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Realizing Network Slices in IP/MPLS Networks

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Abstract

Network slicing provides the ability to partition a physical network

into multiple logical networks of varying sizes, structures, and

functions so that each slice can be dedicated, e.g., to specific services or

customers. Network slices need to operate in parallel while

providing slice elasticity in terms of network resource allocation.

The Differentiated Service (Diffserv) model allows for carrying

multiple services on top of a single physical network by relying on

compliant nodes to apply specific forwarding treatment (scheduling

and drop policy) on to packets that carry the respective Diffserv

code point. This document adopts a similar approach to the Diffserv and

proposes a scalable approach to realize network slicing in IP/MPLS

networks. The solution does not mandate Diffserv to be enabled in

the network to provide a specific forwarding treatment, but can co-

exist with and complement it when enabled.

Status of This Memo

This Internet-Draft is submitted in full conformance with the

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1. Introduction

Network slicing allows a Service Provider to create

logical networks on top of a common or shared physical network

infrastructure. Such network slices can be offered to customers or

used internally by the Service Provider to enhance

the delivery of their service offerings. A Service Provider can also use network

slicing to organize the elements of its infrastructure.

This document provides a path control technology agnostic solution

that a Service Provider can deploy to realize network slicing in IP/

MPLS networks.

[I-D.ietf-teas-ietf-network-slices] provides the definition of a

network slice and discusses the general

framework for requesting and operating IETF Network Slices, their

characteristics, and the necessary system components and interfaces.

It also discusses the function of an IETF Network Slice Controller

and the requirements on its northbound and southbound interfaces.

This document introduces the notion of a Slice-Flow Aggregate which

comprises of one of more IETF network slice traffic streams. It also

describes the Network Resource Partition (NRP) and the NRP Policy

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that can be used to instantiate control and data plane behaviors on

select topological elements associated with the NRP that supports a

Slice-Flow Aggregate - refer to Section 5.1 for further details.

The IETF Network Slice Controller is responsible for the aggregation

of multiple IETF network traffic streams into a Slice-Flow Aggregate,

and for maintaining the mapping required between them. The

mechanisms used by the controller to determine the mapping of one or

more IETF network slice to a Slice-Flow Aggregate are outside the

scope of this document. The focus of this document is on the

mechanisms required at the device level to address the requirements

of network slicing in packet networks.

In a Differentiated Service (Diffserv) domain [RFC2475], packets

requiring the same forwarding treatment (scheduling and drop policy)

are classified and marked with a Class Selector Codepoint at Diffserv domain

ingress nodes. At transit nodes, the CS field inside the packet is

inspected to determine the specific forwarding treatment to be

applied before the packet is forwarded further. A similar approach

is adopted by this document to realize network slicing. The

solution proposed in this document does not mandate Diffserv to be

enabled in the network to provide a specific forwarding treatment.

When logical networks associated with an NRP are realized on top of a

shared physical network infrastructure, it is required to steer

traffic on the specific network resources partition that is allocated

for a given Slice-Flow Aggregate. In packet networks, the packets of a

specific Slice-Flow Aggregate may be identified by one or more

specific fields carried within the packet. An NRP ingress boundary

node populates the respective field(s) in packets that are mapped to

a Slice-Flow Aggregate in order to allow interior NRP nodes to

identify and apply the specific Per Hop Behavior (PHB) associated

with the Slice-Flow Aggregate. The PHB defines the scheduling

treatment and, in some cases, the packet drop probability.

If Diffserv is enabled within the network, the Slice-Flow Aggregate

traffic can further carry a Diffserv CS to enable differentiation of

forwarding treatments for packets within the same Slice-Flow

Aggregate.

For example, when using MPLS as a dataplane, it is possible to

identify packets belonging to the same Slice-Flow Aggregate by

carrying an identifier in an MPLS Label Stack Entry (LSE).

Additional Diffserv classification may be indicated in the Traffic

Class (TC) bits of the global MPLS label to allow further

differentiation of forwarding treatments for traffic traversing the

same NRP.

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This document covers different modes of NRPs and discusses how each

mode can ensure proper establishment of Slice-Flow Aggregate paths and

respective treatment of Slice-Flow Aggregate traffic.

1.1. Terminology

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

BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all

capitals, as shown here.

The reader is expected to be familiar with the terminology specified

in [I-D.ietf-teas-ietf-network-slices].

The following terminology is used in the document:

Slice-Flow Aggregate:

a collection of packets that match an NRP Policy selection

criteria and are given the same forwarding treatment; a Slice-Flow

Aggregate comprises of one or more IETF network slice traffic

streams; the mapping of one or more IETF network slices to a

Slice-Flow Aggregate is maintained by the IETF Network Slice

Controller.

Network Resource Partition Policy:

a policy construct that enables instantiation of mechanisms in

support of IETF network slice specific control and data plane

behaviors on select topological elements; the enforcement of an

NRP Policy results in the creation of an NRP.

NRP Capable Node:

a node that supports one of the NRP modes described in this

document.

NRP Incapable Node:

a node that does not support any of the NRP modes described in

this document.

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Slice-Flow Aggregate Path:

a path that is setup over the NRP that is associated with a

specific Slice-Flow Aggregate.

Slice-Flow Aggregate Packet:

a packet that traverses over the NRP that is associated with a

specific Slice-Flow Aggregate.

NRP Topology:

a set of topological elements associated with a Network Resource

Partition.

Slice-Flow Aggregate Aware TE:

a mechanism for TE path selection that takes into account the

available network resources associated with a specific Slice-Flow

Aggregate.

