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16 March 2023

A Realization of IETF Network Slices for 5G Networks Using Current IP/

MPLS Technologies

draft-srld-teas-5g-slicing-latest

General comment 1:

Is there a clear definition of “5G network slicing” for “distributed RAN”, “Centralize RAN” and “C-RAN Cloud RAN” in this document?

Please also refer to draft-gcdrb-teas-5g-network-slice-application for these definitions.

General comment 2:

Terms such as “slice”, “5G slice” or similar terms are not clear. They shall be replaced by “5G network slice” or “IETF network slice” depends on the context.

Abstract

5G network slicing is a feature that was introduced by the 3rd Generation

Partnership Project (3GPP) in mobile networks. This feature covers

slicing requirements for all mobile domains, including the Radio

Access Network (RAN), Core Network (CN), and Transport Network (TN).

This document describes a basic IETF Network Slice realization model

in IP/MPLS networks with a focus on the Transport Network fulfilling

5G network slicing connectivity requirements. This realization model reuses

many building blocks currently commonly used in service provider

networks.

Status of This Memo

This Internet-Draft is submitted in full conformance with the

provisions of BCP 78 and BCP 79.

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1. Introduction

[I-D.ietf-teas-ietf-network-slices] defines a framework for network

slicing in the context of networks built using IETF technologies.

The IETF network slicing framework introduces the concept of a

Network Resource Partition (NRP), which is simply a collection of

resources identified in the underlay network. There could be

multiple realizations of high-level IETF Network Slice and NRP

concepts, where each realization might be optimized for the different

network slicing use cases that are listed in

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

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This document describes a basic - using only single NRP - IETF

Network Slice realization model in IP/MPLS networks, with a focus on

fulfilling 5G network slicing connectivity requirements. This IETF Network

Slice realization model leverages many building blocks currently

commonly used in service provider networks.

The reader may refer to [I-D.ietf-teas-ns-ip-mpls] for more advanced

realization models.

A brief 5G overview is provided in Appendix B for readers'

convenience. The reader may refer to [RFC6459] and [TS-23.501] for

more details about 3GPP network architectures.

2. Conventions and Definitions

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 document uses the terms defined in

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

This document makes use of the following terms:

Service Management and Orchestration (SMO): O-RAN management/

orchestration entity

Edge Transport Node (ETN): Node, under the transport domain

orchestration, that stitches the transport domain to an adjacent

domain (e.g., enterprise network, data center, peer provider

network). An ETN can be a Provider Edge (PE) or a managed

Customer Equipment (CE).

An extended list of abbreviations used in this document is provided

in Appendix A.

3. 5G Network Slicing Integration in Transport Networks

3.1. 5G Network Slicing versus Transport Network Slicing

Network slicing has a different meaning in the 3GPP mobile and

transport worlds. Hence, for the sake of precision and without

seeking to be exhaustive, this section provides a brief description

of the objectives of 5G Network Slicing and Transport Network

Slicing:

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\* 5G Network Slicing:

The objective of 5G Network Slicing is to provide dedicated

resources of the whole 5G infrastructure to some users/customers,

applications, or Public Land Mobile Networks (PLMNs) (e.g., RAN

sharing). These resources are from the Transport Network (TN),

RAN, and Core Network Functions and the underlying infrastructure.

[TS-28.530] defines 5G Network Slicing by introducing the concept

of Network Slice Subnet (NSS) to represent slices within each of

these domains: RAN, CN, and TN (i.e., RAN NSS, CN NSS, and TN

NSS). As per 3GPP specifications, an NSS can be shared or

dedicated to a single slice.

\* TN Slicing:

The objective of TN Slicing is to isolate, guarantee, or

prioritize Transport Network resources for 5G network slices. Examples of

such resources are: buffers, link capacity, or even Routing

Information Base (RIB) and Forwarding Information Base (FIB).

