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TÜBINGEN

FACULTY OF
SCIENCE
Communication Networks

Implementation Experience of MNA Using P4 on Intel Tofino Hardware

by Fabian Ihle <fabian.ihle@uni-tuebingen.de>

http://kn.inf.uni-tuebingen.de

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Agenda

- Background & Current state of the MNA framework
- Mutable data in MNA
  - HBH NAS Replication and Preservation
  - To PSD or not to PSD
- Operation modes
- Details about the implementation
- P4-MNA example network action
- Discussion

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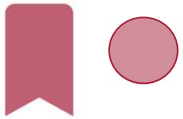
Legend

- Each slide has a colored bookmark to indicate if its content is from IETF drafts or proposed by us
  - Specific parts in the slides are marked with colored circles

From IETF drafts

New proposal



Topic for discussion

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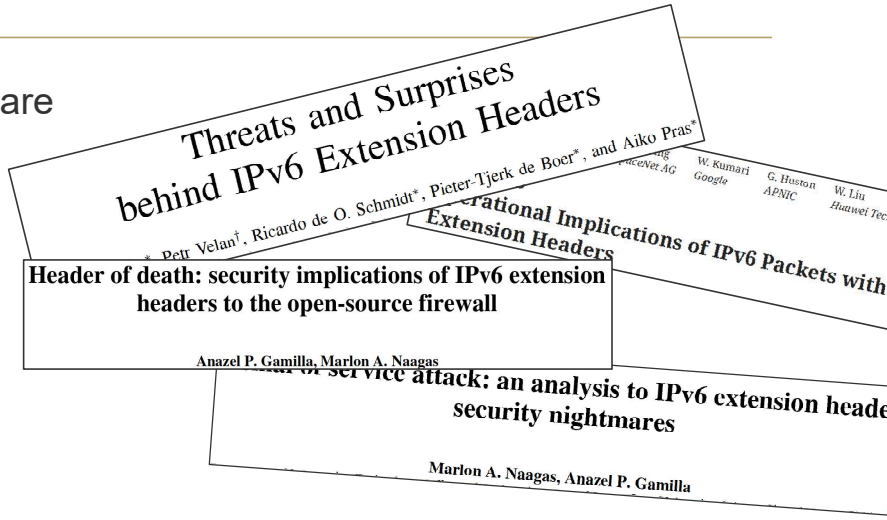
Motivation

- For MNA to be successful, it must be efficiently implementable in hardware
  - Similar case: IPv6 EH



- Intel Tofino™ as reference architecture for a hardware switching ASIC
  - Limited resources and operations
  - Pipelined architecture

- If encoding works on the Intel Tofino™, it most likely also works on vendor ASICs

- Questions
  1. Can the IETF MNA encoding be implemented efficiently on hardware?
  2. What are the challenges in an implementation?
  3. To PSD or not to PSD?

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MNA

BACKGROUND

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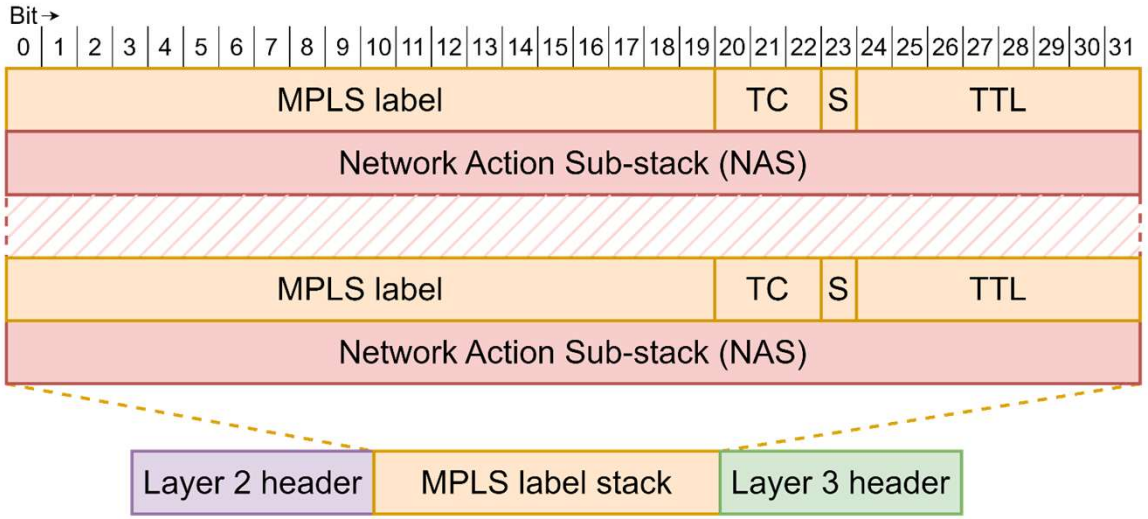
The MNA Framework

- General mechanism for transmitting, processing and executing predefined network actions
- New generalized header encoding introduced for specifying network actions and ancillary data
- The Network Action Sub-stack (NAS)
  - A stack of related LSEs containing
    - Network actions
    - Ancillary data
  - Inserted into the MPLS stack
    - Below forwarding labels



https://www.ietf.org/archive/id/draft-ietf-mpls-mna-hdr-04.html

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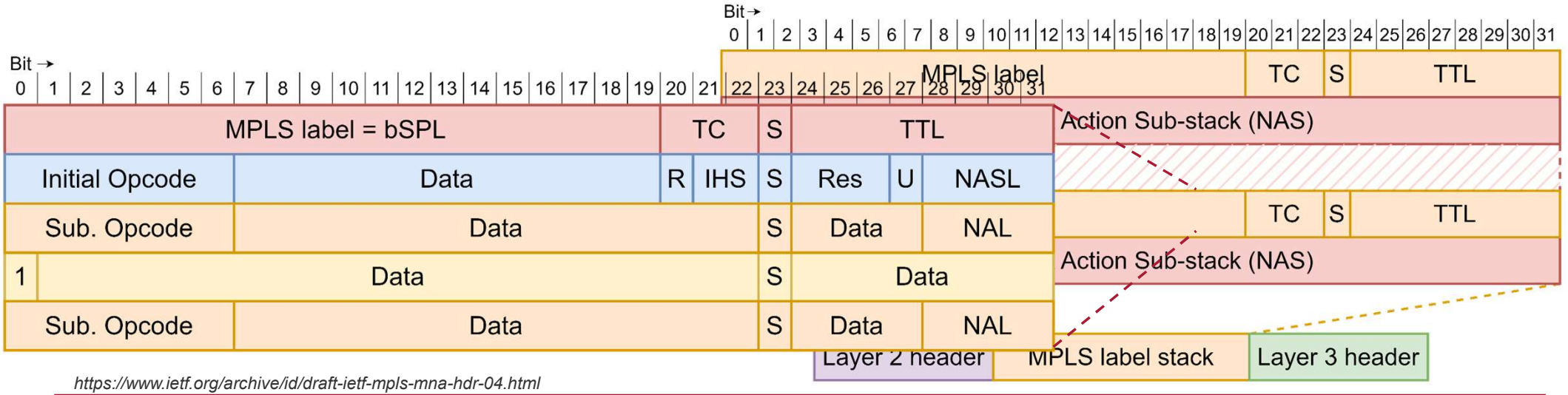
The MNA Header Encoding

- What does a NAS look like?
  - → bSPL followed by network actions and ancillary 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)



https://www.ietf.org/archive/id/draft-ietf-mpls-mna-hdr-04.html

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Some valid NAS

Bit → 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

MNA-Label = bSPL							
Initial Opcode	Data	R	IHS	S	Res	U	NASL=0

Bit → 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

MNA-Label = bSPL							
Initial Opcode	Data	R	IHS	S	Res	U	NASL=3
Sub. Opcode	Data			S	Data		NAL=1
1	Data			S	Data		
Sub. Opcode	Data			S	Data		NAL=0

Bit → 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

MNA-Label = bSPL							
Initial Opcode	Data	R	IHS	S	Res	U	NASL=5
Sub. Opcode	Data			S	Data		NAL=0
Sub. Opcode	Data			S	Data		NAL=0
Sub. Opcode	Data			S	Data		NAL=0
Sub. Opcode	Data			S	Data		NAL=0
Sub. Opcode	Data			S	Data		NAL=0

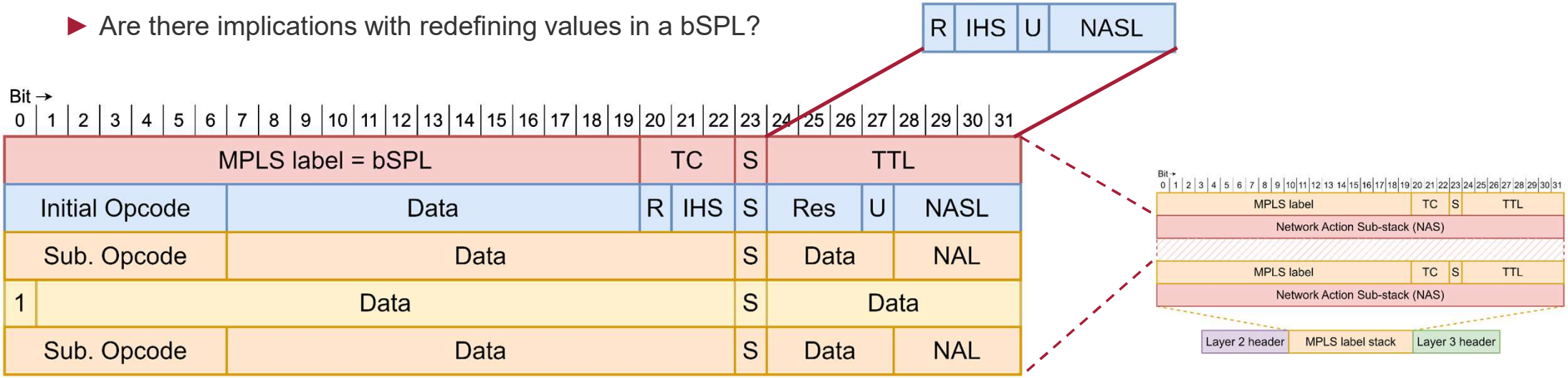
Bit → 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

MNA-Label = bSPL							
Initial Opcode	Data	R	IHS	S	Res	U	NASL=10
Sub. Opcode	Data			S	Data		NAL=1
1	Data			S	Data		
Sub. Opcode	Data			S	Data		NAL=3
1	Data			S	Data		
1	Data			S	Data		
1	Data			S	Data		
Sub. Opcode	Data			S	Data		NAL=0
Sub. Opcode	Data			S	Data		NAL=2
1	Data			S	Data		
1	Data			S	Data		

The MNA Header Encoding

- *Discussion*: Can we move *NASL* + *U* + *IHS* + *R* into the *TTL* field of the bSPL and eliminate the initial opcode encoding?
  - → Simplifies the NAS encoding and saves 8 bits
  - → Right now, the initial opcode cannot carry ancillary data LSEs
  - → Definition of network actions: Having 2 encodings for opcodes with different amounts of data bits available requires to
    a) Constrain specific opcodes to initial / subsequent encoding only, or
    b) Have multiple definitions for network actions

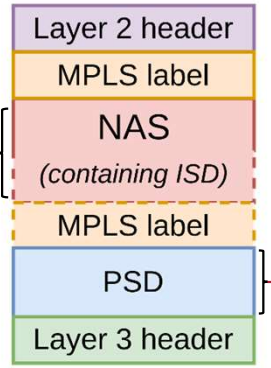
- Are there implications with redefining values in a bSPL?