1.2. Acronyms and Abbreviations

BA: Behavior Aggregate

CS: Class Selector

NRP-PHB: NRP Per Hop Behavior as described in Section 5.1.3

SAS: Slice-Flow Aggregate Selector

SASL: Slice-Flow Aggregate Selector Label as described in

Section 5.1.1

SLA: Service Level Agreement

SLO: Service Level Objective

Diffserv: Differentiated Services

MPLS: Multiprotocol Label Switching

LSP: Label Switched Path

RSVP: Resource Reservation Protocol

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TE: Traffic Engineering

SR: Segment Routing

VRF: VPN Routing and Forwarding

AC: Attachment Circuit

CE: Customer Edge

PE: Provider Edge

PCEP: Path Computation Element (PCE) Communication Protocol (PCEP)

2. Network Resource Slicing Membership

An NRP that supports a Slice-Flow Aggregate can be instantiated over

all or parts of an IP/MPLS network (e.g., all or specific network resources

in the access, aggregation, or core network), and can stretch across

multiple domains administered by a provider. The NRP topology may be

comprised of dedicated and/or shared network resources (e.g., in

terms of processing power, storage, and bandwidth).

The physical network resources may be fully dedicated to a specific

Slice-Flow Aggregate. For example, traffic belonging to a Slice-Flow

Aggregate can traverse dedicated network resources without being

subjected to contention from traffic of other Slice-Flow Aggregates.

Dedicated physical network resource slicing allows for simple

partitioning of the physical network resources amongst Slice-Flow

Aggregates without the need to distinguish packets traversing the

dedicated network resources since only one Slice-Flow Aggregate

traffic stream can traverse the dedicated resource at any time.

To optimize network utilization, sharing of the physical network

resources may be desirable. In such case, the same physical network

resource capacity is divided among multiple NRPs that support

multiple Slice-Flow Aggregates. The shared physical network

resources can be partitioned in the data plane (for example by

applying hardware policers and shapers) and/or partitioned in the

control plane by providing a logical representation of the physical

link that has a subset of the network resources available to it.

3. IETF Network Slice Realization

Figure 1 describes the steps required to realize an IETF network

slice service in a provider network using the solution proposed in

this document. Each of the steps is further elaborated on in a

subsequent section.

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-- -- --

---------- |CE| |CE| |CE|

| Network | -- -- --

| Slice | AC : AC : AC :

| Orchstr | ---------------------- -------

---------- ( |PE|....|PE|....|PE| ) ( IETF )

| IETF ( --: -- :-- ) ( Network )

| Network ( :............: ) ( Slice )

| Slice Svc ( IETF Network Slice ) ( ) Customer

| Req ---------------------- ------- View

..|....................................\........./..................

--v---------- ----> Slice-Flow \ / Controller

|Controllers| | Aggregation Mapping v v View

| ------- | | -----------------------------------------

| |IETF | |-- ( |PE|.......|PE|........|PE|.......|PE| )

| |Network| | ( --: -- :-- -- )

| |Slice | | ( :...................: )

| |Cntrlr | | ( Slice-Flow Aggregate )

| |(NSC) | | -----------------------------------------

| ------- |---------.

| ------- | | Path Placement

| | | | v

| | | | -----------------------------------------

| | | | ( |PE|....-..|PE| |PE|.......|PE| )

| |Network| | ( -- |P| --......-...-- - :-- )

| |Cntrlr | | ( -:.........|P|.......|P|..: )

| |(NC) | | ( Path Set - - )

| | | | -----------------------------------------

| | | |-------.

| | | | | Apply Topology Filters

| | | | v

| ------- | ----------------------------- --------

| | (|PE|..-..|PE|... ..|PE|..|PE|) ( Policy )

----------- ( :-- |P| -- :-: -- :-- ) ( Filter )

| | | ( :.- -:.......|P| :- ) ( Topology )

| | | ( |P|...........:-:.......|P| ) ( )

| | \ ( - Policy Filter Topology ) --------

| | \ ----------------------------- A

| | \ A /

..............\.......................\............../..............

| | Path v Service Mapping \ / Physical N/w

\ \Inst ------------------------------------------------

\ \ ( |PE|.....-.....|PE|....... |PE|.......|PE| )

\ \ ( -- |P| -- :-...:-- -..:-- )

NRP \ --->( : -:..............|P|.........|P| )

Policy\ ( -.......................:-:..- - )

Inst ----->( |P|..........................|P|......: )

( - - )

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------------------------------------------------

Figure 1: IETF network slice realization steps.

3.1. Network Topology Filters

The Physical Network may be filtered into a number of Policy Filter

Topologies. Filter actions may include selection of specific nodes

and links according to their capabilities and are based on network-

wide policies. The resulting topologies can be used to host IETF

Network Slices and provide a useful way for the network operator to

know that all of the resources they are using to plan a network slice

meet specific SLOs. This step can be done offline during planning

activity, or could be performed dynamically as new demands arise.

Section 5.1.4 describes how topology filters can be associated with

the NRP instantiated by the NRP Policy.

3.2. IETF Network Slice Service Request

The customer requests an IETF Network Slice Service specifying the

points of attachment, the connectivity matrix, and the SLOs/SLEs

as described in [I-D.ietf-teas-ietf-network-slices]. These

capabilities are provided based on a Service Level Agreement

(SLA) between the network slice costumer and the provider.

This defines the traffic flows that need to be supported when the

slice is realized. Depending on the mechanism and encoding of the

Attachment Circuit (AC), the IETF Network Slice Service may also

include information that will allow the operator's controllers to

configure the PEs to determine what customer traffic is intended for

this IETF Network Slice.