TN Slicing provides various degrees of sharing of transport network resources

between multiple 5G network slices. For example, the network capacity can be shared

by all 5G network slices, usually with a guaranteed minimum per slice, or

each individual 5G network slice can be allocated dedicated network capacity.

Parts of a given network may use the former, while others use the

latter. For example, shared TN resources could be provided in the

backhaul, and dedicated TN resources could be provided in the

midhaul.

There are different options to implement TN slices based upon

tools, such as VRFs (Virtual Routing and Forwarding instances) for

logical separation, QoS (Quality of Service), or TE (Traffic

Engineering).

A 5G network slicing architecture should integrate TN Slicing for

an optimal control of SLAs, however, it is possible to implement

5G Network Slicing without TN Slicing, as explained in the next

section.

TN Slicing is realized using IETF technologies, therefore,

inline with IETF Network Slices framework [I-D.ietf-teas-ietf-network-slices].

The term "IETF Network Slice" (IETF NS, or INS

in short) is described in [I-D.ietf-teas-ietf-network-slices]. In context of 5G network slicing, IETF network slices are the connectivity among various 5G network functions in RAN and CN networks such as DU, CU, UPF, AMF etc. which are realized in Transport Network.

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3.2. NF-to-NF Datapath vs. Transport Network

The 3GPP specifications loosely define the Transport Network and its

integration in RAN and CN domains: the role of the Transport Network

is to interconnect Network Functions (NFs). In other words, it is

the end-to-end datapath between two NFs. In practice, this end-to-

end datapath results often from a non-uniform architecture made up of

several segments managed by the same or distinct organizations.

This document defines the Transport Network from a service provider

scope. That is, the TN extends up to the PE or the CE if it is also

managed by the TN Orchestration. Additionally, we assume that the

Transport Network is IP, MPLS, or SRv6 capable.

3.2.1. Segmentation of the NF-to-NF Datapath

General comment: IMO it is better to start with an example (something like the picture below or similar).

We then focus on one of the IETF Network slices (e.g., INS1 between CU to UPF) and then generalize the idea with introducing NF1 and NF2 (NF1=CU, NF2=UPF).

<---------------------- 3GPP E2E Network Slice ------------------>

<-------------- RS --------------> <------- CS ------>

<- INS3 -> <- INS4 -> <- INS1 -> <- INS2 ->

..................................... .....................

: RAN : :CN :

: ....... ...... : ...... : ..... :

: |---| : : |---| : : |---| : : : : |---| : : |---| :

: |NF1| : TN3 : | DU| : TN4 : | CU| : :TN1 : : | NF| :TN2: | NF| :

: |---| : (FH): |---| : (MH): |---| : :(BH): : |---| : : |---| :

: :.....: :.....: : :....: : :...: :

:...................................: :...................:

Legend

INS: IETF Network Slice

RS: RAN Slice

CS: Core Slice

FN: Fronthaul IETF network

MN: Midhaul IETF network

BH: Backhual IETF network

DU: Distributed Unit

CU: Central Unit

The datapath between NFs may be decomposed into two types of segments

based on Orchestration domains:

\* TN Segment: The TN Segment provides connectivity between two sites

that host NFs. The realization of this segment is driven by the

IETF Network Slice Controller (NSC)(see [I-D.ietf-teas-ietf-network-slices]) and the Transport Network

Orchestrator (TNO).

\* Local Segment: The Local segment either connects two NFs within a

given site or connects a NF to the TN. In the first case, the

realization of the segment is driven by the 5G Orchestration

without any involvement of the IETF NSC or TNO. In the second

case, the realization of this segment partially relies on the IETF

NSC/TNO for the configuration of the TN-side of the segment (e.g.,

the configuration of the attachment circuit on a PE interface).

Generally, the Local Segment is a datapath local to a site with a

potential extension to reach the TN. A site can be (but not

limited to): a Data Center (DC), a Point of Presence (PoP), a

Central Office (CO), or a virtualized infrastructure in a Public

Cloud.