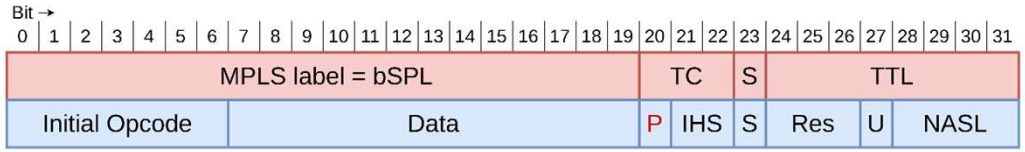
https://www.ietf.org/archive/id/draft-ietf-mpls-mna-hdr-04.html

How to PSD in MNA

- Post-stack data (PSD) inserted below bottom of MPLS stack



- Dedicate a bit to indicate presence of PSD („P bit“)
  - Current proposal: Reserved Bit in initial opcode
  - Ongoing discussion: Use a different bit or an opcode, or don’t use PSD at all



- Post-stack encoding
  - Same principle as a NAS
  - Post-Stack Network Action Top Header ≙ NAS indicator
  - Post-Stack Network Action Header
    - encodes network action

https://datatracker.ietf.org/doc/draft-jags-mpls-ps-mna-hdr/

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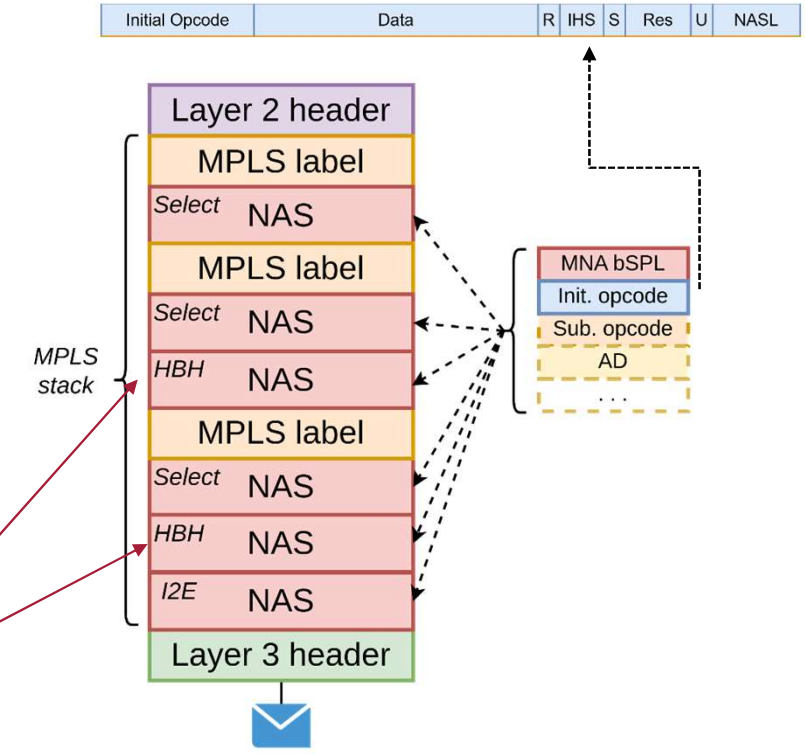
Scopes and Placement in the MPLS Stack

- Scope defines on which nodes a network action is to be processed
  - Set in IHS field in initial opcode LSE
  - *HBH*: On every node along the path
  - *Select*: Only on specific nodes on the path
  - *I2E*: Only on the egress node
- At most one NAS per scope per hop should be allowed
  - A NAS must not appear on top of an MPLS stack
  - A node that exposes a NAS to the top must pop it
- We look at SR-MPLS!
  - MNA with label switching is easier
- Ingress LER must ensure that the NAS can be read by the relevant nodes
  - LSR signal their RLD (readable label depth)
    - Number of LSE a node can read without performance impact
  - → Multiple copies of HBH NAS may need to be placed in the stack
    - = HBH NAS Replication



https://www.ietf.org/archive/id/draft-ietf-mpls-mna-hdr-04.html

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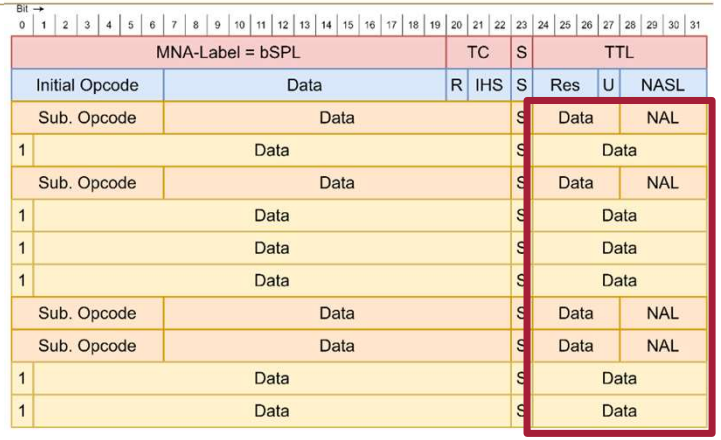
Mutable Data in MNA

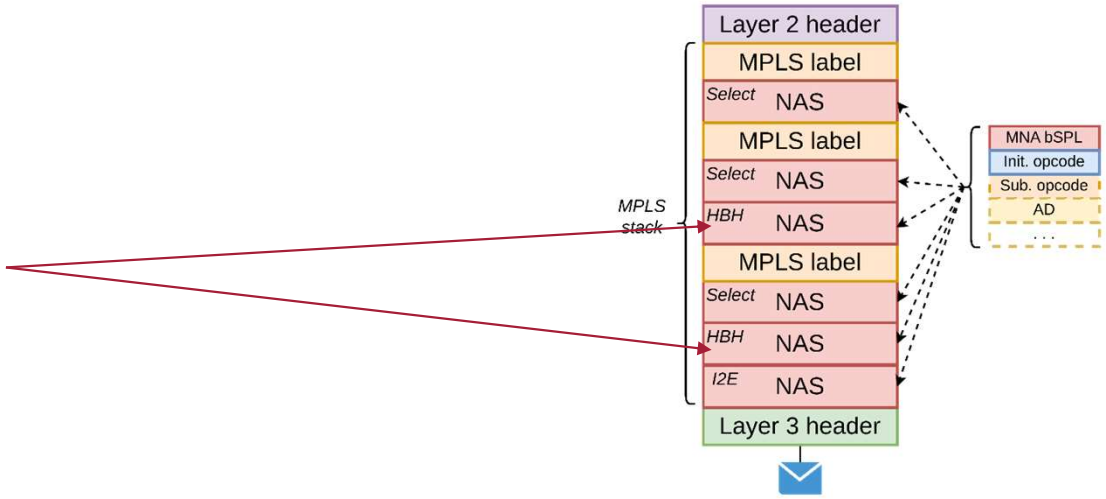
- Mutable data = data where the value changes during packet forwarding



- 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 8 bits are mutable
  - MPLS label and TC may be hashed for ECMP

- Challenges
  - How to carry more mutable data?
  - How to carry mutable data with HBH NAS replication?



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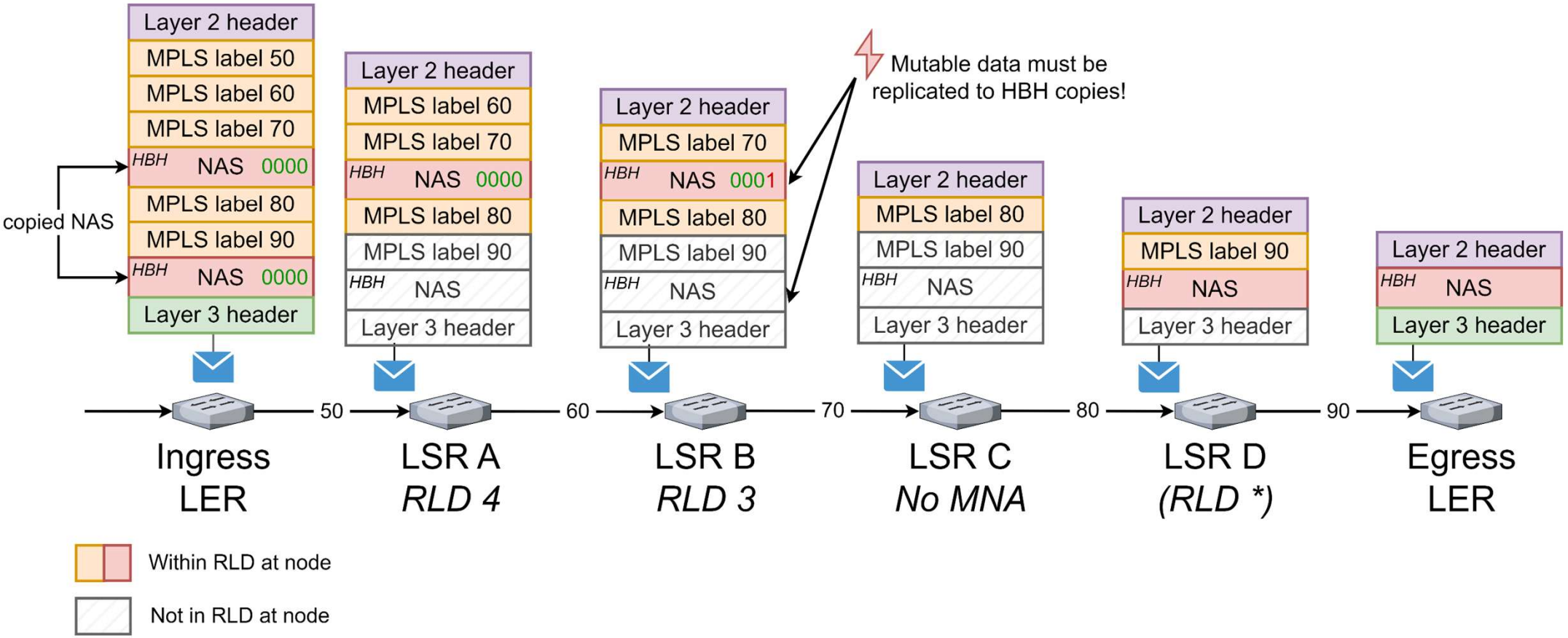
Problem: HBH NAS Replication with Mutable Data



Note: NAS consist of more than one LSE. For simplicity they are counted as one here.

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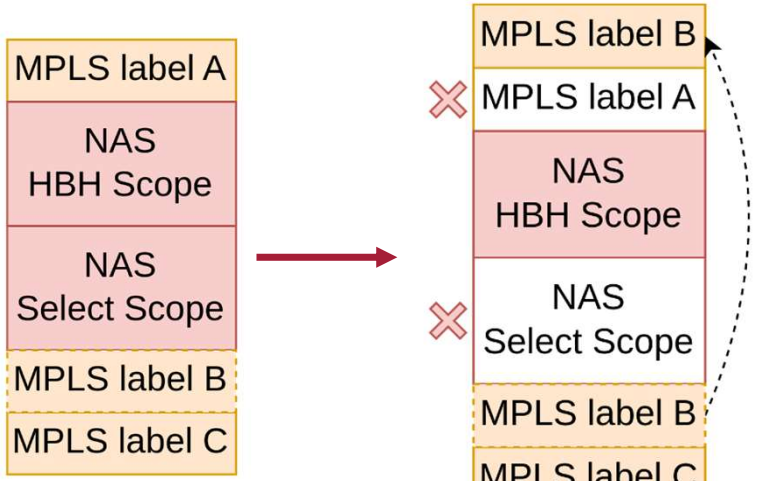
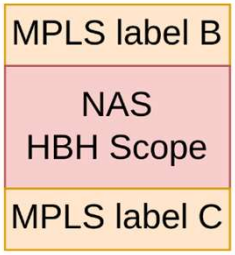
HBH NAS Preservation

- With HBH Label Replication …
  - Multiple HBH copies may have to be present in the stack
    - → The stack grows larger ☹
    - Creates problems with mutable data

- Our proposal: HBH NAS Preservation
  - Place a single HBH NAS below the top-of-stack MPLS segment label
  - A node…
    1. Pops the topmost MPLS segment label
    2. Moves the HBH scope below the next MPLS label
       - *Actually: Moves the next MPLS label to the top*
  - Advantages
    + The stack only holds one HBH NAS
    + Mutable data is up to date inherently
    + RLD of nodes is not that important → We do not have to search for a buried HBH NAS
  - Disadvantages
    – Every node on the path MUST be MNA-capable
    – Does not follow the traditional MPLS paradigm *„push, pop, swap“*





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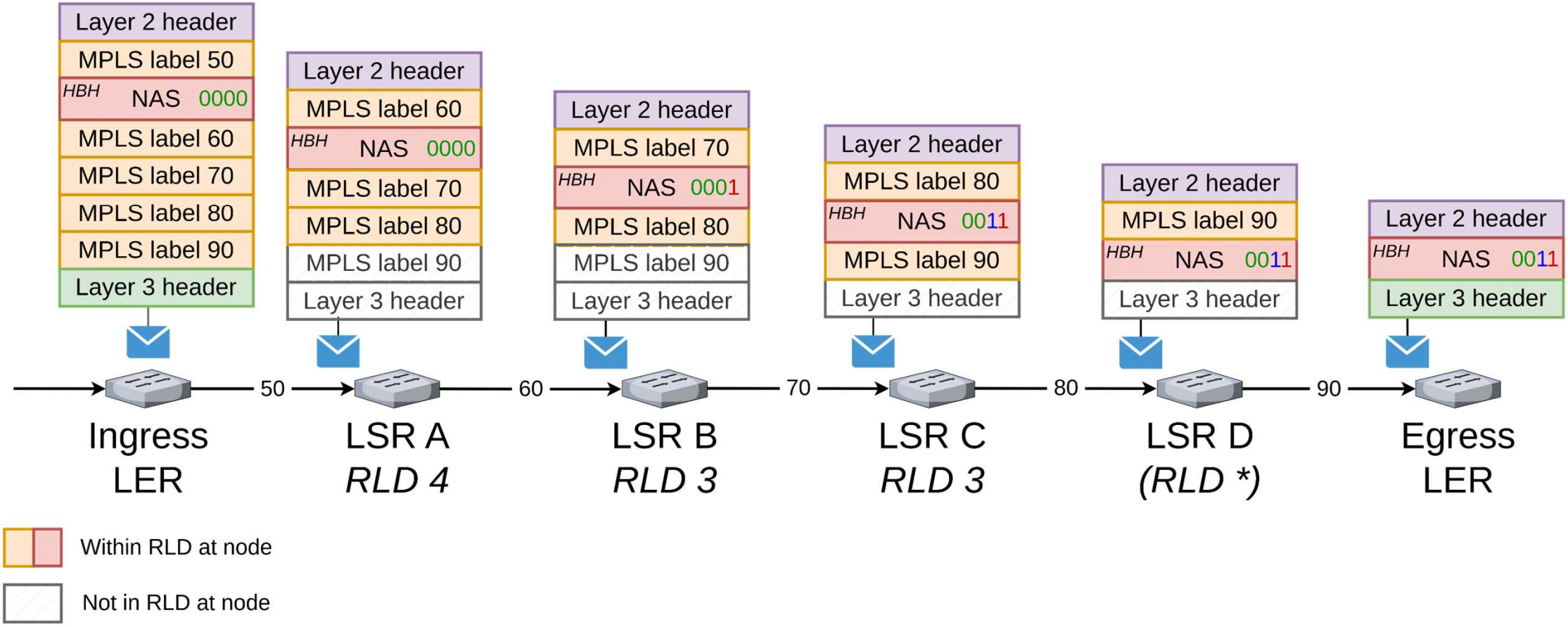
HBH NAS Preservation Example