IETF Network Slice Service Requests are likely to arrive at various

times in the life of the network, and may also be modified.

3.3. Slice-Flow Aggregation Mapping

A network may be called upon to support many IETF Network

Slices, and this could present scaling challenges in the operation of

the network. In order to overcome this, the IETF Network Slices may

be aggregated into groups according to similar characteristics.

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A Slice-Flow Aggregate is a construct that comprises the traffic

flows of one or more IETF Network Slices. The mapping of IETF

Network Slices into a Slice-Flow Aggregate is a matter of local

operator policy is a function executed by the Controller. The Slice-

Flow Aggregate may be preconfigured, created on demand, or modified

dynamically.

3.4. Path Placement over Slice-Flow Aggregate Topology

Depending on the underlying network technology, a Controller may plan

the paths that the traffic flows will take through the network in

order to best deliver the SLOs for the different services in the

Slice-Flow Aggregate. The Controller performs the path placement

function on the Policy Filter Topology selected to support the Slice-

Flow Aggregate.

Note that this step may indicate the need to increase the capacity of

the underlying Policy Filter Topology or to create a new Policy

Filter Topology.

3.5. NRP Policy Installation

A Controller programs the physical network with policies for

handling the traffic flows belonging to the Slice-Flow Aggregate.

These policies instruct underlying routers how to handle traffic for a

specific Slice-Flow Aggregate: the routers correlate markers present

in the packets that belong to the Slice-Flow Aggregate. The way in

which the NRP Policy is installed in the routers and the way that the

traffic is marked is implementation specific. The NRP Policy

instantiation in the network is further described in Section 5.

3.6. Path Instantiation

Depending on the underlying network technology, a Controller

may install the forwarding state specific to the Slice-Flow Aggregate

so that traffic is routed along paths derived in the Path Placement

step described in Section 3.4. The way in which the paths are

instantiated is implementation specific.

3.7. Service Mapping

Once the network has been set up, the edge points (PEs) can be

configured to support the service. This involves telling them what

customer traffic should be mapped to which Slice-Flow Aggregate

possibly using information supplied when the IETF network slice

service was requested. It also instructs the edge points how to mark

the packets so that the network routers will know which policies and

routing instructions to apply.

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3.8. Network Slice-Flow Aggregate Relationships

The following describes the generalization relationships between the

IETF network slice and different parts of the solution as described

in Figure 1.

o A customer may request 1 or more IETF Network Slices.

o Any given Attachment Circuit (AC) may support the traffic for 1 or

more IETF Network Slice, but if there is more than one IETF Network

Slice using a single AC, the IETF Network Slice Service request must

include enough information to allow the edge nodes to demultiplex the

traffic for the different IETF Network Slices.

o By definition, multiple IETF Network Slices may be mapped to a

single Slice-Flow Aggregate. However, it is possible for a Slice-

Flow Aggregate to contain just a single IETF Network Slice.

Furthermore, a Slice-Flow Aggregate can be planned and preconfigured,

and may be "empty" having no IETF Network Slices mapped to it.

o The physical network may be filtered to multiple Policy Filter

Topologies. Each such Policy Filter Topology provides a short-cut to

planning the placement and support of Slice-Flow Aggregate by

presenting only the subset of links and nodes that meet specific

criteria. Note, however, that a network operator does not need to

derive any Policy Filter Topologies, choosing to operate directly on

the full physical network.

o It is anticipated that there may be very many IETF Network Slices

supported by a network operator over a single physical network. The

scaling mechanisms are deployment choices, but it may be that there

are no more than 1000 Slice-Flow Aggregates supported by a network,

with each Slice-Flow Aggregate supporting any number of IETF Network

Slices.

4. Network Resource Partition Modes

An NRP Policy can be used to dictate if the network resource

partitioning of the shared network resources among multiple Slice-

Flow Aggregates can be achieved:

a) in data plane only,

b) in control plane only, or

c) in both control and data planes.

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4.1. Data plane Network Resource Partition Mode

The physical network resources can be partitioned on network devices

by applying a Per Hop forwarding Behavior (PHB) onto packets that

traverse the network devices. In the Diffserv model, a Class

Selector Codepoint (CS) is carried in the packet and is used by transit nodes

to apply the PHB that determines the scheduling treatment and drop

probability for packets.

When data plane NRP mode is applied, packets need to be forwarded on

the specific NRP that supports the Slice-Flow Aggregate to ensure the

proper forwarding treatment dictated in the NRP Policy is applied

(refer to Section 5.1). In this case, a Slice-Flow Aggregate

Selector (SAS) MUST be carried in each packet to identify the Slice-

Flow Aggregate that it belongs to.

The ingress node of an NRP domain, in addition to marking packets

with a Diffserv CS, MAY also add an SAS to each Slice-Flow Aggregate

packet. The transit nodes within an NRP domain uses the SAS to

determine the

Network Resource Partition Per Hop Behavior (NRP-PHB) that is applied

to the packet (refer to Section 5.1.3 for further details). The CS

MAY be used to apply a Diffserv PHB on to the packet to allow

differentiation of traffic treatment within the same Slice-Flow

Aggregate.

When data-plane-only NRP mode is used, routers may rely on a network

state independent view of the topology to determine the best paths to

forward packets. In this case, the best path selection dictates

the forwarding path of packets to the destination. The SAS field

carried in each packet determines the specific NRP-PHB treatment

along the selected path.