Note that more complex scenarios can be considered (for example,

adding an extra segmentation of TN or Local Segments). Additionally,

sites can be of different types (such as Edge, Data Center, or Public

Cloud), each with specific network design, hardware dependencies,

management interface, and diverse networking technologies (e.g.,

MPLS, SRv6, VXLAN, or L2VPN vs. L3VPN). The objective of this

section is to clarify the scope of the Transport Network rather than

to cover random technology or design combination.

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The realization of IETF Network Slices (i.e., connectivity with

performance commitments SLO) applies to the TN Segments. We consider

Local Segments as an extension of the connectivity of the RAN/CN

domain without slice-specific performances requirements by assuming

that the local infrastructure is overprovisioned and implements

traditional QoS/Scheduling logic.

Also, since the TN domain can extend either to the CE or to the PE,

we introduce the term Edge Transport Node (ETN) to denote this

boundary. The ETN is, therefore, a Transport node that stitches

Local Segments and TN Segments. Note that depending on the design,

the placement of the Service Demarcation Point (SDP)

[I-D.ietf-teas-ietf-network-slices] may or may not be enforced on the

ETN itself.

Figure 1 is a representation of the ~~end-to-end~~ datapath between NFs

including Segments and ETNs (in practice PE or a managed CE), where

applicable.

General comment on this picture:

I have some reservation on this picture and dividing it into various segments.

Question 1) What is the connectivity between NF1 and NF2?

Let’s assume this picture shows N3 interface connectivity across backhaul between CU and UPF, i.e.

NF1 = CU

NF2 = UPF

What is the connectivity between NF1 and NF2? IMO this is “IETF network slice” but the pictures shows otherwise.

We need to discuss this since the whole draft is based on the assumption in this picture.

SMO/Site TN SMO/Site

Orchestration Orchestration Orchestration

│ │ │

│ │ │

┌ ─ ─ ─ ─ ┼ ┐ ┌ ─ ─ ─│─ ─ ─ ┐ ┌ ┼ ─ ─ ─ ─ ┐

│ │ │

│ ┌──┐ ▼ │ ┌─┴─┐ ▼ ┌─┴─┐ │ ▼ ┌──┐ │

│NF1├────────┤ETN├─────────┤ETN├─────────┤NF2│

│ └──┘ │ └─┬─┘Transport└─┬─┘ │ └──┘ │

5G Site 1 Network 5G Site 2

└ ─ ─ ─ ─ ─ ┘ └ ─ ─ ─ ─ ─ ─ ┘ └ ─ ─ ─ ─ ─ ┘

└─────────┘ └─────────┘ └─────────┘

Local TN Local

Segment Segment Segment

■─────────────■

IETF Network Slice

◀─────────────────────────────────────▶

~~End-to-end~~ datapath between NF1 and NF2

Figure 1: Segmentation of the NF-NF Datapath

NFs may also be placed in the same site and interconnected via a

Local Segment. In such a case, there is no TN Segment (i.e., no

Transport Network Node is present in the datapath).

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SMO/Site

Orchestration

│

│

┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┼ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐

│

│ ┌──┐ ▼ ┌──┐ │

│NF├─────────────────────────────────────┤NF│

│ └──┘ └──┘ │

5G Site

└ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘

└─────────────────────────────────────┘

Local Segment

◀─────────────────────────────────────▶

End-to-end datapath between NFs

Figure 2: NF-to-NF Datapath within the Same Site

Figure 3 provides samples to illustrate the different realizations of

Local and TN Segments, as well the SDPs:

\* Layer 2 vs. Layer 3 Local Segment: The Local Segment can

interconnect the NF and the ETN thanks to a unique VLAN/LAN with

no intermediate routing hop (the simplest example is an NF

directly connected to a PE): A1, A2, A3, and A4. Alternatively,

the NF interfaces may be attached in a different VLAN/LAN than the

ETN interface assuming some additional local routing capabilities

between the ETN and the NF (e.g., CE, IP Fabric): B1, B2, B3, and

B4.

