MPLS Working Group L. Andersson

Internet-Draft Bronze Dragon Consulting

Intended status: Informational S. Bryant

Expires: 29 October 2022 University of Surrey 5GIC

 M. Bocci

 Nokia

 T. Li

 Juniper Networks

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 MPLS Network Actions Framework

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Abstract

 This document specifies an architectural framework for the MPLS

 Network Actions (MNA) technologies. MNA technologies are used to

 indicate actions for Label Switched Paths (LSPs) and/or packets and

 to transfer data needed for these actions.

 The document describes a common set of protocol actions and

 information elements supporting additional operational models and

 capabilities of MPLS networks. Some of these actions are defined in

 existing MPLS specifications, while others require extensions to

 existing specifications to meet the requirements found in

 "Requirements for MPLS Label Stack Indicators and Ancillary Data".

 This document is the result of work started in MPLS Open Desgign

 Team, with participation by the MPLS, PALS and DETNET working groups.

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1. Introduction

 This document specifies an architectural framework for the MPLS

 Network Actions (MNA) technologies. MNA technologies are used to

 indicate actions for LSPs and/or packets and to transfer data needed

 for these actions.

 The document describes a common set of protocol actions and

 information elements supporting additional operational models and

 capabilities of MPLS networks. Some of these actions are defined in

 existing MPLS specifications, while others require extensions to

 existing specifications to meet the requirements found in

 [I-D.bocci-mpls-miad-adi-requirements]. [Ed.: In a future draft, the

 language in the requirements draft will be changed to align with the

 terminology found here.]

 Forwarding actions are instructions to MPLS routers to apply

 additional actions when forwarding a packet. These might include

 load-balancing a packet given its entropy, whether or not to perform

 fast reroute on a failure, and whether or not a packet has metadata

 relevant to the forwarding decisions along the path.

 This document generalizes the concept of "forwarding actions" into

 "network actions" to include any action that an MPLS router is

 requested to take on the packet. That includes any forwarding

 action, but may include other operations (such as security functions,

 OAM procedures, etc.) that are not directly related to forwarding of

 the packet.

 This document is the result of work started in MPLS Open Desgign

 Team, with participation by the MPLS, PALS and DETNET working groups.

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1.1. Requirement Language

 The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",

 "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and

 "OPTIONAL" in this document are to be interpreted as described in

 BCP14 [RFC2119] [RFC8174] when, and only when, they appear in all

 capitals, as shown here.

1.2. Terminology

1.2.1. Normative Definitions

 \* Ancillary Data (AD): Data relating to the MPLS packet that may be

 used to affect the forwarding or other processing of that packet,

 either at an Label Edge Router (LER) [RFC4221] or Label Switching

 Router (LSR). This data may be encoded within a network action

 sub-stack (see below) (in-stack data), and/or after the bottom of

 the label stack (post-stack data).

 \* Network Action: An operation to be performed on a packet. A

 network action may affect router state, packet forwarding, or it

 may affect the packet in some other way. A network action is said

 to be present if there is an indicator in the packet that invokes

 the action.

 \* Network Action Indication (NAI): An indication in the packet that

 a certain network action is to be perfomed. There may be

 associated ancillary data in the packet.

 \* Network Action Sub-Stack (NAS): A set of related, contiguous Label

 Stack Entries (LSEs). The first LSE is the Network Action Sub-

 stack Indicator. The TC and TTL values in the sub-stack may be

 redefined. The label field in the second and following LSE may be

 redefined. Solutions MUST NOT redefine the S bit. See

 Section 3.1 through Section 3.5.

 \* Network Action Sub-Stack Indicator (NSI): An LSE that contains a

 special label that indicates the start of a Network Action Sub-

 stack.

 \* Scope: The set of nodes that should perform a given action.