For example, the Segment-Routing Flexible Algorithm

[I-D.ietf-lsr-flex-algo] may be deployed in a network to steer

packets on the IGP computed lowest cumulative delay path. An NRP

Policy may be used to allow links along the least latency path to

share its data plane resources amongst multiple Slice-Flow

Aggregates. In this case, the packets that are steered on a specific

NRP carry the SAS that enables routers (along with the Diffserv CS)

to determine the NRP-PHB to enforce on the Slice-Flow Aggregate

traffic streams.

4.2. Control Plane Network Resource Partition Mode

Multiple NRPs can be realized over the same set of physical

resources. It is possible in this case to allow the state

reservations to occur on each NRP.

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The network reservation state for a specific partition can then be

represented in a topology that can contain all or a subset of the

physical network elements (nodes and links). The logical network

resources that appear in the topology can reflect a part, whole, or

in-excess of the physical network resource capacity (e.g., when

oversubscription is desired).

For example, the physical link bandwidth can be divided into

fractions, each dedicated to an NRP that supports a Slice-Flow

Aggregate. The topology associated with the NRP supporting a Slice-

Flow Aggregate can be used by routing protocols, or by the ingress/

PCE when computing Slice-Flow Aggregate aware TE paths.

To perform network state dependent path computation in this mode

(Slice-Flow Aggregate aware TE), the resource reservation on each

link needs to be Slice-Flow Aggregate aware. Details of required IGP

extensions to support SA-TE are described in

[I-D.bestbar-lsr-slice-aware-te].

The same physical link may be member of multiple slice policies that

instantiate different NRPs. The NRP reservable or utilized bandwidth

on such a link is updated (and may be advertised) whenever new paths

are placed in the network. The NRP reservation state, in this case,

may be maintained on each device or off the device on a resource

reservation manager that holds reservation states for those links in

the network.

Multiple NRPs that support Slice-Flow Aggregates can form a group and

share the available network resources allocated to each. In this

case, a node can update the reservable bandwidth for each NRP to take

into consideration the available bandwidth from other NRPs in the

same group.

For illustration purposes, the diagram below represents bandwidth

partitioning or sharing amongst a group of NRPs. In Figure 1a, the

NRPs: NRP1, NRP2, NRP3 and NRP4 are not sharing any bandwidths

between each other. In Figure 1b, the NRPs: NRP1 and NRP2 can share

the available bandwidth portion allocated to each amongst them.

Similarly, NRP3 and NRP4 can share amongst themselves any available

bandwidth allocated to them, but they cannot share available

bandwidth allocated to NRP1 or NRP2. In both cases, the Max

Reservable Bandwidth may exceed the actual physical link resource

capacity to allow for over subscription.

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I-----------------------------I I-----------------------------I

<--NRP1-> I I-----------------I I

I---------I I I <-NRP1-> I I

I I I I I-------I I I

I---------I I I I I I I

I I I I-------I I I

<-----NRP2------> I I I I

I-----------------I I I <-NRP2-> I I

I I I I I---------I I I

I-----------------I I I I I I I

I I I I---------I I I

<---NRP3----> I I I I

I-------------I I I NRP1 + NRP2 I I

I I I I-----------------I I

I-------------I I I I

I I I I

<---NRP4----> I I-----------------I I

I-------------I I I <-NRP3-> I I

I I I I I-------I I I

I-------------I I I I I I I

I I I I-------I I I

I NRP1+NRP2+NRP3+NRP4 I I I I

I I I <-NRP4-> I I

I-----------------------------I I I---------I I I

<--Max Reservable Bandwidth--> I I I I I

I I---------I I I

I I I

I NRP3 + NRP4 I I

I-----------------I I

I NRP1+NRP2+NRP3+NRP4 I

I I

I-----------------------------I

<--Max Reservable Bandwidth-->

(a) No bandwidth sharing (b) Sharing bandwidth between

between NRPs. NRPs of the same group.

Figure 2: Bandwidth isolation/sharing among NRPs.

4.3. Data and Control Plane Network Resource Partition Mode

In order to support strict guarantees for Slice-Flow Aggregates, the

network resources can be partitioned in both the control plane and

data plane.

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The control plane partitioning allows the creation of customized

topologies per NRP that each supports a Slice-Flow Aggregate. The

ingress routers or a Path Computation Engine (PCE) can use the

customized topologies to determine optimal path placement for

specific demand flows (Slice-Flow Aggregate aware TE).

The data plane partitioning provides isolation for Slice-Flow

Aggregate traffic, and protection when resource contention occurs due

to bursts of traffic from other Slice-Flow Aggregate traffic that

traverses the same shared network resource.

5. Network Resource Partition Instantiation

A network slice can span multiple technologies and multiple

administrative domains. Depending on the network slice customer

requirements, a network slice can be differentiated from other

network slices in terms of data, control, and management planes.

The customer of a network slice service expresses their intent by specifying

requirements rather than mechanisms to realize the slice as described

in Section 3.2.

The network slice controller is fed with the network slice service

to realize it with an appropriate Network Resource Partition

Policy (NRP Policy). Multiple IETF network slices may be mapped to

the same Slice-Flow Aggregate as described in Section 3.3.

The network wide consistent NRP Policy definition is distributed to

the devices in the network as shown in Figure 1. The specification

of the network slice intent on the northbound interface of the

controller and the mechanism used to map the network slice to a

Slice-Flow Aggregate are outside the scope of this document.

5.1. NRP Policy Definition

The NRP Policy is network-wide construct that is supplied to network

devices, and may include rules that control the following:

\* Data plane specific policies: This includes the SAS, any firewall

rules or flow-spec filters, and QoS profiles associated with the

NRP Policy and any classes within it.