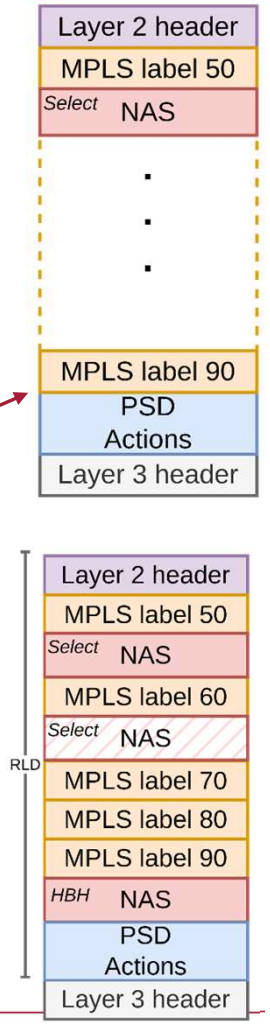


Note: NAS consist of more than one LSE. For simplicity they are counted as one here.

To PSD or Not To PSD

- Mutable data in MNA
  - ↯ Only the last 8 bits in an LSE are mutable due to ECMP hashing compatibility
  - ↯ Modifications to mutable data in HBH scopes must be reflected in all HBH copies in the stack
  - – HBH Label Preservation fixes this, but only works if all nodes support MNA 😐

- PSD solves the issue with mutable data in the HBH NAS replication example
  - PSD not hashed for ECMP: All bits are mutable
  - Mutable data kept in one place: post-stack → no copying across different NAS
  - But can it be implemented efficiently?
    - Challenge: How to get to PSD?
      a) Jump over the MPLS stack to the end using a pointer or lookahead
      b) Parse the full MPLS stack
    - → In P4 we have to parse the full stack!



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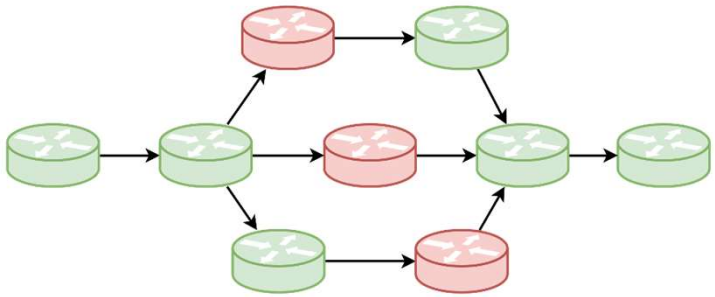
Operation Modes

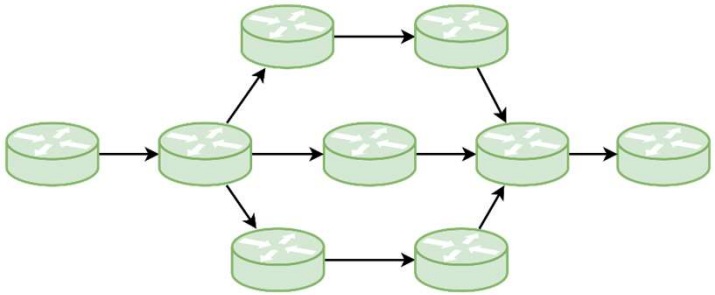
1. Compatibility Mode
   - Implementation with HBH NAS Replication
   - Brownfield deployment: Mixture of MNA-incapable and MNA-capable nodes

   a) ISD only
      - Less restrictive wrt. RLD, but only few mutable data bits available
      - Use case: Network actions that do not require mutable data
        - E.g., draft-ietf-mpls-inband-pm-encapsulation-11 (RFC9341), IOAM DEX

   b) With ISD and PSD
      - More mutable data available, but we have to get to PSD
      - Use case: Network actions that require more mutable data
        - E.g., INT / IOAM without DEX



2. Greenfield Mode
   - Implementation with HBH NAS Preservation
   - Greenfield deployment: Only MNA-capable nodes
   - Require Entropy Labels
     - → Stack must not need to be hashed
     - → All data bits can be mutable
     - ISD only, no need for PSD
   - Use case: all of the above



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Compatibility Mode ISD only, Compatibility Mode with ISD and PSD, Greenfield Mode

P4-MNA IMPLEMENTATION

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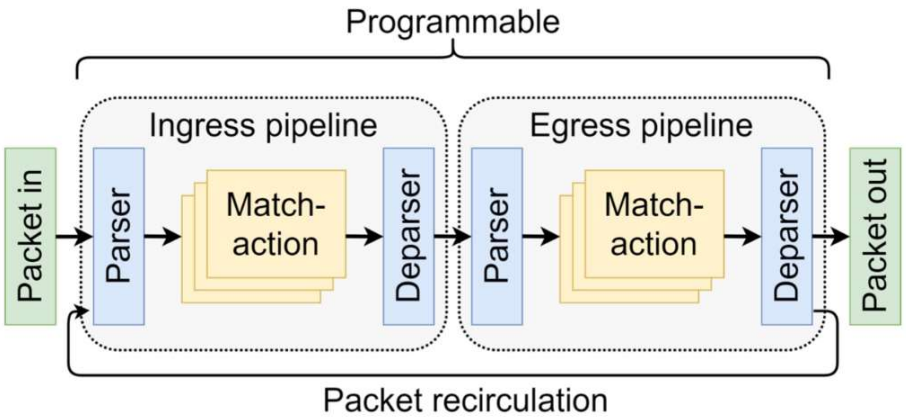
The P4 Programming Language

- High-level programming language to describe data plane
  - Compiler maps P4 program onto programmable pipeline of target
  - Pipeline: Parser → Control block → Deparser

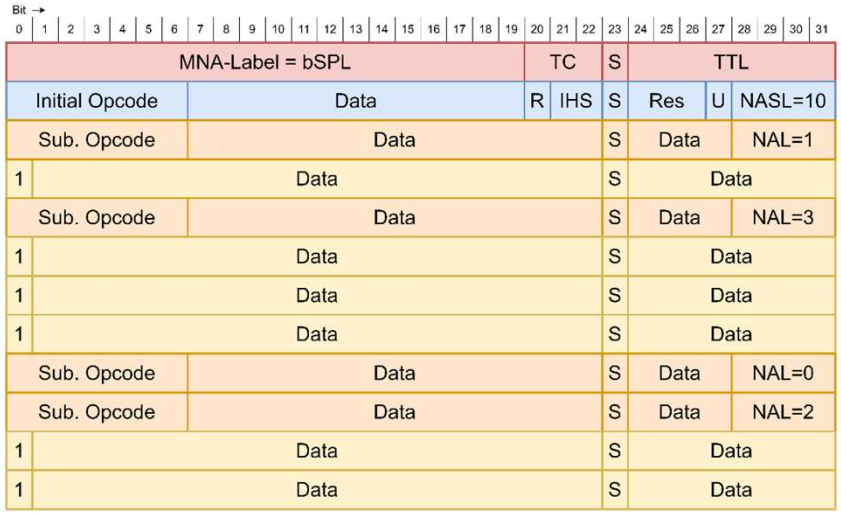
- P4 control blocks define packet processing operations
  - Match+Action Units
  - Branching constructs, logical and simple arithmetic expressions
  - Recirculation models loop behaviour



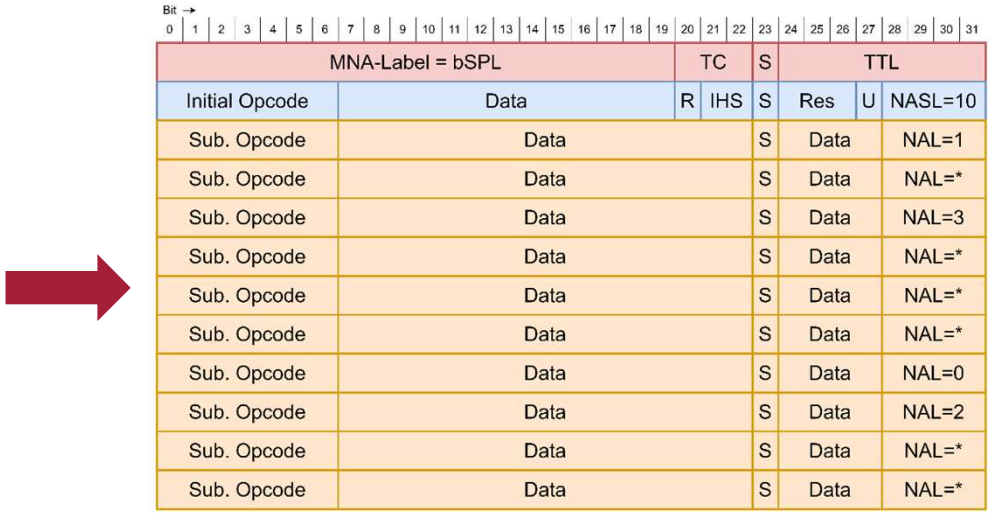
P4-MNA Parser

- The dynamic combination of AD LSE and subsequent opcodes requires a lot of state in the parser

- Therefore, we ignore the different encodings of subsequent opcodes and AD entries
  - They are all parsed as a single subsequent opcode stack using the *NASL* length field
  - The semantics of AD and opcodes are later derived in the control block using the *NAL* length field



Pushed NAS



Parsed NAS

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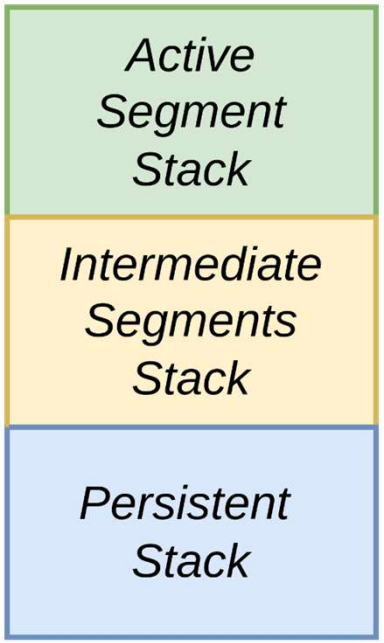
Substacks in the P4-MNA Implementation

- The internal representation of the MPLS stack in the P4 program is divided into 3 substacks
  1. Active Segment Stack
     - Forwarding label of this segment
     - NAS relevant for the node of this segment
  2. Intermediate Segments Stack
     - LSE that are not relevant for this node, but must be parsed, if
       - A HBH NAS buried in the stack has to be searched
       - We have to reach the bottom of stack, e.g., for PSD
  3. Persistent Stack
     - HBH NAS buried in the stack
     - PSD



- This is only specific to our P4 implementation!