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1.2.2. Abbreviations

 +==============+===========+========================================+

 | Abbreviation |Meaning | Reference |

 +==============+===========+========================================+

 | AD |Ancillary | [I-D.bocci-mpls-miad-adi-requirements] |

 | |Data | |

 +--------------+-----------+----------------------------------------+

 | bSPL |Base | [RFC9017] |

 | |Special | |

 | |Purpose | |

 | |Label | |

 +--------------+-----------+----------------------------------------+

 | ECMP |Equal Cost | |

 | |Multipath | |

 +--------------+-----------+----------------------------------------+

 | eSPL |Extended | [RFC9017] |

 | |Special | |

 | |Purpose | |

 | |Label | |

 +--------------+-----------+----------------------------------------+

 | HBH |Hop by hop | In the MNA context, this document. |

 +--------------+-----------+----------------------------------------+

 | I2E |Ingress to | In the MNA context, this document. |

 | |Egress | |

 +--------------+-----------+----------------------------------------+

 | ISD |In stack | [I-D.bocci-mpls-miad-adi-requirements] |

 | |data | |

 +--------------+-----------+----------------------------------------+

 | LSE |Label Stack| [RFC3032] |

 | |Entry | |

 +--------------+-----------+----------------------------------------+

 | MNA |MPLS | This documnent |

 | |Network | |

 | |Actions | |

 +--------------+-----------+----------------------------------------+

 | NAI |Network | [I-D.bocci-mpls-miad-adi-requirements] |

 | |Action | |

 | |Indicator | |

 +--------------+-----------+----------------------------------------+

 | NAS |Network | This document |

 | |Action Sub-| |

 | |Stack | |

 +--------------+-----------+----------------------------------------+

 | PSD |Post stack | [I-D.bocci-mpls-miad-adi-requirements] |

 | |data | and Section 3.6 |

 +--------------+-----------+----------------------------------------+

 | SPL |Special | [RFC9017] |

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 | |Purpose | |

 | |Label | |

 +--------------+-----------+----------------------------------------+

 Table 1: Abbreviations

2. Structure

 An MNA solution is envisioned as a set of network action sub-stacks

 that indicate the network actions being invoked, plus possible post-

 stack data. A solution must specify where in the label stack the

 network actions sub-stacks occur, if and how frequently they should

 be replicated, and how network action sub-stack and post-stack data

 are encoded.

 A network action sub-stack contains:

 \* Label: A special label is used to indicate the start of a network

 action sub-stack.

 \* Indicators: A set of indicators that describes the set of network

 actions.

 \* In-Stack Data: A set of zero or more LSEs that carry ancillary

 data for the present network actions.

 Each network action present in the network action sub-stack may have

 zero or more LSEs of in-stack data. The ordering of the in-stack

 data LSEs corresponds to the ordering of the network action

 indicators. The encoding of the in-stack data, if any, for a network

 action must be specified in the document that defines the network

 action.

 Certain network actions may also specify that data is carried after

 the label stack. This is called post-stack data. The encoding of

 the post-stack data, if any, for a network action must be specified

 in the document that defines the network action. If multiple network

 actions are present and have post-stack data, the ordering of their

 post-stack data corresponds to the ordering of the network action

 indicators.

 A solution must specify the order that network actions are to be

 applied to the packet.

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2.1. Scopes

 A network action may need to be processed by every node along the

 path, or some subset of the nodes along its path. Some of the scopes

 that an action may have are:

 \* Hop-by-hop (HBH): Every node along the path will perform the

 action.

 \* Ingress-to-Egress (I2E): Only the last node on the path will

 perform the action.

 \* Select: Only specific nodes along the path will perform the

 action.

 If a solution supports the select scope, it must describe how it

 specifies the set of nodes to perform the actions.

2.2. Partial Processing

 Legacy devices that do not recognize the MNA label will discard the

 packet as described in [RFC3031].

 Devices that do recognize the MNA label may not implement all of the

 present network actions. A solution must specify how unrecognized

 present network actions should be handled.

 One alternative is that an implementation should stop processing

 network actions when it encounters an unrecognized network action.

 Subsequent present network actions would not be applied. The result

 is dependent on the solution's order of operations.

 Another alternative is that an implementation should drop any packet

 that contains any unrecognized present network actions.

 A third alternative is that an implementation should perform all

 recognized present network actions, but ignore all unrecognized

 present network actions.

 Other alternatives may also be possible and should be specified by

 the solution.

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2.3. Signaling

 A node that wishes to make use of MNA and apply network actions to a

 packet must understand the nodes that the packet will transit and

 whether or not the nodes support MNA and the network actions that are

 to be invoked. These capabilities are presumed to be signaled by

 protocols that are out-of-scope for this document and are presumed to

 have per-network action granularity. If a solution requires

 alternate signaling, it must specify so explicitly.

 A node that pushes a NAS onto the label stack is responsible for

 determining that all nodes that should process the NAS will have the

 NAS within its Readable Label Depth (RLD). A node should use

 signaling (e.g., [RFC9088]) to determine this.