\* Control plane specific policies: This includes guaranteed

bandwidth, any network resource sharing amongst slice policies,

and reservation preference to prioritize any reservations of a

specific NRP over others.

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\* Topology membership policies: This defines the topology filter

policies that dictate node/link/function membership to a specific

NRP.

There is a desire for flexibility in realizing network slices to

support the services across networks consisting of implementtaions from

multiple vendors. These networks may also be grouped into disparate

domains and deploy various path control technologies and tunnel

techniques to carry traffic across the network. It is expected that

a standardized data model for NRP Policy will facilitate the

instantiation and management of the NRP on the topological elements

selected by the NRP Policy topology filter. A YANG data model for

the Network Resource Partition Policy instantiation on the controller

and network devices is described in

[I-D.bestbar-teas-yang-slice-policy].

It is also possible to distribute the NRP Policy to network devices

using several mechanisms, including protocols such as NETCONF or

RESTCONF, or exchanging it using a suitable routing protocol that

network devices participate in (such as IGP(s) or BGP). The

extensions to enable specific protocols to carry an NRP Policy

definition will be described in separate documents.

5.1.1. Network Resource Partition Data Plane Selector

A router MUST be able to identify a packet belonging to a Slice-Flow

Aggregate before it can apply the associated forwarding treatment or

NRP-PHB. One or more fields within the packet MAY be used as a SAS

to do this.

Forwarding Address Based Selector:

It is possible to assign a different forwarding address (or MPLS

forwarding label in case of MPLS network) for each Slice-Flow

Aggregate on a specific node in the network. [RFC3031] states in

Section 2.1 that: 'Some routers analyze a packet's network layer

header not merely to choose the packet's next hop, but also to

determine a packet's "precedence" or "class of service"'.

Assigning a unique forwarding address (or MPLS forwarding label)

to each Slice-Flow Aggregate allows Slice-Flow Aggregate packets

destined to a node to be distinguished by the destination address

(or MPLS forwarding label) that is carried in the packet.

This approach requires maintaining per Slice-Flow Aggregate state

for each destination in the network in both the control and data

plane and on each router in the network. For example, consider a

network slicing provider with a network composed of 'N' nodes,

each with 'K' adjacencies to its neighbors. Assuming a node can

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be reached over 'M' different Slice-Flow Aggregates, the node

assigns and advertises reachability to 'N' unique forwarding

addresses, or MPLS forwarding labels. Similarly, each node

assigns a unique forwarding address (or MPLS forwarding label) for

each of its 'K' adjacencies to enable strict steering over the

adjacency for each slice. The total number of control and data

plane states that need to be stored and programmed in a router's

forwarding is (N+K)\*M states. Hence, as 'N', 'K', and 'M'

parameters increase, this approach suffers from scalability

challenges in both the control and data planes.

Global Identifier Based Selector:

An NRP Policy MAY include a Global Identifier SAS (GISS) field as

defined in [I-D.kompella-mpls-mspl4fa] that is carried in each

packet in order to associate it to the NRP supporting a Slice-Flow

Aggregate, independent of the forwarding address or MPLS

forwarding label that is bound to the destination. Routers within

the NRP domain can use the forwarding address (or MPLS forwarding

label) to determine the forwarding next-hop(s), and use the GISS

field in the packet to infer the specific forwarding treatment

that needs to be applied on the packet.

The GISS can be carried in one of multiple fields within the

packet, depending on the dataplane used. For example, in MPLS

networks, the GISS can be encoded within an MPLS label that is

carried in the packet's MPLS label stack. All packets that belong

to the same Slice-Flow Aggregate MAY carry the same GISS in the

MPLS label stack. It is also possible to have multiple GISS's map

to the same Slice-Flow Aggregate.

The GISS can be encoded in an MPLS label and may appear in several

positions in the MPLS label stack. For example, the VPN service

label may act as a GISS to allow VPN packets to be mapped to the

Slice-Flow Aggregate. In this case, a single VPN service label

acting as a GISS MAY be allocated by all Egress PEs of a VPN.

Alternatively, multiple VPN service labels MAY act as GISS's that

map a single VPN to the same Slice-Flow Aggregate to allow for

multiple Egress PEs to allocate different VPN service labels for a

VPN. In other cases, a range of VPN service labels acting as

multiple GISS's MAY map multiple VPN traffic to a single Slice-

Flow Aggregate. An example of such deployment is shown in

Figure 3.

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SR Adj-SID: GISS (VPN service label) on PE2: 1001

9012: P1-P2

9023: P2-PE2

/-----\ /-----\ /-----\ /-----\

| PE1 | ----- | P1 | ------ | P2 |------ | PE2 |

\-----/ \-----/ \-----/ \-----/

In

packet:

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

| IP | | 9012 | | 9023 | | 1001 |

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

| Pay- | | 9023 | | 1001 | | IP |

| Load | +------+ +------+ +------+

+----- + | 1001 | | IP | | Pay- |

+------+ +------+ | Load |

| IP | | Pay- | +------+

+------+ | Load |

| Pay- | +------+

| Load |

+------+

Figure 3: GISS or VPN label at bottom of label stack.

In some cases, the position of the GISS may not be at a fixed

position in the MPLS label header. In this case, the GISS label

can show up in any position in the MPLS label stack. To enable a

transit router to identify the position of the GISS label, a

special purpose label (ideally a base special purpose label

(bSPL)) can be used to indicate the presence of a GISS in the MPLS

label stack. [I-D.kompella-mpls-mspl4fa] proposes a new bSPL

called Forwarding Actions Identifier (FAI) that is assigned to

alert of the presence of multiple actions and action data

(including the presence of the GISS). The NRP ingress boundary

node, in this case, imposes two labels: the FAI label and a

forwarding actions label that includes the GISS to identify the

Slice-Flow Aggregate packets as shown in Figure 4.