- Each substack has a fixed (maximum) allocated size
  - The space is limited
  - Substack sizes can be optimized depending on requirements
    - Long paths in the network → increase intermediate segments stack size
    - Many / large HBH actions → increase persistent stack size

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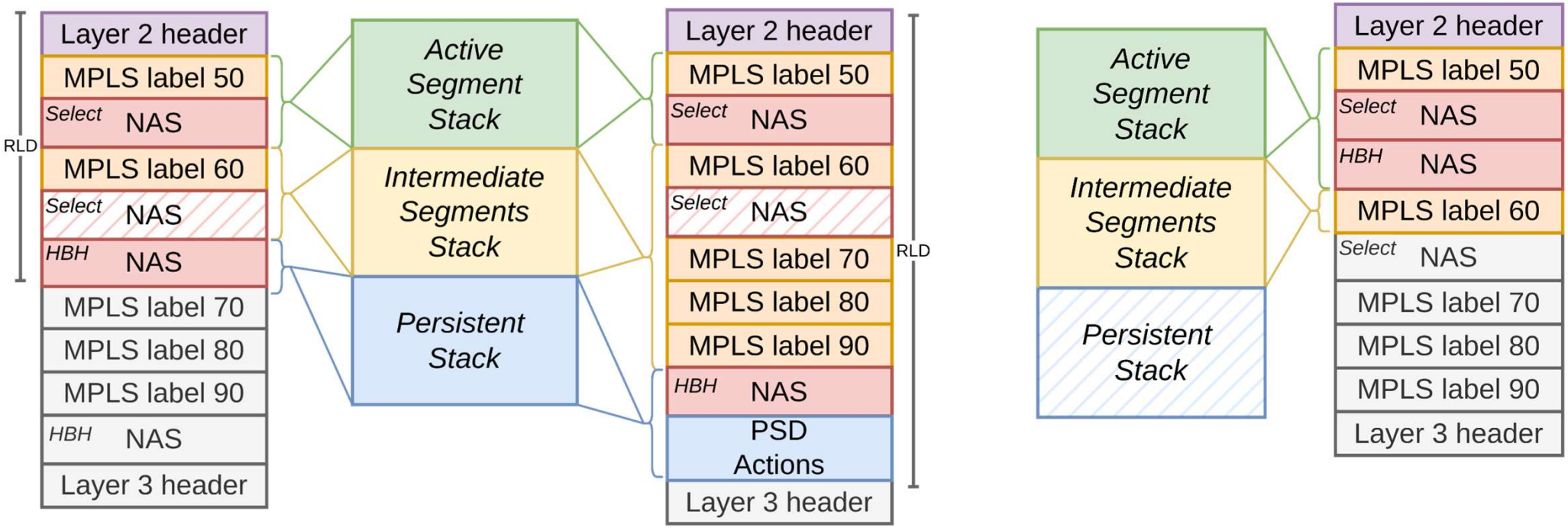
P4-MNA Required RLD (Parsing Depth)



Compatibility Mode ISD only

- Multiple HBH replications

Compatibility Mode with ISD and PSD

- Single HBH NAS at bottom: In RLD anyway

Greenfield Mode

- Single HBH NAS at top

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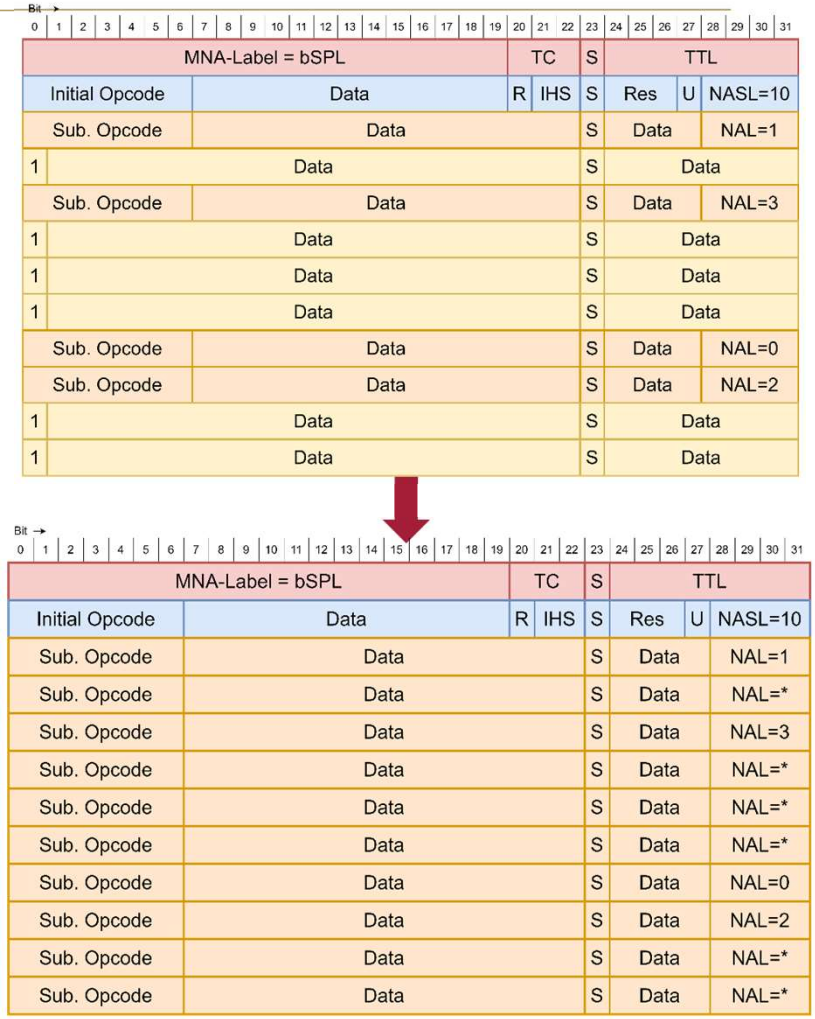
P4-MNA Processing Pipeline

- One match+action table (MAT) for each LSE in a NAS required
  - Each MAT holds network actions for an LSE in the NAS
  - → 16 MATs for HBH scope, 16 MATs for Select Scope
  - We ignore the I2E scope for now
  - MATs are applied sequentially

- We ignored the different LSE encodings during parsing ☹
  - How to find out if an LSE is an opcode or contains AD?
  - → We match on the *NAL* field of a subsequent opcode LSE
  - → We execute an action that treats the next <*NAL*> LSE as AD entries

- Pipeline space is limited
  - We can fit *n* MATs with network actions into one pipeline iteration
    - Then we have to recirculate



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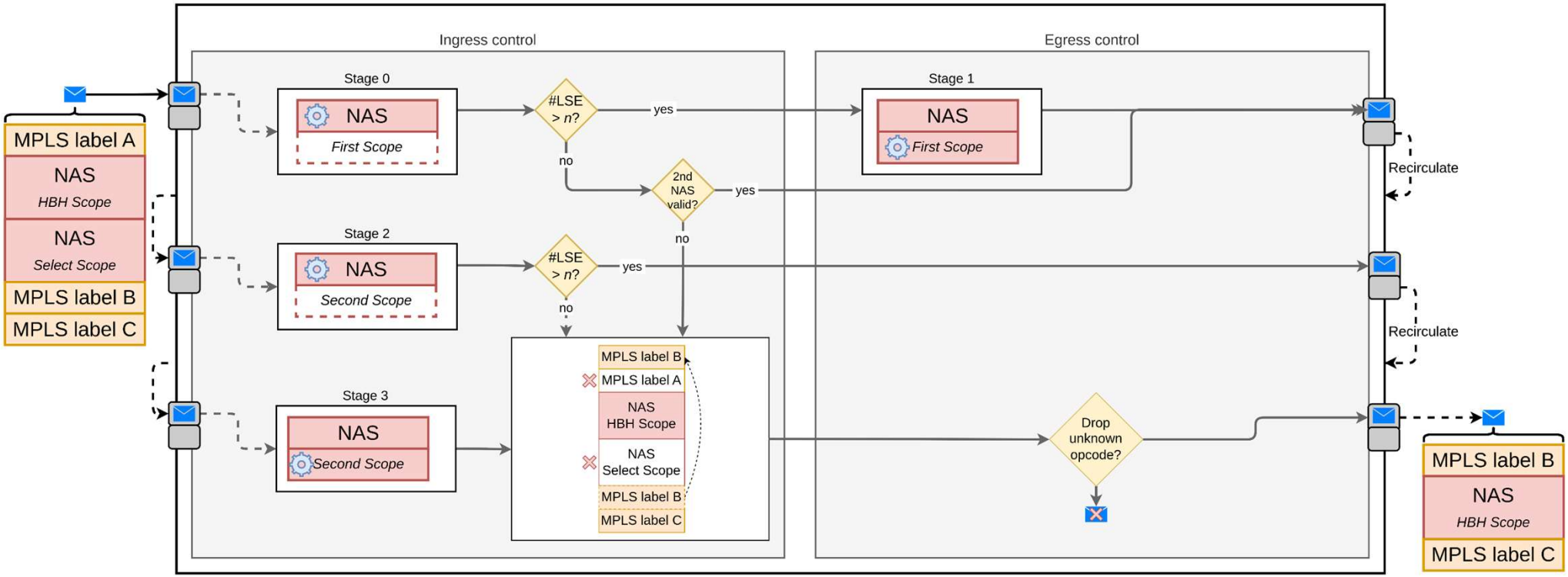
P4-MNA Pipeline – Greenfield Mode



- In the first iteration a maximum NAS with 16 network actions can be processed!
- Recirculations are only required in the worst case, i.e., if we have multiple NAS

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Requirements to the P4-MNA PSD Implementation

1. Everything must be within RLD!
   - Full MPLS stack and PSD
     - We can do this on the Intel Tofino™ at line-rate ☺

2. Optimize the distribution of the substacks to the network requirements

► PSD processing may increase the number of recirculations
- Parsing and processing is more difficult with PSD than with ISD only
- Future work: Optimize the number of recirculations!

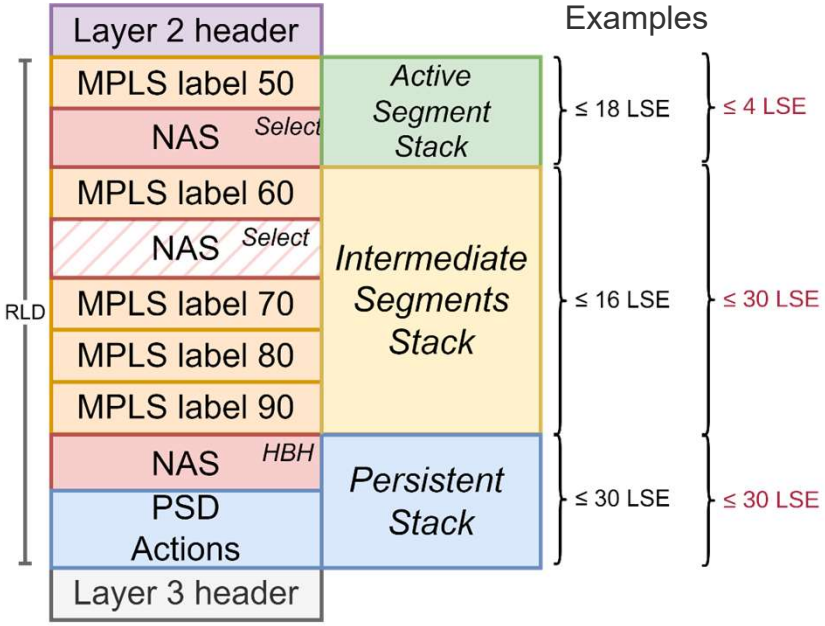

Fig.: Example of how the stack sizes could be distributed.

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Requirements to the P4-MNA PSD Implementation

- If we are doing the Compatibility Mode with PSD in P4…
  - We have the whole MPLS stack within RLD
  - → We do not need copies of HBH NAS in the stack
  - → We place a single HBH NAS at the bottom of stack to indicate the PSD
  - → We can place all HBH network actions and their data in PSD
  - → We can shrink the size of the HBH NAS to
    - 2 LSE (bSPL + initial opcode), or
    - 1 LSE if we move the flags of the initial opcode into the bSPL
  - → This reduces the number of recirculations in our implementation
  - This does not require changes in the encoding / specification!

- Discussion: Should we use the HBH NAS only to indicate PSD?
  - Do there have to be “ISD-only” HBH actions in parallel with PSD or can we move everything to PSD?
  - Is this an implementation-specific constraint or should this be considered in a draft?