\* ETN: It can be either a PE (A3, A4, B3, and B4) or a CE if it is

managed by the TN Orchestration (A1, A2, B1, and B2).

\* SDP: It can be located in many places as per Section b 4.2 of

[I-D.ietf-teas-ietf-network-slices]: A1/B1 for case (1), A2/B2 for

case (2), A3/B3 for case (3), and A4/B4 for case (4).

\* Redundancy/Scale-out: No example of redundancy/multihoming/scale-

out is provided for the simplicity’s sake . Nonetheless,

each node/NF can be represented by multiple instances (e.g.,

multiple containers in a cloud architecture).

Local Segment Transport Network

◀───────────────────────────▶◀─────────────────── ─ ─ ─ ─

┌─────────────────────┐ ┌─────────────────── ─ ─ ─ ┐

│ Site Type A1 │ │

│ ┌────┐ │ ┌─■──┐ ┌────┐ . │

│ │ NF ├───────────────────┤ CE ├────┤ PE ├─────╱ ╲

│ └────┘ │ └─┬──┘ └────┘ ; : │

└─────────────────────┘ │ ; :

┌─────────────────────┐ │ ; : │

│ Site Type A2 │ │ │ │

│ ┌────┐ │ ┌────┤ ┌────┐ │ │ │

│ │ NF ├────────────────┤ CE ■───────┤ PE ├───│ │

│ └────┘ │ └────┤ └────┘ ; : │

└─────────────────────┘ │ ; ┌───┐ :

┌─────────────────────┐ │ │ │ P │ │ │

│ Site Type A3 │ │ │ └───┘ │

│ ┌────┐ │ ├────┐ │ │ │

│ │ NF ├─────────────────────■ PE ├──────────│ │

│ └────┘ │ ├────┘ │ │ │

└─────────────────────┘ │ │ │

┌─────────────────────┐ │ │ │ │

│ Site Type A4 │ │ ; :

│ ┌────┐ │ ┌─■──┐ ; : │

│ │ NF ├───────────────────┤ PE ├───────────│ ┌───┐ │

│ └────┘ │ └─┬──┘ │ │ P │ │ │

└─────────────────────┘ │ │ └───┘ │

┌─────────────────────┐ │ │ │ │

│ Site Type B1.───. │ │ │ │

│ ,' `. │ │ │ │ │

│ ; Local :│ │ │ │

│ ┌────┐ │ Routing ││ ┌─■──┐ ┌────┐ │ │ │

│ │ NF ├───┤ managed ├─────┤ CE ├────┤ PE ├─┤ │

│ └────┘ : by SMO ;│ └─┬──┘ └────┘ │ │ │

│ ╲ ╱ │ │ │ │

│ `. ,' │ │ │ ┌───┐ │ │

│ `─' │ │ │ │ P │ │

└─────────────────────┘ │ │ └───┘ │ │

┌─────────────────────┐ │ │ │

│ Site Type B2.───. │ │ │ │ │

│ ,' `. │ │ │ │

│ ; Local :│ │ │ │ │

│ ┌────┐ │ Routing ││ ┌────┤ ┌────┐ │ │

│ │ NF ├───┤ managed ├──┤ CE ■───────┤ PE ├─┤ │ │

│ └────┘ : by SMO ;│ └────┤ └────┘ │ │

│ ╲ ╱│ │ │ │ │

│ `. ,' │ │ │ ┌───┐ │

│ `─' │ │ │ │ P │ │ │

└─────────────────────┘ │ │ └───┘ │

┌─────────────────────┐ │ │ │ │

│ Site Type B3.───. │ │ : ;

│ ,' `. │ │ : ; │

│ ; Local :│ │ │ │

│ ┌────┐ │ Routing ││ ├────┐ │ │ │

│ │ NF ├───┤ managed ├───────■ PE ├──────────│ │

│ └────┘ : by SMO ;│ ├────┘ │ │ │

│ ╲ ╱ │ │ │ │

│ `. ,' │ │ │ ┌───┐ │ │

│ `─' │ │ │ │ P │ │

└─────────────────────┘ │ : └───┘ ; │

┌─────────────────────┐ │ : ;