2.4. Positioning

 A network action sub-stack should never occur at the top of the MPLS

 label stack. A node that is responsible for popping a forwarding

 label immediately above a network action sub-stack must also pop any

 network action sub-stacks that immediately follow.

2.5. State

 A network action can affect state in the network. This implies that

 a packet may affect how subsequent packets are handled.

3. Encoding

 Several possibilities to carry NAI's have been discussed in MNA

 drafts and in the MPLS Open DT. In this section, we enumerate the

 possibilities and some considerations for the various alternatives.

 All types of network actions are represented in the MPLS label stack

 by a set of LSEs termed a network action sub-stack (NAS). An NAS

 consists of a special label, followed by LSEs that specify which

 network actions are to be performed on the packet, and the in-stack

 ancillary data for each indicated network action.

 [I-D.bocci-mpls-miad-adi-requirements] requires that a solution not

 add unnecessary LSEs to the sub-stack (Section 3.1, requirement 5).

 Accordingly, solutions should also make efficient use of the bits

 within the sub-stack, as inefficient use of the bits will result in

 the addition of unnecessary LSEs.

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3.1. The MNA Label

 The first LSE in a network action sub-stack contains a special label

 that indicates a network action sub-stack. A solution has several

 choices for this special label.

3.1.1. Existing Base SPL

 A solution may reuse an existing Base SPL (bSPL). If it elects to do

 so, it must explain how the usage is backwards compatible, including

 in the case where there is ISD.

3.1.2. New Base SPL

 A solution may select a new bSPL.

3.1.3. New Extended SPL

 A solution may select a new eSPL. If it elects to do so, it must

 address the requirement for the minimal number of LSEs.

3.1.4. User-Defined Label

 A solution may allow the network operator to define the label that

 indicates the network action sub-stack. This creates management

 overhead for the network operator to coordinate the use of this label

 across all nodes on the path using management or signaling protocols.

 If a solution elects to use a user-defined label, the solution should

 justify this overhead.

3.2. TC and TTL

 In the first LSE of the network action sub-stack, only the 20 bits of

 Label Value and the Bottom of Stack bit are significant, the TC field

 (3 bits) and the TTL (8 bits) are not used. This leaves 11 bits that

 could be used for other purposes.

3.2.1. TC and TTL retained

 If the solution elects to retain the TC and TTL field, then the first

 LSE of the network action sub-stack would appear as:

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 0 1 2 3

 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

 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

 | Label | TC |S| TTL |

 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

 Label: Label value, 20 bits

 TC: Traffic Class, 3 bits

 S: Bottom of Stack, 1 bit

 TTL: Time To Live

 Further LSEs would be needed to encode NAIs. If a solution elects to

 retain these fields, it must address the requirement for the minimal

 number of LSEs.

3.2.2. TC and TTL Repurposed

 If the solution elects to reuse the TC and TTL field, then the first

 LSE of the network action sub-stack would appear as:

 0 1 2 3

 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

 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

 | Label |x x x|S|x x x x x x x x|

 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

 Label: Label value, 20 bits

 x: Bit available for solution definition

 S: Bottom of Stack, 1 bit

 The solution may use more LSEs to contain NAIs.

3.3. Length of the NAS

 A solution must have a mechanism to indicate the length of the NAS.

 This must be easily processed even by implementations that do not

 understand the full contents of the NAS. Two options are described

 below, other solutions may be possible.

3.3.1. Last/Continuation Bits

 A solution may use a bit per LSE to indicate whether the NAS

 continues into the next LSE or not. The bit may indicate

 continuation by being set or by being clear. The overhead of this

 approach is one bit per LSE and has the advantage that it can

 effectively encode an arbitrarily sized NAS. This approach is

 efficient if the NAS is small.

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3.3.2. Length Field

 A solution may opt to have a fixed size length field at a fixed

 location within the NAS. The fixed size of the length field may not

 be large enough to support all possible NAS contents. This approach

 may be more efficient if the NAS is longer, but not longer than can

 be described by the length field.

 Advice from hardware designers advocates a length field as this

 minimizes branching in the logic.

3.4. Encoding of Scopes

 A solution may choose to explicitly encode the scope of the actions

 contained in a network action sub-stack. A solution may also choose

 to have the scope encoded implicitly, based on the actions present in

 the network action sub-stack. This choice may have performance

 implications as an implementation might have to parse the network

 actions that are present in a network action sub-stack only to

 discover that there are no actions for it to perform.

