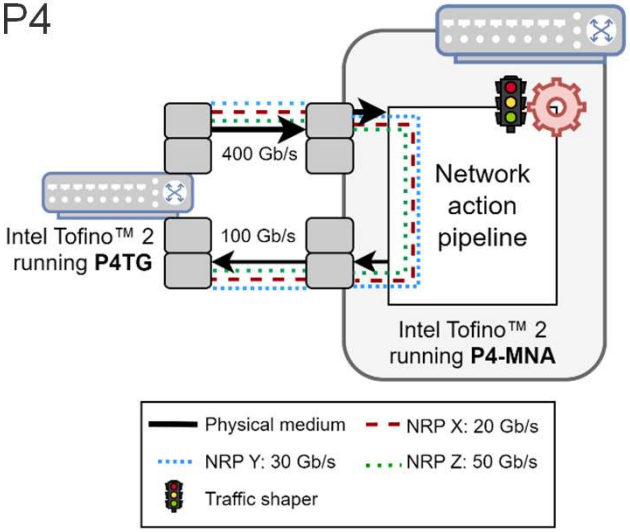
P4-MNA Prototype

- We implemented the MNA framework on the Intel Tofino 2 switching ASIC in P4
  - In-stack data
  - RLD of 51 LSEs
  - Up to 32 network actions in a packet supported
  - Line rate of 400 Gb/s



- Implemented use cases
  - Packet loss measurement using AMM
  - Bandwidth reservation using network slicing

- MPLS Network Actions: Technological Overview and P4-Based Implementation on a High-Speed Switching ASIC", accepted for IEEE Open Journal of the Communications Society (OJ-COMS), 2025 (preprint)

- https://github.com/uni-tue-kn/P4-MNA
  - Source code
  - Wireshark dissector for MNA traffic
  - Python library for building MNA packets

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Conclusion

- The MPLS Network Actions (MNA) framework introduces a mechanism for transmitting network actions
  - MNA is to MPLS what IPv6 extension headers are to IPv6
  - The MPLS encoding is repurposed to hold network actions in a container (NAS)
  - Network actions can be processed on different nodes indicated by the scope
- The readable label depth (RLD) is a critical parameter when deploying MNA
- Use cases include…
  - Per-link packet loss measurement
  - Network slicing
  - Egress protection
- More information: MPLS Network Actions: Technological Overview and P4-Based Implementation on a High-Speed Switching ASIC", accepted for IEEE Open Journal of the Communications Society (OJ-COMS), 2025 (preprint)

Any Questions?

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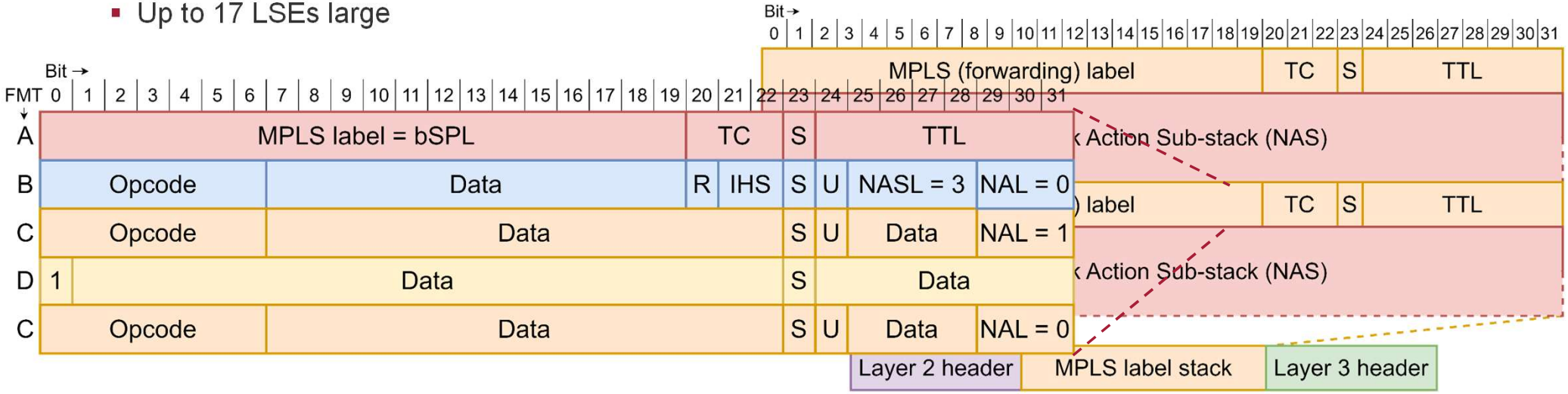
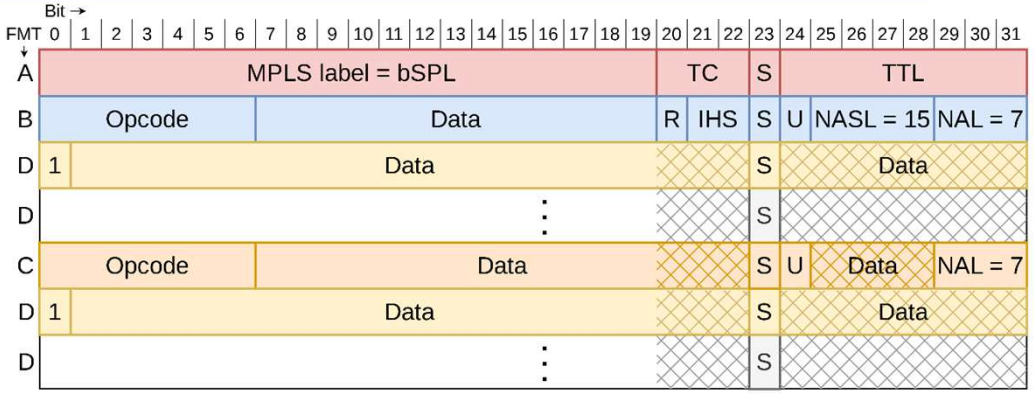