│ Site Type B4.───. │ │ │ │ │

│ ,' `. │ │ │ │

│ ; Local :│ │ │ │ │

│ ┌────┐ │ Routing ││ ┌─■──┐ : ;

│ │ NF │───┤ managed ├─────┤ PE ├──────────────: ; │

│ └────┘ : by SMO ;│ └─┬──┘ │ │

│ ╲ ╱ │ │ : ; │

│ `. ,' │ │ ╲ ╱

│ `─' │ │ ' │

└─────────────────────┘ └──────────────────── ─ ─ ─

├───────────────┤

ETN

■ Service Demarcation Point

Figure 3: Examples of various combinations of Local Segments,

ETN, and SDP

3.2.2. Orchestration of Local Segment Terminations at ETNs

The interconnection between a 5G site and the Transport Network is

made up of shared networking resources. More precisely, the Local

Segment terminates to an interface of the ETN, which must be

configured with consistent dataplane network information (e.g., VLAN-

ID and IP addresses/subnets). Hence, the realization of this

interconnection requires a coordination between the Service

Management and Orchestration (SMO) and the Transport Orchestration

(IETF NSC). In this document, and aligned with [RFC8969], we assume

that this coordination is based upon standard YANG data models and

APIs (more details in further sections).

General comment on Figure 4

how does this example relate to framework picture below? i.e. what is “Customer higher level” and “network controller”? and how they relate to TN and SMO Orchestration?

Also what is the definition of IETF Network Slice in figure-4?

Where are SDPs?

Table

Description automatically generated with low confidence

Figure 4 is a basic example of a Layer 3 CE-PE link realization with

shared network resources, such as VLAN-ID and IP prefixes, which must

be passed between Orchestrators via the Network Slice Service

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Interface ([I-D.ietf-teas-ietf-network-slice-nbi-yang]) or an

Attachement Circuit Service Interface

([I-D.boro-opsawg-teas-attachment-circuit]).

Datapath network resources (e.g., VLAN-IDs or IP

prefixes) exchanged via SMO-NSC interface (NSI)

┌ ─ ─ ─ ─ ─ ─ ┐ ┌ ─ ─ ─ ─ ─ ─ ┐

TN

│ │ │Orchestration│

SMO / Site IETF APIs/DM

│Orchestration│ ◀────────────▶ │ IETF NSC │

─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

│ │

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▼ ▼

│ ┌──┐ ┌──┐.1│ 192.0.2.0/31 │.0┌──┐ │

│NF├──────┤CE├──────────────────────────┤PE│

│ └──┘ └──┘ │ VLAN 100 │ └──┘ │

Site

│ │ │ TN │

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Local Segment

Figure 4: An Example of Data Exchange

Note that the allocation of these resources (e.g., VLAN-IDs or IP

prefixes) can be either managed by the SMO or the Transport Network.

In other words, the initial SMO request for the creation of a new

IETF Network Slice on a given 5G site may or may not include all

network resources. In the latter case, this information is exchanged

in a second step.

3.3. 5G Network Slice to IETF Network Slice Mapping

There are multiple options to map a 5G network slice to IETF Network

Slices:

\* 1 to N: A single 5G Network Slice can map to multiple IETF Network

Slices (1 to N). One example of such a case is the separation of

the 5G Control Plane and User Plane: this use case is represented

in Figure 5 where a slice (EMBB) is deployed with a separation of

User Plane and Control Plane at the TN.