 Solutions need to consider the order of scoped NAIs and their

 associated AD within individual sub-stacks and the order of per-scope

 sub-stacks in order that network actions and the AD can be most

 readily found and not need to processed by nodes that are not

 required to handle those actions.

3.5. Encoding a Network Action

 Two options for encoding NAIs are described below, other solutions

 may be possible. Any solution should allow encoding of an arbitrary

 number of NAIs.

3.5.1. Bit Catalogs

 A solution may opt to encode the set of network actions as a list of

 bits, sometimes known as a catalog. The solution must provide a

 mechanism to determine how many LSEs are devoted to the catalog. A

 set bit in the catalog would indicate that the corresponding network

 action is present.

 Catalogs are efficient if the number of present network actions is

 relatively high and if the size of the necessary catalog is small.

 For example, if the first 16 actions are all present, a catalog can

 encode this in 16 bits. However, if the number of possible actions

 is large, then a catalog can become inefficient. Selecting only one

 action that is the 256th action would require a catalog of 256 bits,

 which would require more than one LSE.

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3.5.2. Operation Codes

 A solution may opt to encode the set of present network actions as a

 list of operation codes (opcodes). Each opcode is a fixed number of

 bits. The size of the opcode bounds the number of network actions

 that the solution can support.

 Opcodes are efficient if there are only one or two active network

 actions. For example, if an opcode is 8 bits, then two active

 network actions could be encoded in in 16 bits. However, if there

 are 16 actions required, then opcodes would consume 128 bits.

 Opcodes are efficient at encoding a large number of possible actions.

 If only the 256th action is to be selected, that still requires 8

 bits.

3.6. Encoding of Post-Stack Data

 If there are multiple instances of post-stack data, they should occur

 in the same order as their relevant network action sub-stacks and

 then in the same order as their relevant network functions occur

 within the network action sub-stacks.

3.6.1. First Nibble Considerations

 The first nibble after the label stack has been used to convey

 information in certain cases.

 For example, in [RFC4928] this nibble is investigated to find out if

 it has the value "4" or "6", if it is not, it is assumed that the

 packet payload is not IPv4 or IPv6 and Equal Cost Multipath (ECMP) is

 not performed.

 It should be noted that this is an inexact method, for example an

 Ethernet Pseudowire without a control word might have "4" or "6" in

 the first nibble and thus will be ECMP'ed.

 Nevertheless, the method is implemented and deployed, it is used

 today and will be for the foreseeable future.

 The use of the first nibble for BIER is specified in [RFC8296]. Bier

 sets the first nibble to 5. The same is true for BIER payload, as

 for any use of the first nibble, it is not possible from the first

 nibble itself being set to 5, conclude that the payload is BIER.

 However, it achieves the design goal of [RFC8296], to exclude that

 the payload is IPv4, IPv6 or a pseudowire.

 There are possibly more examples, they will be added if we find that

 they further highlight the issue with using the first nibble.

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 [Ed. Outstanding comments from Adrian:

 Shouldn't we include RFC4385 for 0b0000 for the PW control word and

 0b0001 for the PW ACH?

 This section is all very well, but it doesn't give any direction to

 the solution developer for what they should do with the first nibble

 in the post stack data.

 Is it also relevant to note that there may be other post-stack

 information that comes before the payload (such as the PW control

 word, and that the solution must consider the location of the post-

 stack data in relaiton to that (e.g., immeidately after the LSE with

 the S bit set) etc.]

4. Definition of a Network Action

 Network actions should be defined in a document and must contain:

 \* Name: The name of the network action.

 \* Network Action Indicator: The bit position or opcode that

 indicates that the network action is active.

 \* Scope: The document should specify which nodes should perform the

 network action. The action may apply to each transit node (HBH),

 only the egress node that pops the final label off of the label

 stack, or specific nodes along the label switched path.

 \* State: The document should specify if the network action can

 modify state in the network, and if so, the state that may be

 modified and its side-effects.

 \* Required/Optional: The document should specify whether a node is

 required to perform the network action.

 \* In-Stack Data: The number of LSEs of in-stack data. If this is of

 a variable length, then the solution must specify how an

 implementation can determine this length without implementing the

 network action.

 \* Post-Stack Data: The encoding of post-stack data, if any. If this

 is of a variable length, then the solution must specify how an

 implementation can determine this length without implementing the

 network action.

 A solution should create an IANA registry for network actions.