[I-D.decraene-mpls-slid-encoded-entropy-label-id] also proposes to

repurpose the ELI/EL [RFC6790] to carry the Slice Identifier in

order to minimize the size of the MPLS stack and ease incremental

deployment.

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SR Adj-SID: GISS: 1001

9012: P1-P2

9023: P2-PE2

/-----\ /-----\ /-----\ /-----\

| PE1 | ----- | P1 | ------ | P2 |------ | PE2 |

\-----/ \-----/ \-----/ \-----/

In

packet:

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

| IP | | 9012 | | 9023 | | FAI |

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

| Pay- | | 9023 | | FAI | | 1001 |

| Load | +------+ +------+ +------+

+------+ | FAI | | 1001 | | IP |

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

| 1001 | | IP | | Pay- |

+------+ +------+ | Load |

| IP | | Pay- | +------+

+------+ | Load |

| Pay- | +------+

| Load |

+------+

Figure 4: FAI and GISS label in the label stack.

When the slice is realized over an IP dataplane, the GISS can be

encoded in the IP header. For example, the GISS can be encoded in

portion of the IPv6 Flow Label field as described in

[I-D.filsfils-spring-srv6-stateless-slice-id].

5.1.2. Network Resource Partition Resource Reservation

Network resource allocation strategies for slice

policies are essential to achieve optimal placement of paths within

the network while still meeting the target SLOs.

Resource reservation allows for the managing of available bandwidth

and for prioritization of existing allocations to enable preference-

based preemption when contention on a specific network resource

arises. Sharing of a network resource's available bandwidth amongst

a group of NRPs may also be desirable. For example, a Slice-Flow

Aggregate may not be using all of the NRP reservable bandwidth; this

allows other NRPs in the same group to use the available bandwidth

resources for other Slice-Flow Aggregates.

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Congestion on shared network resources may result from sub-optimal

placement of paths in different slice policies. When this occurs,

preemption of some Slice-Flow Aggregate paths may be desirable to

alleviate congestion. A preference-based allocation scheme enables

prioritization of Slice-Flow Aggregate paths that can be preempted.

Since network characteristics and its state can change over time, the

NRP topology and its network state need to be propagated in the

network to enable ingress TE routers or Path Computation Engine

(PCEs) to perform accurate path placement based on the current state

of the NRP network resources.

5.1.3. Network Resource Partition Per Hop Behavior

In Diffserv terminology, the forwarding behavior (node level) that is assigned to

a specific class is called a Per Hop Behavior (PHB). The PHB defines

the forwarding precedence that a marked packet with a specific CS

receives in relation to other traffic on the Diffserv-aware network.

The NRP Per Hop Behavior (NRP-PHB) is the externally observable

forwarding behavior applied to a specific packet belonging to a

Slice-Flow Aggregate. The goal of an NRP-PHB is to provide a

specified amount of network resources for traffic belonging to a

specific Slice-Flow Aggregate. A single NRP may also support

multiple forwarding treatments or services that can be carried over

the same logical network.

The Slice-Flow Aggregate traffic may be identified at NRP ingress

boundary nodes by carrying a SAS to allow routers to apply a specific

forwarding treatment that guarantee the SLA(s).

With Diffserv it is possible to carry

multiple services over a single network. Packets requiring

the same forwarding treatment are marked with a Class Selector Codepoint

at domain ingress nodes. Up to eight classes or Behavior Aggregates

(BAs) may be supported for a given Forwarding Equivalence Class (FEC)

[RFC2475]. To support multiple forwarding treatments over the same

Slice-Flow Aggregate, a Slice-Flow Aggregate packet MAY also carry a

Diffserv CS to identify the specific Diffserv forwarding treatment to

be applied on the traffic belonging to the same NRP.

At transit nodes, the CS field carried inside the packets are used to

determine the specific PHB that determines the forwarding and

scheduling treatment before packets are forwarded, and in some cases,

drop probability for each packet.

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5.1.4. Network Resource Partition Topology

A key element of the NRP Policy is a customized topology that may

include the full or subset of the physical network topology. The NRP

topology could also span multiple administrative domains and/or

multiple data plane technologies.

An NRP topology can overlap or share a subset of links with another

NRP topology. A number of topology filtering policies can be defined

as part of the NRP Policy to limit the specific topology elements

that belong to the NRP. For example, a topology filtering policy can

leverage Resource Affinities as defined in [RFC2702] to include or

exclude certain links that the NRP is instantiated on in supports of

the Slice-Flow Aggregate.

The NRP Policy may also include a reference to a predefined topology

(e.g., derived from a Flexible Algorithm Definition (FAD) as defined

in [I-D.ietf-lsr-flex-algo], or Multi-Topology ID as defined

[RFC4915]. A YANG data model that covers generic topology filters is

described in [I-D.bestbar-teas-yang-topology-filter]. Also, the Path

Computation Element (PCE) Communication Protocol (PCEP) extensions to

carry topology filters are defined in [I-D.xpbs-pce-topology-filter].

5.2. Network Resource Partition Boundary

A network slice originates at the edge nodes of a network slice

provider. Traffic that is steered over the corresponding NRP

supporting a Slice-Flow Aggregate may traverse NRP capable as well as

NRP incapable interior nodes.