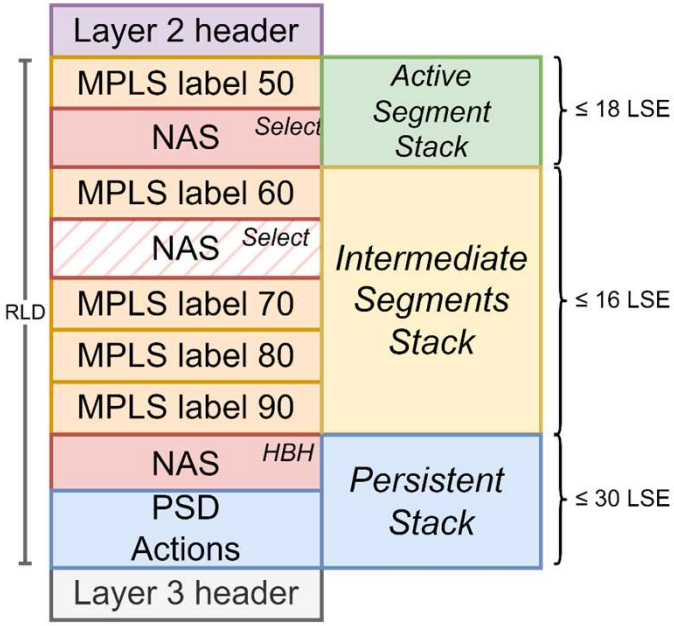


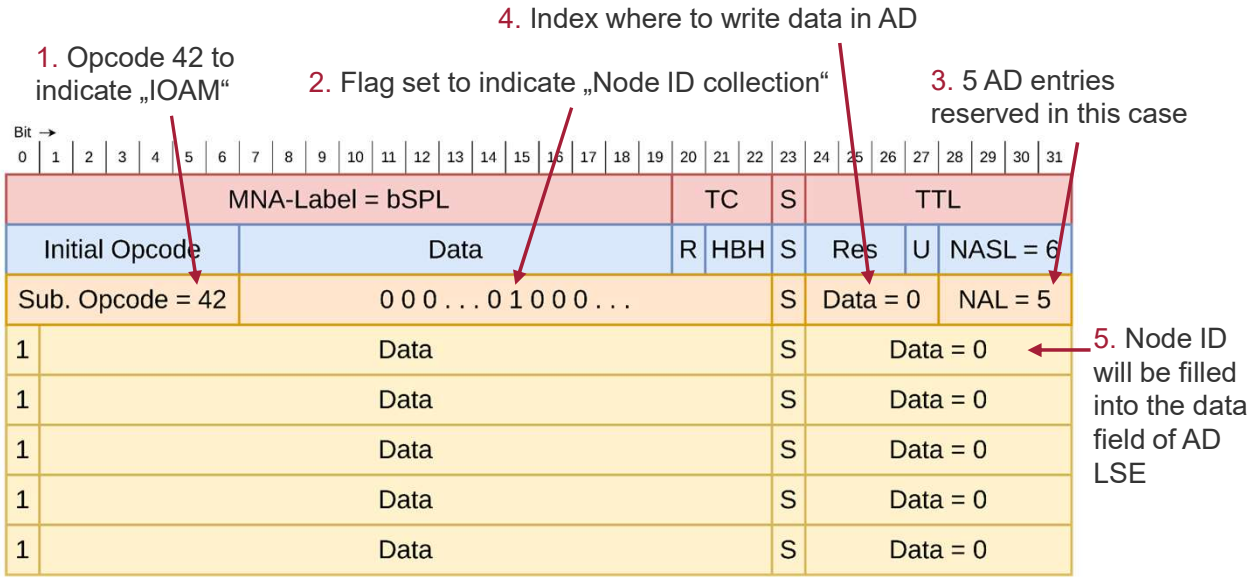
Fig.: Example of how the stack sizes could be distributed.

Comp. Mode ISD Only vs. Greenfield Mode

P4-MNA EXAMPLE NETWORK ACTION

P4-MNA Example Network Action

- Simplified version of a „Path Tracing“ mechanism in the context of IOAM
  - Goal: Collect the Node ID of each traversed node and evaluate the path at the tail end node
  - Method:
    1. Head end node pushes NAS with opcode to indicate that INT is desired
    2. Treat data field of subsequent opcodes as flags: Indicate which data to collect
    3. Reserve AD LSE to fill in the data → transit nodes do not have to add LSE
    4. Mutable data field of sub. Opcode holds index of position to be filled with data
    5. Node ID (e.g., 4 bit) is filled into data field of AD LSE



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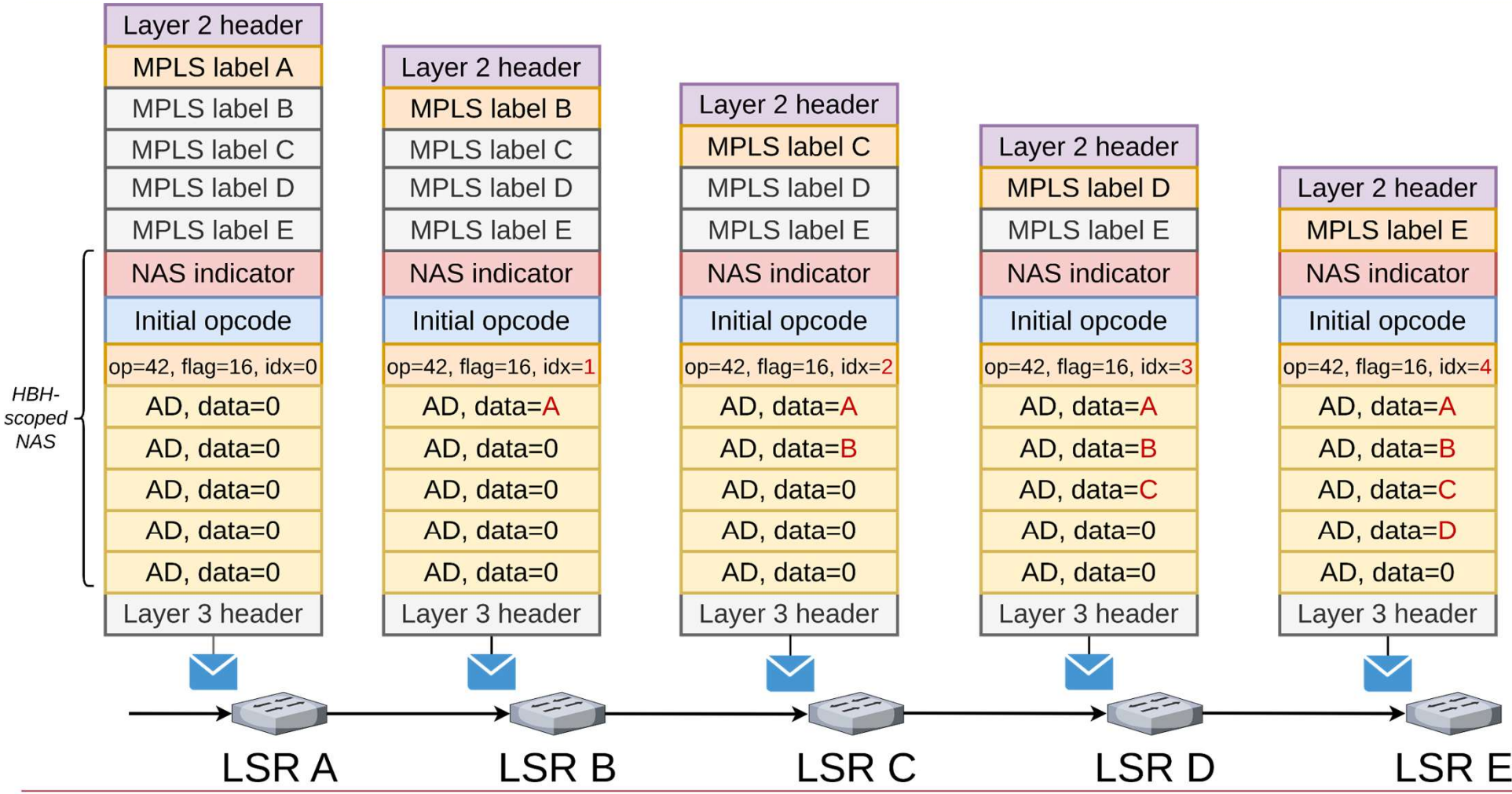
P4-MNA Example Network Action: Comp. Mode ISD Only



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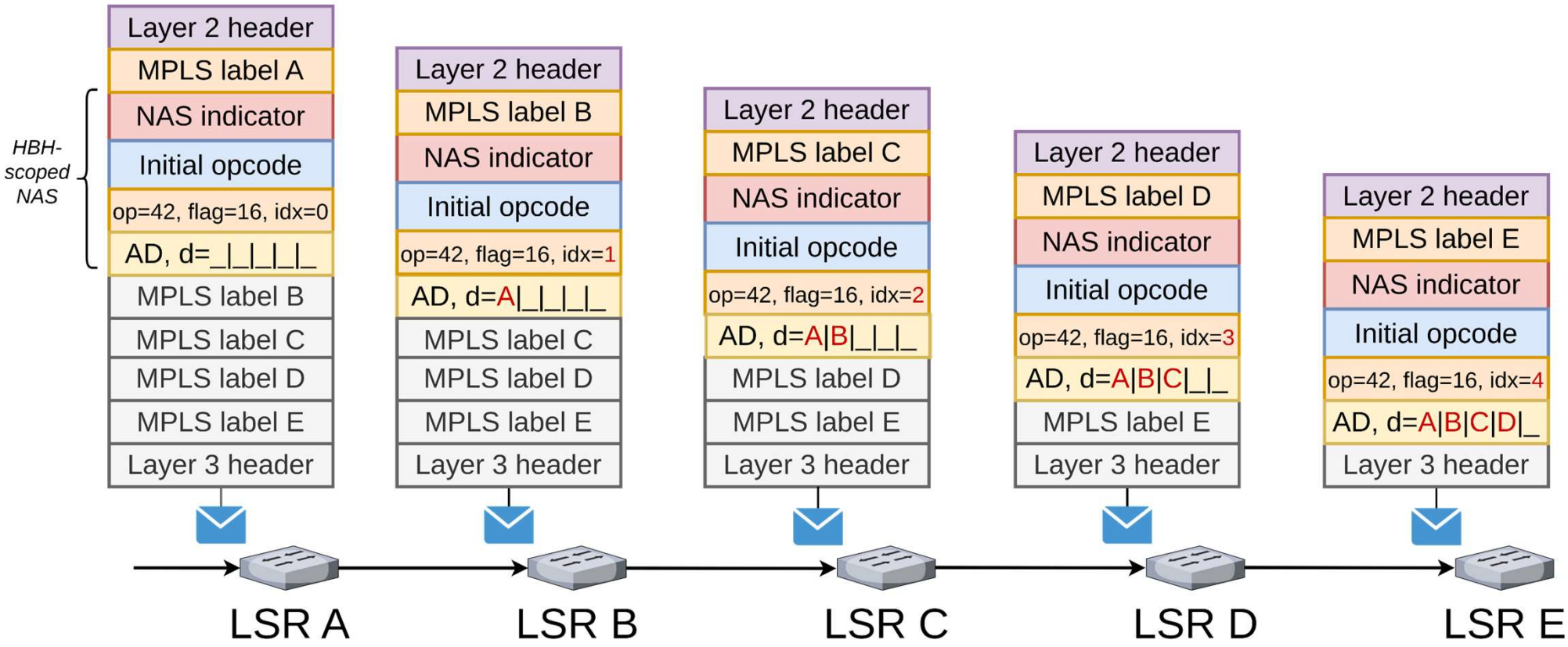
P4-MNA Example Network Action: Greenfield Mode



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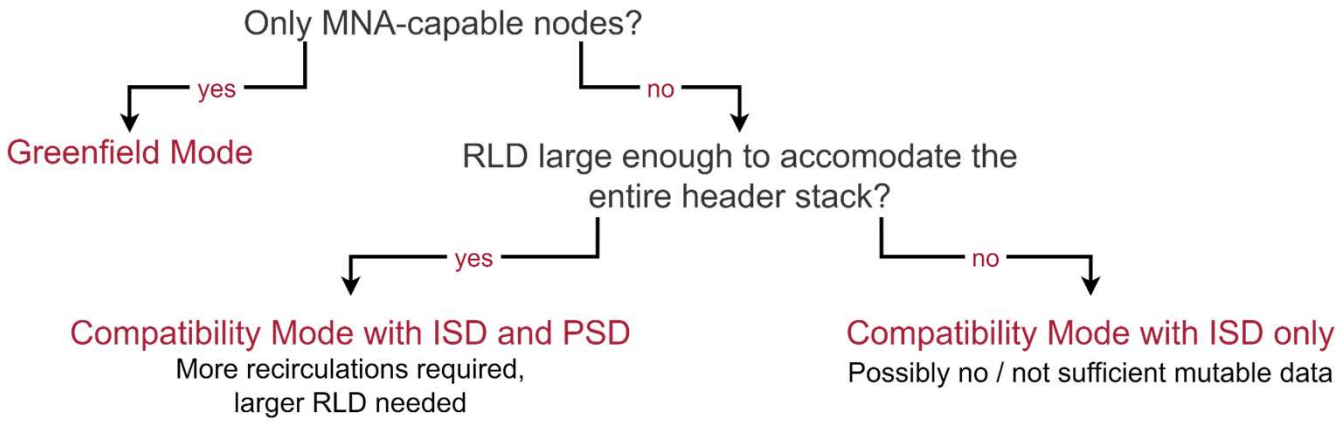
Conclusion

- We proposed 3 operational modes for deployment of MNA in the network to address the identified challenges
  1. Compatibility mode with ISD only
  2. Compatibility mode with ISD and PSD
  3. Greenfield Mode
  - We implemented all 3 modes in P4 on the Intel Tofino™ 1
    - Side products: Python library for building MNA packets, Wireshark dissector extension for visualizing MNA traffic
1. Can the IETF MNA encoding be implemented efficiently on hardware?
   - → Yes! The encoding works. Depending on the size and distribution of the substacks, we have to recirculate
2. What are the challenges in an implementation?
   - → Mutable data is difficult with ISD and HBH NAS Replication, PSD brings some harsh requirements



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Future Work

- Optimize the implementation
  - Reduce the number of required recirculations for large stacks
  - Better performance (more LSE and less recirculations) with the Intel Tofino™ 2 expected
  - Make the greenfield mode more compatible with MNA-incapable nodes
- Extend the range of implemented network actions
  - E.g., draft-ietf-mpls-inband-pm-encapsulation-11 (RFC9341), IOAM DEX
- Paper about our findings is WIP
  - Open for collaborations!