Mutable Data in MNA

- Mutable data = data where the value changes during packet forwarding



- Example: Collecting telemetry data along a path
  - Each node on the path adds information to the NAS, e.g., the node ID
  - That information must not be discarded on forwarding

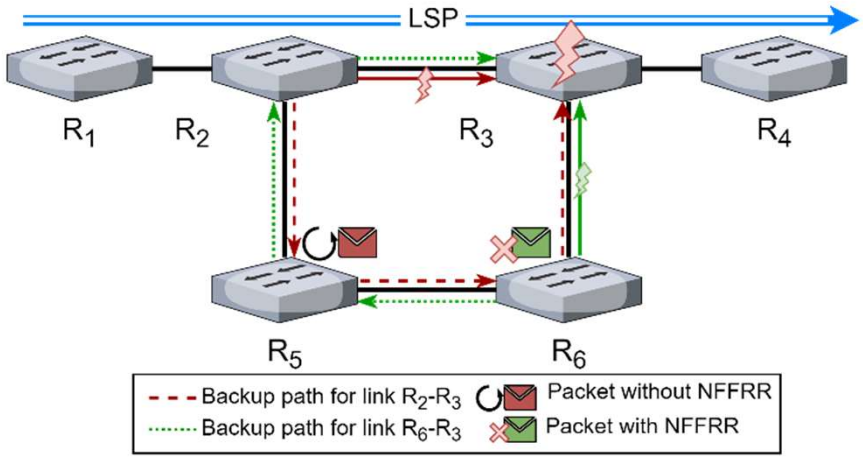
- For backward compatibility, only last 12 bits are mutable
  - MPLS label may be hashed for ECMP by legacy nodes

- → A post-stack data implementation may be more feasible for mutable data

Use Cases – NFFRR

- No Further Fast Reroute (NFFRR)
  - Multiple failures may lead to looping packets in backup tunnels
  - → Congestion

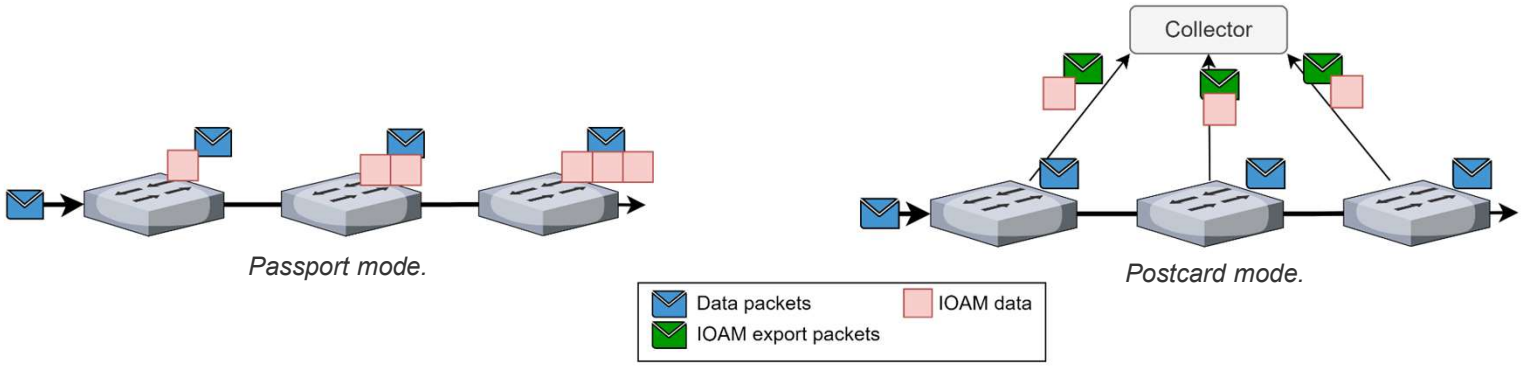
- Network action indicates if a packet was rerouted through a backup tunnel
  - If a second reroute will be applied, they can be dropped



https://datatracker.ietf.org/doc/draft-li-mpls-mna-nffrr/01/

Use Cases – IOAM

- In-situ operations, administration, and maintenance (IOAM)
  - Collect metrics (timestamps, interfaces, …) along a path
- Two operation modes
  - Passport: Write metrics into data fields of network actions
  - Postcard: Trigger export to an entity in the network
- Network action contains mode and information on which metrics to collect
  - E.g., for path tracing



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