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\* N to 1: Multiple 5G Network Slices may rely upon the same IETF

Network Slice (i.e., in [TS-28.530] semantic, two RAN/CN NSSes

uses a shared TN NSS). In such a case, the Service Level

Agreement (SLA) differentiation of slices would be entirely

controlled at 5G Control Plane, for example, with appropriate

placement strategies: this use case is represented in Figure 6,

where a User Plane Function (UPF) for the URLLC slice is

instantiated at the edge cloud close to the gNB CU-UP User Plane

for better latency/jitter control, while the 5G Control Plane and

the UPF for EMBB slice are instantiated in the regional cloud.

\* N to M: The 5G to IETF Network Slice mapping combines both

approaches with a mix of shared and dedicated associations.

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│ 5G Slice eMBB │

│ ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐ │

┌─────┐ N3 ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐ N3 ┌─────┐

│ │CU-UP├─────── IETF Network Slice UP\_eMBB ───────┤ UPF │ │

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│ │ │ │

┌─────┐ N2 ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐ N2 ┌─────┐

│ │CU-CP├─────── IETF Network Slice CP ───────┤ AMF │ │

└─────┘ └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘ └─────┘

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Transport Network

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Figure 5: 1 (5G Slice) to N (IETF Network Slice) Mapping

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Edge Cloud

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│ │UPF\_URLLC│ │

└─────┬───┘

└ ─ ─ ─ │ ─ ─ ┘

┌ ─ ─ ─ ─ ─ ─ ─ ┐ ┌ ─ ─ ─ │ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

┌ ─ ─ ┴ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ │ ┌ ─ ─ ─ ─ ─ ─ ─

│ Cell Site │ │ │ │

│ │ │ Regional

│ ┌───────────┐ │ │ │ Cloud │

│CU-UP\_URLLC├─────┤ │ │ ┌──────────┐

│ └───────────┘ │ │ IETF Network ├─────┤ 5GC CP │ │

│ Slice ALL │ │ └──────────┘

│ ┌───────────┐ │ │ │ │

│CU-UP\_eMBB ├─────┤ │ │ ┌──────────┐

│ └───────────┘ │ │ ├─────┤ UPF\_eMBB │ │

─ ─ ─ ─ ─ ─ ─ ─ │ │ │ └──────────┘

│ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘ │

│ └ ─ ─ ─ ─ ─ ─ ─

│ Transport Network

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Figure 6: N (5G Slice) to 1 (IETF Network Slice) Mapping

Note that the actual realization of the mapping depends on several

factors, such as the actual business cases, the NF vendor

capabilities, the NF vendor reference designs, as well as service

provider or even legal requirements.

Specifically, the actual mapping is a design choice of service

operators that may be a function of number of instantiated

slices, requested services, or local engineering capabilities and other

guidelines. However, operators should carefully consider means to

ease slice migration strategies (e.g., move from 1-to-1 mapping to N-

to-1).

3.4. First 5G Slice versus Subsequent Slices

A 5G Network Slice is fully functional with both 5G Control Plane and

User Plane capabilities (i.e., dedicated NF functions or contexts).

In this regard, the creation of the "first slice" is subject to a

specific logic since it must deploy both CP and UP. This is not the

case for the deployment of subsequent slices because they can share

the same CP of the first slice, while instantiating dedicated UP. An

example of an incremental deployment is depicted in Figure 7.

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At the time of writing (2023), Section 6.2 of [NG.113] specifies that

the eMBB slice (SST=1 and no SD) should be supported globally. This

5G network slice would be the first slice in any 5G deployment.

Note that the actual realization of the mapping depends on several

factors such as the actual business cases, the NF vendor

capabilities, the NF vendor reference designs, as well as service

providers or even legal requirements.