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5. Management Considerations

 Network operators will need to be cognizant of which network actions

 are supported by which nodes and will need to ensure that this is

 signalled appropriately. Some solutions may require network-wide

 configuration to synchronize the use of the labels that indicate the

 start of an NAS. Solution documents must make clear what management

 considerations apply to the solutions they are describing. Solutions

 documents must describe mechanisms for performing network diagnostics

 in the presence of MNAs.

6. Security Considerations

 The forwarding plane is insecure. If an adversary can affect the

 forwarding plane, then they can inject data, remove data, corrupt

 data, or modify data. MNA additionally allows an adversary to make

 packets perform arbitrary network actions.

 Link-level security mechanisms can help mitigate some on-link

 attacks, but does nothing to preclude hostile nodes.

 End-to-end encryption of an LSP can help provide security, but would

 make it impossible to process post-stack data.

7. IANA Considerations

 This document does not make any allocations of code points from IANA

 registries.

 As long as the "does not make any allocations ..." from IANA is true,

 this pragraph shoukd be removed by the RFC-Editor. If it turns out

 that we will need to do IANA allocation, a proper IANA section will

 be added.

8. Acknowledgements

 The authors would like to thank Adrian Farrel for his contributions

 and to John Drake for his comments.

9. Editorial attic

 This section contains old material that will be discarded before

 publication, assuming we don't find it useful between now and then.

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9.1. Process Note on E2E

 There has been some discussion on the of the E2E abbreviation. 1. In

 a mail to the MPLS Working group mailing list Joel Halpern pointed

 out that the abbreviation E2E has been used in several different

 meanings. Joel suggested to use another abbreviation.

 1. Some variants has been proposed, for example.

 \* Ingress to Egress (I2E); alernative abbreviation (i2e)

 \* Egress

 \* LSP Ingress to LSP Egress (LI2LE)

 \* Egress (because the Ingress has already done its thing)

 \* Ultimate Hop

 \* Destination

 \* Start-to-End

 \* Last-LSR

 \* Head to Tail

 In a few days (counting from the publication date of this document)

 the working group chairs will take an initiative to poll the working

 groups for consensus on this.

9.2. Concepts used in this Framework

 +=============+====================+===========+======+

 | Concept | Meaning | Reference | Note |

 +=============+====================+===========+======+

 | E2E concept | E2E in MNA context | this | - |

 | | is defined in... | document | |

 +-------------+--------------------+-----------+------+

 | concept | free text | this | - |

 | | | document | |

 +-------------+--------------------+-----------+------+

 Table 2: Concepts

 Not complete, help appreciated. [Ed. This section is planned for

 removal as it seems unhelpful so far.]

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9.3. LSE

 An individual LSE has the following format [RFC3032]:

 0 1 2 3

 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

 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

 | Label | TC |S| TTL |

 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

 Label: Label Value, 20 bits

 TC: Traffic Class, 3 bits

 S: Bottom of Stack, 1 bit

 TTL: Time to Live, 8 bits

 Figure 1: A Label Stack Entry (LSE)

9.4. MPLS Forwarding model

 This is section here to basically to have a place holder where to

 discuss the development of the MPLS forwrding model. It might be

 removed. [Ed. So far, it adds no value. Wave bye-bye.]

9.4.1. Orginal Model

 +-----------------------------------------------------------------+

 | |

 | +---------------------+ |

 | | +------------+ | |

 | | | MPLS Label | LSE | |

 | | +---|--------+ | |

 | +-----|---------------+ |

 | | |

 | | +----------------------+ |

 | | | FIB | |

 | | | | |

 | | | +------------+ | +----------------------+ |

 | +------->|FIB Entry |-----+-->|Forwarding Code | |

 | | +------------+ | | +----------------------+ |

 | +----------------------| | |

 | | | +----------------------+ |

 | +-->|Forwarding Parameters | |

 | +----------------------+ |

 | |

 | |

 | LSE = Label Stack Entry (what many people call a label) |

 | FIB = Forwarding Information (date)Base |

 +-----------------------------------------------------------------+

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 Figure 2: MPLS Original Forwarding Model

10. References

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Authors' Addresses

 Loa Andersson

 Bronze Dragon Consulting

 Email: loa@pi.nu

 Stewart Bryant

 University of Surrey 5GIC

 Email: sb@stewartbryant.com

 Matthew Bocci

 Nokia

 Email: matthew.bocci@nokia.com

 Tony Li

 Juniper Networks

 Email: tony.li@tony.li

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