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Thanks for your time!

DISCUSSION

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MNA Operation Modes and Use Cases

	Compatibility Mode with ISD only	Compatibility Mode with ISD and PSD	Greenfield Mode
Requirements to Nodes	MNA-capable + MNA-incapable	MNA-capable + MNA-incapable	MNA-capable
Requirements to RLD	Active Segment Stack up until first HBH NAS is found	Full MPLS Stack and PSD in RLD	Active Segment Stack + next MPLS label
HBH NAS Handling	HBH NAS Replication	Single HBH NAS at bottom of stack	HBH NAS Preservation
# Mutable Bits per LSE	• 0 if multiple HBH NAS present in stack • 4 (sub. Opcode), 8 (AD LSE) if single HBH NAS in stack which is placed at the bottom	• 32 bits (Post-stack encoding)	• 30 bits (AD LSE) • 16 bits (sub. Opcode)
Location of Mutable Bits	ISD	PSD	ISD
Other Requirements	-	-	Entropy Labels
Use Cases	Network actions that do not require mutable data, e.g., IOAM-DEX	Network actions that require mutable data, e.g., Per-hop tracing IOAM	All of the others, greenfield deployment, e.g., satellite networks

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BACKUP SLIDES

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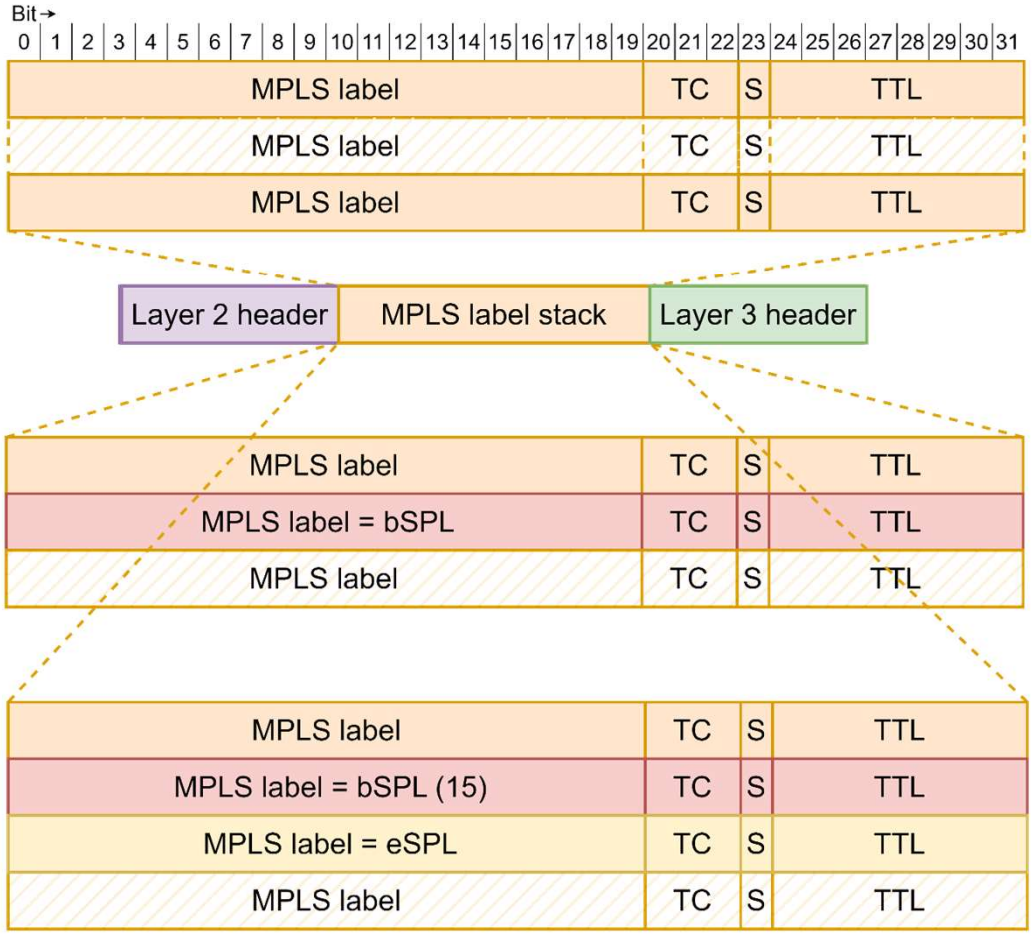
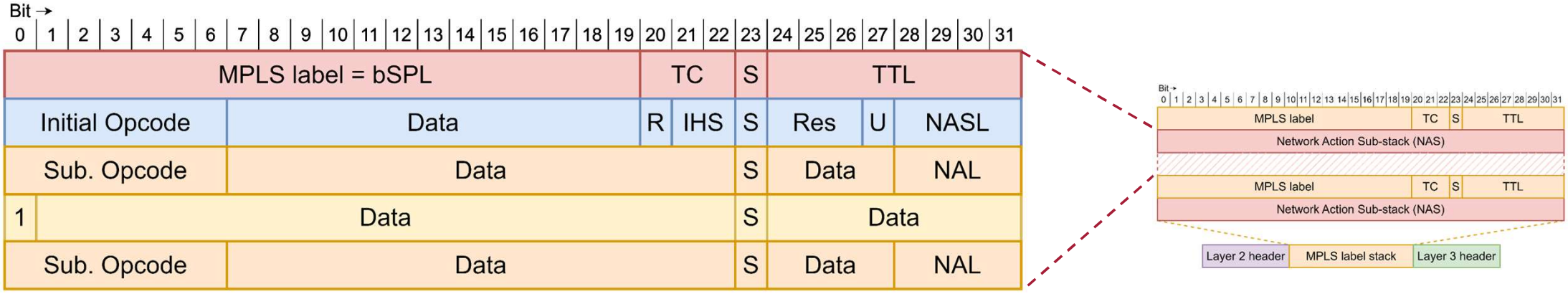
MPLS and Special Purpose Labels (SPL)

- MPLS label stack
  - … consists of Label Stack Entries (LSE)
- Forwarding labels
  - Indicated in orange
- Base Special Purpose Labels (bSPL)
  - Indicated in red
  - 16 reserved label values for special purposes
  - E.g., ECMP load balancing (Entropy labels)
- Extended Special Purpose Labels (eSPL)
  - Increase the range of reserved label values for special purposes
  - ↯ Some extensions assume only one eSPL per packet
    - We want to be flexible with network actions!



The MNA Header Encoding

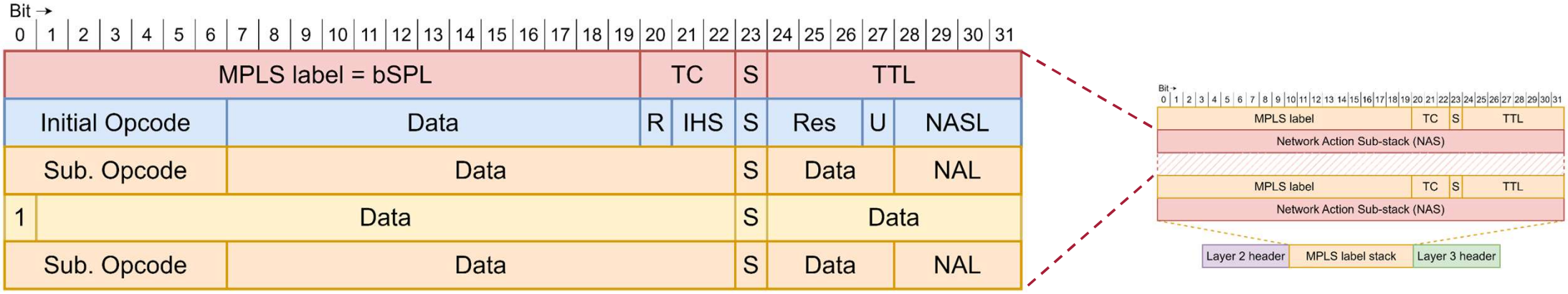
- NAS indicator
  - bSPL entry to indicate a following NAS
  - „Traditional“ LSE encoding



https://www.ietf.org/archive/id/draft-ietf-mpls-mna-hdr-04.html

The MNA Header Encoding

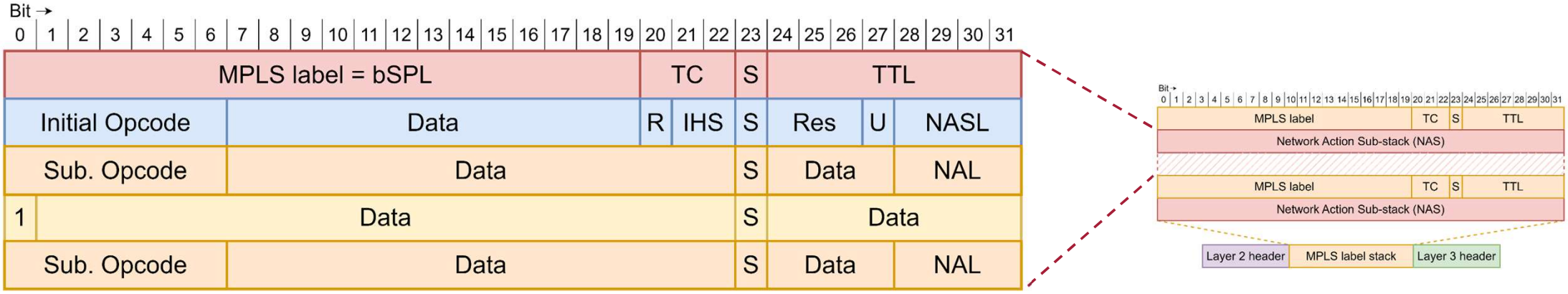
- Initial Opcode LSE (mandatory)
  - Opcode to identify the first network action. Must be non-zero
  - Data, e.g., flags
  - IHS: Scope of this NAS (more later)
  - NASL: Number of following subsequent opcodes and ancillary data in this NAS
    - here: 3, allows for a maximum of 15 subsequent opcodes and ancillary data entries



https://www.ietf.org/archive/id/draft-ietf-mpls-mna-hdr-04.html

The MNA Header Encoding

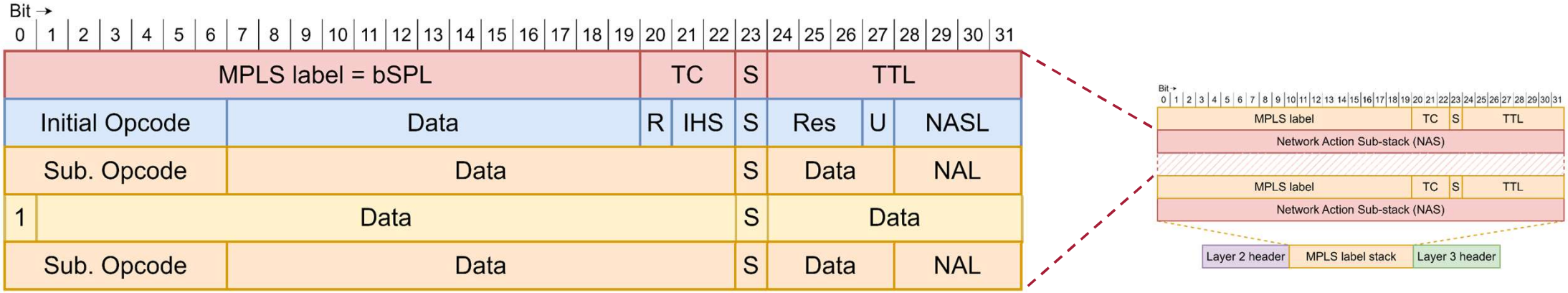
- Subsequent Opcode LSE (optional)
  - Opcode to identify the network action. Must be non-zero
  - Data, e.g., flags
  - NAL: Number of related ancillary data entries following this subsequent network action
    - here: 1, and 0 respectively