The network slice may encompass one or more domains administered by a

provider. For example, an organization's intranet or an ISP. The

network provider is responsible for ensuring that adequate network

resources are provisioned and/or reserved to support the SLAs offered

by the network end-to-end.

5.2.1. Network Resource Partition Edge Nodes

NRP edge nodes sit at the boundary of a network slice provider

network and receive traffic that requires steering over network

resources specific to a NRP that supports a Slice-Flow Aggregate.

These edge nodes are responsible for identifying Slice-Flow Aggregate

specific traffic flows by possibly inspecting multiple fields from

inbound packets (e.g., implementations may inspect IP traffic's

network 5-tuple in the IP and transport protocol headers) to decide

on which NRP it can be steered.

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Network slice ingress nodes may condition the inbound traffic at

network boundaries in accordance with the requirements or rules of

each service's SLAs. The requirements and rules for network slice

services are set using mechanisms which are outside the scope of this

document.

When data plane NRP mode is employed, the NRP ingress nodes are

responsible for adding a suitable SAS onto packets that belong to

specific Slice-Flow Aggregate. In addition, edge nodes MAY mark the

corresponding Diffserv CS to differentiate between different types of

traffic carried over the same Slice-Flow Aggregate.

5.2.2. Network Resource Partition Interior Nodes

An NRP interior node receives slice traffic and may be able to

identify the packets belonging to a specific Slice-Flow Aggregate by

inspecting the SAS field carried inside each packet, or by inspecting

other fields within the packet that may identify the traffic streams

that belong to a specific Slice-Flow Aggregate. For example, when

data plane NRP mode is applied, interior nodes can use the SAS

carried within the packet to apply the corresponding NRP-PHB

forwarding behavior. Nodes within the network slice provider network

may also inspect the Diffserv CS within each packet to apply a per

Diffserv class PHB within the NRP Policy, and allow differentiation

of forwarding treatments for packets forwarded over the same NRP that

supports the Slice-Flow Aggregate.

5.2.3. Network Resource Partition Incapable Nodes

Packets that belong to a Slice-Flow Aggregate may need to traverse

nodes that are NRP incapable. In this case, several options are

possible to allow the slice traffic to continue to be forwarded over

such devices and be able to resume the NRP forwarding treatment once

the traffic reaches devices that are NRP-capable.

When data plane NRP mode is employed, packets carry a SAS to allow

slice interior nodes to identify them. To enable end-to-end network

slicing, the SAS MUST be maintained in the packets as they traverse

devices within the network - including NRP incapable devices.

For example, when the SAS is an MPLS label at the bottom of the MPLS

label stack, packets can traverse over devices that are NRP incapable

without any further considerations. On the other hand when the SASL

is at the top of the MPLS label stack, packets can be bypassed (or

tunneled) over the NRP incapable devices towards the next device that

supports NRP as shown in Figure 5.

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SR Node-SID: SASL: 1001 @@@: NRP Policy enforced

1601: P1 ...: NRP Policy not enforced

1602: P2

1603: P3

1604: P4

1605: P5

@@@@@@@@@@@@@@ ........................

.

/-----\ /-----\ /-----\ .

| P1 | ----- | P2 | ----- | P3 | .

\-----/ \-----/ \-----/ .

| @@@@@@@@@@

|

/-----\ /-----\

| P4 | ------ | P5 |

\-----/ \-----/

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

| 1001 | | 1604 | | 1001 |

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

| 1605 | | 1001 | | IP |

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

| IP | | 1605 | | Pay- |

+------+ +------+ | Load |

| Pay- | | IP | +------+

| Load | +------+

+----- + | Pay- |

| Load |

+------+

Figure 5: Extending network slice over NRP incapable device(s).

5.2.4. Combining Network Resource Partition Modes

It is possible to employ a combination of the NRP modes that were

discussed in Section 4 to realize a network slice. For example, data

and control plane NRP modes can be employed in parts of a network,

while control plane NRP mode can be employed in the other parts of

the network. The path selection, in such case, can take into account

the NRP available network resources. The SAS carried within packets

allow transit nodes to enforce the corresponding NRP-PHB on the parts

of the network that apply the data plane NRP mode. The SAS can be

maintained while traffic traverses nodes that do not enforce data

plane NRP mode, and so slice PHB enforcement can resume once traffic

traverses capable nodes.

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5.3. Mapping Traffic on Slice-Flow Aggregates

The usual techniques to steer traffic onto paths can be applicable

when steering traffic over paths established for a specific Slice-

Flow Aggregate.

For example, one or more (layer-2 or layer-3) VPN services can be

directly mapped to paths established for a Slice-Flow Aggregate. In

this case, the per Virtual Routing and Forwarding (VRF) instance

traffic that arrives on the Provider Edge (PE) router over external

interfaces can be directly mapped to a specific Slice-Flow Aggregate

path. External interfaces can be further partitioned (e.g., using

VLANs) to allow mapping one or more VLANs to specific Slice-Flow

Aggregate paths.

Another option is steer traffic to specific destinations directly

over multiple slice policies. This allows traffic arriving on any

external interface and targeted to such destinations to be directly

steered over the slice paths.

A third option that can also be used is to utilize a data plane

firewall filter or classifier to enable matching of several fields in

the incoming packets to decide whether the packet belongs to a

specific Slice-Flow Aggregate. This option allows for applying a

rich set of rules to identify specific packets to be mapped to a

Slice-Flow Aggregate. However, it requires data plane network

resources to be able to perform the additional checks in hardware.