https://www.ietf.org/archive/id/draft-ietf-mpls-mna-hdr-04.html

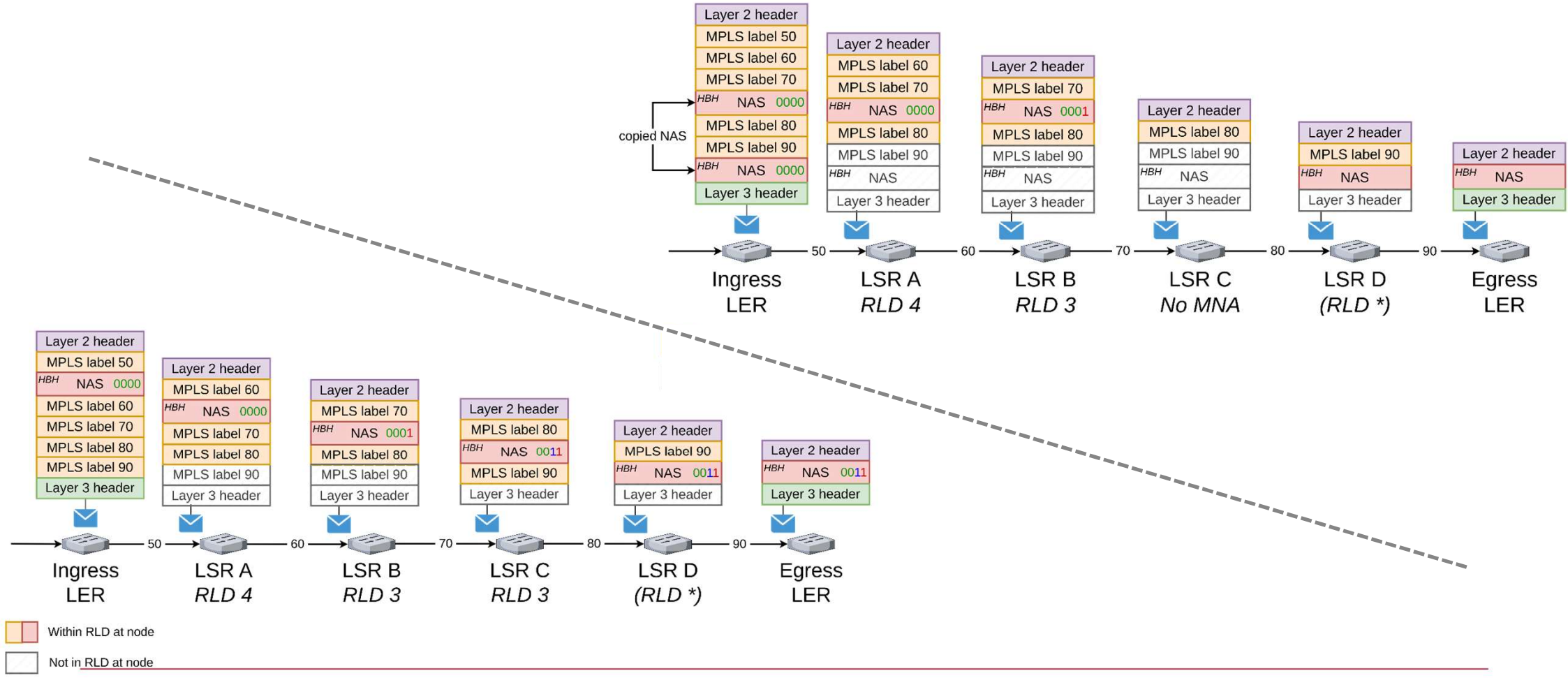
The MNA Header Encoding

- Ancillary data (AD) LSE (optional)
  - Only follows a subsequent opcode
  - Most significant bit must be set
  - Immutable data
  - Mutable data



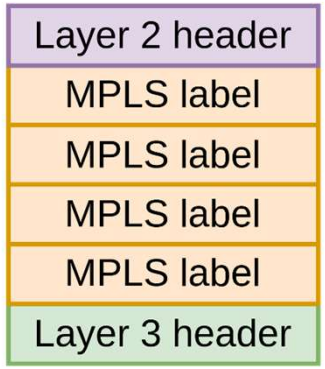
https://www.ietf.org/archive/id/draft-ietf-mpls-mna-hdr-04.html

HBH NAS Replication / Preservation Overview

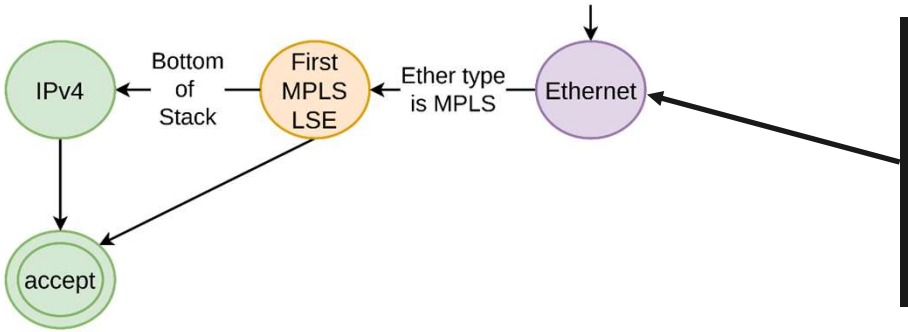


Parsing in P4

- User-defined packet headers are defined in the P4 program
  - Struct objects: reflect header fields, e.g., an MPLS LSE
  - Aggregate structs to header stacks, e.g., an MPLS stack
    - Fixed maximum length
    - All entries of this stack must share the same structure!
  - Combine header structs and header stack to describe the entire packet header

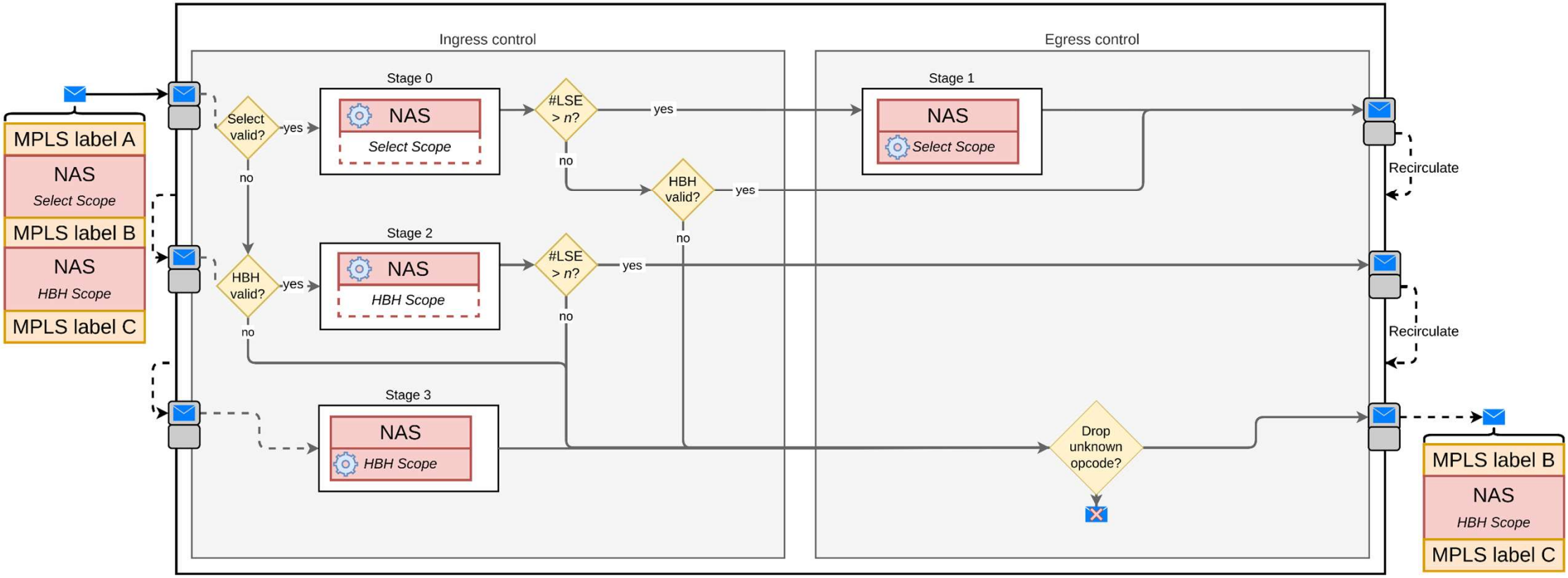


- Programmable P4 parser
  - Modeled as finite state machine
    - States extract header information from packets




```
state parse_ethernet {
    pkt.extract(hdr.ethernet);
    transition select(hdr.ethernet.ether_type) {
        ETHERTYPE_IPV4: parse_ipv4;
        ETHERTYPE_MPLS: parse_mpls;
        default: accept;
    }
}
```

P4-MNA Pipeline – Compatibility Mode ISD only



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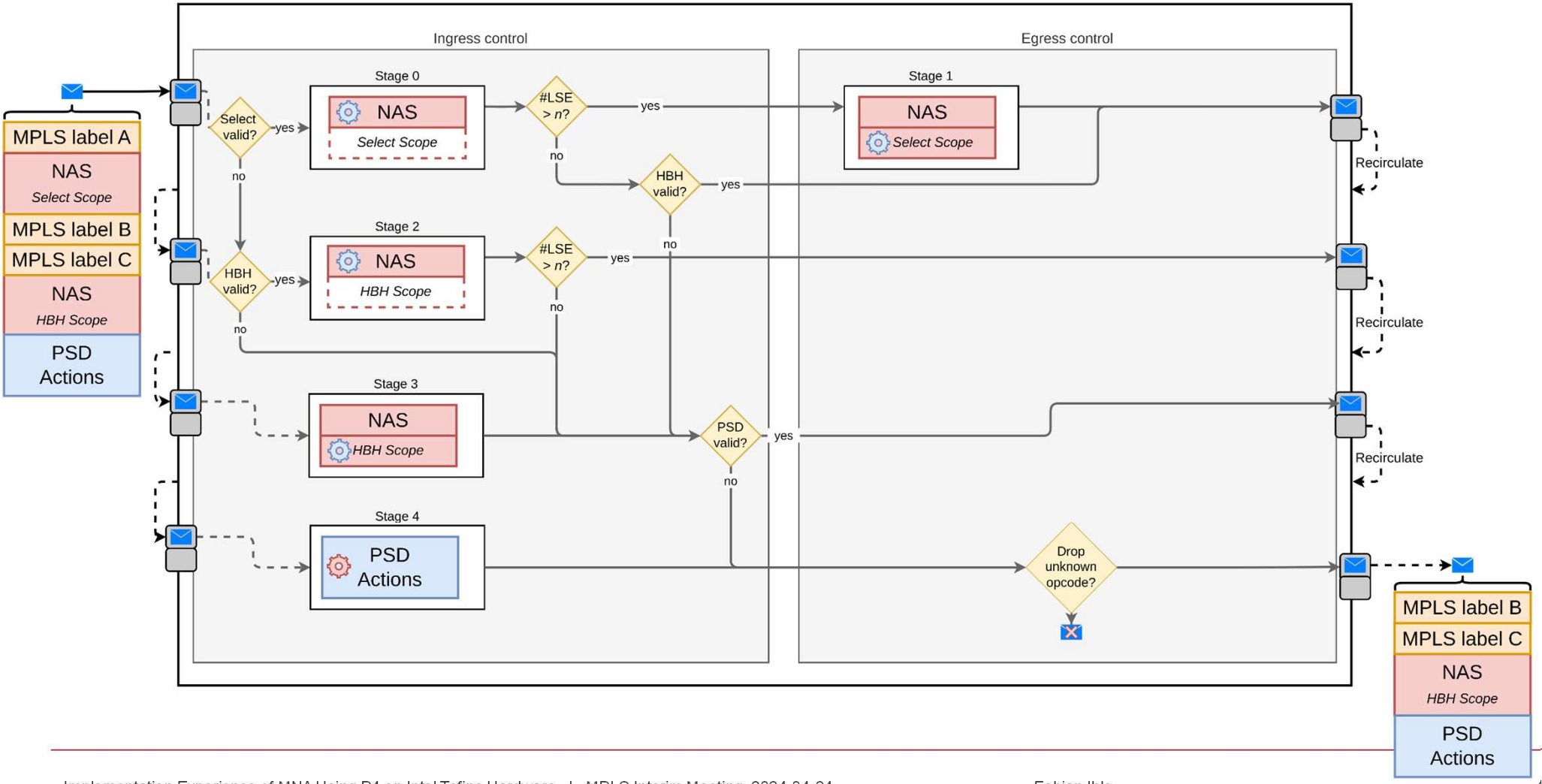
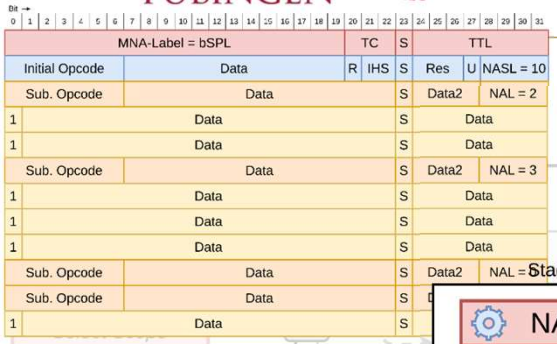
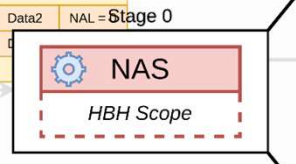
P4-MNA Pipeline – Compatibility Mode ISD with PSD



P4-MNA Processing Pipeline






```
MAT_hbh_initial_action.apply();
MAT_hbh_subsequent_action_0.apply();
MAT_hbh_subsequent_action_1.apply();
MAT_hbh_subsequent_action_2.apply();

MAT_hbh_subsequent_action_3.apply();
MAT_hbh_subsequent_action_4.apply();
MAT_hbh_subsequent_action_5.apply();
MAT_hbh_subsequent_action_6.apply();
MAT_hbh_subsequent_action_7.apply();
Metadata:

struct already_processed {
   bit<1> processed[15];
}
```

MAT_hbh_subsequent_action_0

opcode[0]	nal[0]	already_ processed[0]	data[0]	data2[0]	action
42	0	0	*	*	action_0_with_0_ad
42	1	0	*	*	action_0_with_1_ad
42	2	0	*	*	action_0_with_2_ad
...	...	0	...	...	...

```
action action_0_with_2_ad(){
   pkt.subsequent_opcodes[0].data2 = 1;  // Data field of opcode
   pkt.subsequent_opcodes[1].data2 = 15; // Write into AD1 entry
   pkt.subsequent_opcodes[1].nal = 15;  // Write into AD1 entry
   pkt.subsequent_opcodes[2].data2 = 15; // Write into AD2 entry

   meta.already_processed[0] = 1;
   meta.already_processed[1] = 1;  // Prevent AD from being
   meta.already_processed[2] = 1;  // processed by next MAT
}
```

MAT_hbh_subsequent_action_1

opcode[1]	nal[1]	already_ processed[1]	data[1]	data2[1]	action
42	0	0	*	*	action_1_with_0_ad
42	1	0	*	*	action_1_with_1_ad
42	2	0	*	*	action_1_with_2_ad
...	...	0	...	...	...

1. Match on the NAL field in each MAT along with the opcode
2. Treat <*NAL*> following entries as AD in the matched action
3. Set them to “already processed” in metadata
4. Only match in the next MAT if it is not set to “already processed”

→ Entry[1] is marked as processed
→ We do not treat the AD entry as an opcode!

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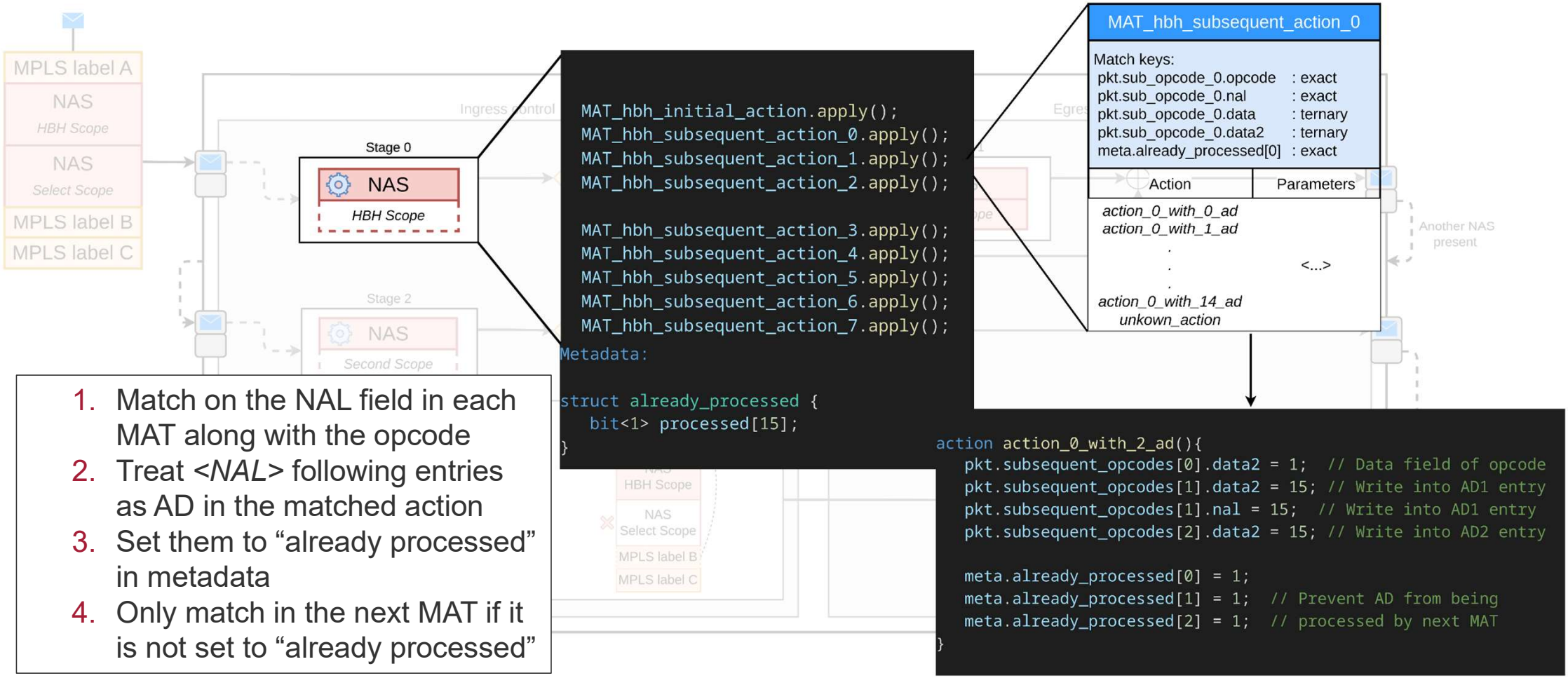
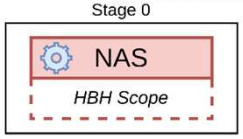
P4-MNA Processing Pipeline (2)



1. Match on the NAL field in each MAT along with the opcode
2. Treat <*NAL*> following entries as AD in the matched action
3. Set them to “already processed” in metadata
4. Only match in the next MAT if it is not set to “already processed”

P4-MNA Pipeline (3)

Stage 0




```
action action_0_with_2_ad(){
   pkt.subsequent_opcodes[0].data2 = 1;  // Data field of opcode
   pkt.subsequent_opcodes[1].data2 = 15; // Write into AD1 entry
   pkt.subsequent_opcodes[1].nal = 15;  // Write into AD1 entry
   pkt.subsequent_opcodes[2].data2 = 15; // Write into AD2 entry

   meta.already_processed[0] = 1;
   meta.already_processed[1] = 1;  // Prevent AD from being
   meta.already_processed[2] = 1;  // processed by next MAT
}
```

1. Execute the first subsequent opcode
2. Treat the following 2 entries as AD (NAL)
3. Set all 3 entries to „processed“

Bit →

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
MNA-Label = bSPL																				TC			S	TTL							
Initial Opcode								Data												R	IHS		S	Res			U	NASL = 10			
Sub. Opcode								Data															S	Data2				NAL = 2			
1	Data																						S	Data							
1	Data																						S	Data							
Sub. Opcode								Data															S	Data2				NAL = 3			
1	Data																						S	Data							
1	Data																						S	Data							
1	Data																						S	Data							
Sub. Opcode								Data															S	Data2				NAL = 0			
Sub. Opcode								Data															S	Data2				NAL = 1			
1	Data																						S	Data							

MAT_hbh_subsequent_action_0

opcode[0]	nal[0]	already_ processed[0]	data[0]	data2[0]	action
42	0	0	*	*	action_0_with_ 0_ad
42	1	0	*	*	action_0_with_ 1_ad
42	2	0	*	*	action_0_with_ 2_ad
...	...	0	...	...	...

MAT_hbh_subsequent_action_1

opcode[1]	nal[1]	already_ processed[1]	data[1]	data2[1]	action
42	0	0	*	*	action_1_with_ 0_ad
42	1	0	*	*	action_1_with_ 1_ad
42	2	0	*	*	action_1_with_ 2_ad
...	...	0	...	...	...

→ Entry[1] is marked as processed
→ We do not treat the AD entry as an opcode!

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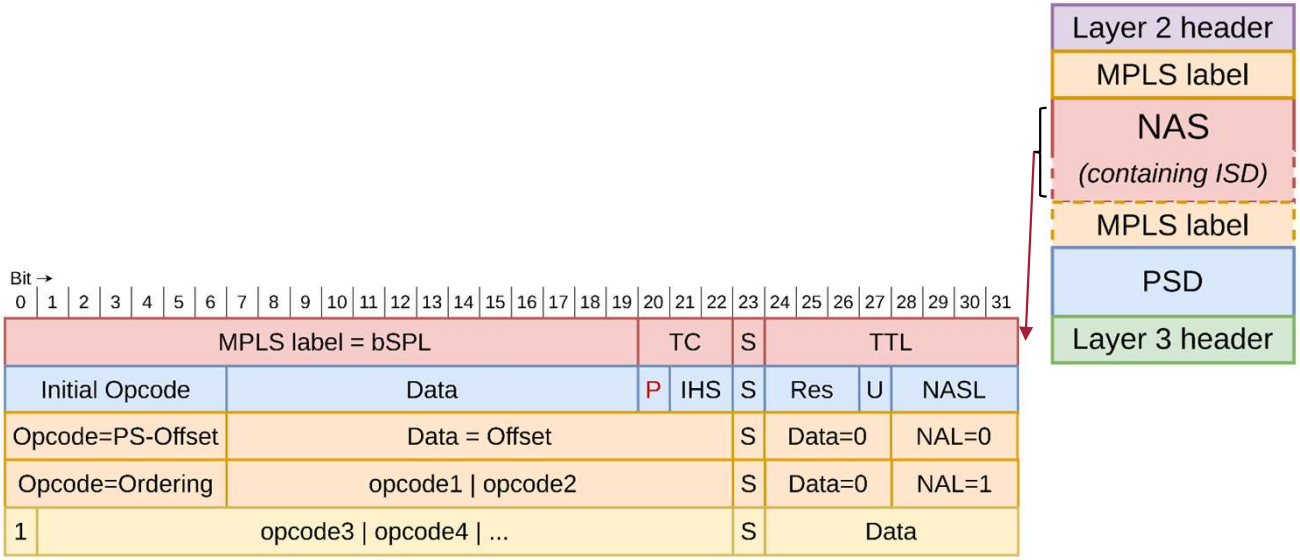
How to PSD in MNA

2. Extending in-stack actions to use PSD

   - New ISD network action: Post-Stack Network Action Offset
     - Initial or subsequent opcode
     - Data: Start offset of the Post Stack Network Action Top Header after BoS
       - Value of 1: PS starts 4 bytes after BoS

   - New network action: PS-IS-NA ordering
     - Define order of execution for PSD / ISD
     - Data field contains one or more 7-bit opcodes that defines the order of execution



► Signaling
   - Nodes must signal their Maximum Post-Stack MNA length

https://datatracker.ietf.org/doc/draft-jags-mpls-ps-mna-hdr/

Wireshark Dissector

```
Frame 10906: 176 bytes on wire (1408 bits), 176 bytes captured (1408 bits) on interface ens18, id 0
Ethernet II, Src: b2:48:81:3d:33:90 (b2:48:81:3d:33:90), Dst: 08:00:00:00:02:22 (08:00:00:00:02:22)
MPLS Stack
  MPLS Forwarding Label 50
  NAS Select, Length: 7
  MPLS Forwarding Label 70
      0000 0000 0000 0100 0110 .... .... .... = Label: 70
      .... .... .... .... .... 111. .... .... = Traffic Class: 7
      .... .... .... .... .... ...0 .... .... = Bottom of Stack: 0
      .... .... .... .... .... .... 0011 1111 = TTL: 63
  NAS Select, Length: 7
  NAS HBH, Length: 6
    MNA bSPL NAS Indicator
    MNA NAS Initial Opcode LSE
        1000 000. .... .... .... .... .... .... = Opcode: 64
        .... ...0 0000 0000 0000 .... .... .... = Data1: 0
        .... .... .... .... .... 0... .... .... = Reserved: 0
        .... .... .... .... .... .01. .... .... = Scope: 1
        .... .... .... .... .... ...0 .... .... = Bottom of Stack: 0
        .... .... .... .... .... .... 000. .... = Reserved: 0
        .... .... .... .... .... .... ...0 .... = Unknown Action Handling: 0
        .... .... .... .... .... .... .... 0110 = NASL: 6
    MNA NAS Subsequent Opcode LSE
    MNA NAS Ancillary data LSE
    MNA NAS Subsequent Opcode LSE
    MNA NAS Subsequent Opcode LSE
    MNA NAS Subsequent Opcode LSE
    MNA NAS Subsequent Opcode LSE
  MPLS Forwarding Label 60
Internet Protocol Version 4, Src: 10.0.1.1, Dst: 10.0.2.2
User Datagram Protocol, Src Port: 50081, Dst Port: 50083
Data (18 bytes)
```