6. Path Selection and Instantiation

6.1. Applicability of Path Selection to Slice-Flow Aggregates

The path selection in the network can be network state dependent, or

network state independent as described in Section 5.1 of

[I-D.ietf-teas-rfc3272bis]. The latter is the choice commonly used

by IGPs when selecting a best path to a destination prefix, while the

former is used by ingress TE routers, or Path Computation Engines

(PCEs) when optimizing the placement of a flow based on the current

network resource utilization.

When path selection is network state dependent, the path computation

can leverage Traffic Engineering mechanisms (e.g., as defined in

[RFC2702]) to compute feasible paths taking into account the incoming

traffic demand rate and current state of network. This allows

avoiding overly utilized links, and reduces the chance of congestion

on traversed links.

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To enable TE path placement, the link state is advertised with

current reservations, thereby reflecting the available bandwidth on

each link. Such link reservations may be maintained centrally on a

network wide network resource manager, or distributed on devices (as

usually done with RSVP). TE extensions exist today to allow IGPs

(e.g., [RFC3630] and [RFC5305]), and BGP-LS [RFC7752] to advertise

such link state reservations.

When the network resource reservations are maintained for NRPs, the

link state can carry per NRP state (e.g., reservable bandwidth).

This allows path computation to take into account the specific

network resources available for an NRP. In this case, we refer to

the process of path placement and path provisioning as Slice-Flow

Aggregate aware TE.

6.2. Applicability of Path Control Technologies to Slice-Flow

Aggregates

The NRP modes described in this document are agnostic to the

technology used to setup paths that carry Slice-Flow Aggregate

traffic. One or more paths connecting the endpoints of the mapped

IETF network slices may be selected to steer the corresponding

traffic streams over the resources allocated for the NRP that

supports a Slice-Flow Aggregate.

The feasible paths can be computed using the NRP topology and network

state subject the optimization metrics and constraints.

6.2.1. RSVP-TE Based Slice-Flow Aggregate Paths

RSVP-TE [RFC3209] can be used to signal LSPs over the computed

feasible paths in order to carry the Slice-Flow Aggregate traffic.

The specific extensions to the RSVP-TE protocol required to enable

signaling of Slice-Flow Aggregate aware RSVP LSPs are outside the

scope of this document.

6.2.2. SR Based Slice-Flow Aggregate Paths

Segment Routing (SR) [RFC8402] can be used to setup and steer traffic

over the computed Slice-Flow Aggregate feasible paths.

The SR architecture defines a number of building blocks that can be

leveraged to support the realization of NRPs that support Slice-Flow

Aggregates in an SR network.

Such building blocks include:

\* SR Policy with or without Flexible Algorithm.

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\* Steering of services (e.g. VPN) traffic over SR paths

\* SR Operation, Administration and Management (OAM) and Performance

Management (PM)

SR allows a headend node to steer packets onto specific SR paths

using a Segment Routing Policy (SR Policy). The SR policy supports

various optimization objectives and constraints and can be used to

steer Slice-Flow Aggregate traffic in the SR network.

The SR policy can be instantiated with or without the IGP Flexible

Algorithm (Flex-Algorithm) feature. It may be possible to dedicate a

single SR Flex-Algorithm to compute and instantiate SR paths for one

Slice-Flow Aggregate traffic. In this case, the SR Flex-Algorithm

computed paths and Flex-Algorithm SR SIDs are not shared by other

Slice-Flow Aggregates traffic. However, to allow for better scale,

it may be desirable for multiple Slice-Flow Aggregates traffic to

share the same SR Flex-Algorithm computed paths and SIDs. Further

details on how the NRP modes presented in this document can be

realized in an SR network are discussed in

[I-D.bestbar-spring-scalable-ns], and [I-D.bestbar-lsr-spring-sa].

7. Network Resource Partition Protocol Extensions

Routing protocols may need to be extended to carry additional per NRP

link state. For example, [RFC5305], [RFC3630], and [RFC7752] are

ISIS, OSPF, and BGP protocol extensions to exchange network link

state information to allow ingress TE routers and PCE(s) to do proper

path placement in the network. The extensions required to support

network slicing may be defined in other documents, and are outside

the scope of this document.

The instantiation of an NRP Policy may need to be automated.

Multiple options are possible to facilitate automation of

distribution of an NRP Policy to capable devices.

For example, a YANG data model for the NRP Policy may be supported on

network devices and controllers. A suitable transport (e.g., NETCONF

[RFC6241], RESTCONF [RFC8040], or gRPC) may be used to enable

configuration and retrieval of state information for slice policies

on network devices. The NRP Policy YANG data model is outside the

scope of this document, and is defined in

[I-D.bestbar-teas-yang-slice-policy].

8. IANA Considerations

This document has no IANA actions.

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9. Security Considerations

The main goal of network slicing is to allow for varying treatment of

traffic from multiple different network slices that are utilizing a

common network infrastructure and to allow for different levels of

services to be provided for traffic traversing a given network

resource.

A variety of techniques may be used to achieve this, but the end

result will be that some packets may be mapped to specific resources

and may receive different (e.g., better) service treatment than

others. The mapping of network traffic to a specific NRP is

indicated primarily by the SAS, and hence an adversary may be able to

utilize resources allocated to a specific NRP by injecting packets

carrying the same SAS field in their packets.

Such theft-of-service may become a denial-of-service attack when the

modified or injected traffic depletes the resources available to

forward legitimate traffic belonging to a specific NRP.

The defense against this type of theft and denial-of-service attacks

consists of a combination of traffic conditioning at NRP domain

boundaries with security and integrity of the network infrastructure

within an NRP domain.

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