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│ 1 ┌─────┐ ┌──────────────────────────┐ │ ┌─────┐ │

s S │NF-CP├──────┤ CP IETF NS (INS-1) ├──────┤NF-CP│

│ t l └─────┘ └──────────────────────────┘ │ └─────┘ │

i │

│ 5 c ┌─────┐ ┌──────────────────────────┐ │ ┌─────┐ │

G e │NF-UP├──────┤ UP IETF NS (INS-2) ├──────┤NF-UP│

│ └─────┘ └──────────────────────────┘ │ └─────┘ │

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│ Transport Network

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Deployment of first 5G slice

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┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

│ 1 ┌─────┐ ┌──────────────────────────┐ │ ┌─────┐ │

s S │NF-CP├──────┤ CP IETF NS (INS-1) ├──────┤NF-CP│

│ t l └─────┘ └──────────────────────────┘ │ └─────┘ │

i │

│ 5 c ┌─────┐ ┌──────────────────────────┐ │ ┌─────┐ │

G e │NF-UP├──────┤ UP IETF NS (INS-2) ├──────┤NF-UP│

│ └─────┘ └──────────────────────────┘ │ └─────┘ │

─ ─ ─ ─ ─ ─ ─ ─ ─ ┼ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

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2 │

│ n S ┌──────┐ │ ┌──────────────────────────┐ ┌──────┐ │

d l │NF-UP2├─────┤ UP2 IETF NS (INS-3)├─────┤NF-UP2│

│ i └──────┘ │ └──────────────────────────┘ └──────┘ │

5 c │

│ G e │ │

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Transport Network │

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Deployment of additional 5G slice with shared Control Plane

Figure 7: First and Subsequent Slice Deployment

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4. Overview of IETF Network Slice Realization Models in the context of 5G Network Slice

[I-D.ietf-teas-ietf-network-slices] introduces the concept of the

Network Resource Partition (NRP), which is defined as a collection of

resources identified in the underlay network. In the basic

realization model described in this document, a single NRP is used

with the following characteristics:

\* L2VPN/L3VPN service instances for logical separation:

The L2VPN/L3VPN service might be used to realize the IETF network slices. This realization model of transport for 5G network slices assumes Layer-3

delivery for midhaul and backhaul networks, and a

Layer 2 or Layer 3 (eCPRI supports both) delivery model for

fronthaul connections. L2VPN/L3VPN service instances might be

used as basic form of logical separation. Further, using VPN

service instances results in additional outer header (as packets

are encapsulated/decapsulated at the nodes performing PE

functions) providing clean discrimination between 5G QoS and TN

QoS, as explained in Section 5.

\* Fine-grained resource control at the ETN:

This is sometimes called 'admission control' or 'traffic

conditioning'. The main purpose is the enforcement of the

bandwidth contract for the slice right at the edge of the

transport domain where the traffic is handed-off between the

transport domain and the 5G domains (i.e., RAN/Core).

The toolset used here is granular ingress policing (rate limiting)

to enforce contracted bandwidths per slice and, potentially, per

traffic class within the slice. Out-of-contract traffic might be

immediately dropped, or marked as high drop probability traffic,

which is more likely to be dropped somewhere at the transit if

congestion occurs. In the egress direction at the edge of the

transport domain, hierarchical schedulers/shapers can be deployed,

providing guaranteed rates per slice, as well as guarantees per

traffic class within the slice.

In the managed CE use cases (use cases A1, A2, B1, and B2 depicted

in Figure 7) edge admission control could be distributed between

CE and PE, where one part of the edge admission control is

implemented on CE, and another part of the edge admission control

is implemented on PE.

\* Coarse resource control at the TN transit (non-attachment

circuits) links of the transport domain, using a single NRP,

spanning the entire TN domain. Transit nodes do not maintain any

state of individual slices. Instead, only a flat (non-

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hierarchical) QoS model is used on transit links with up to 8

traffic classes. At the transport domain edge, traffic-flows from

multiple slice services are mapped to the limited number of

traffic classes used on transit links.

\* Capacity planning/management for efficient usage of TN edge and TN

transit resources:

The role of capacity management is to ensure the transport

capacity can be utilized without causing any bottlenecks. The

toolset used here can range from careful network planning, to

ensure more less equal traffic distribution (i.e., equal cost load

balancing), to advanced traffic engineering techniques, with or

without bandwidth reservations, to force more consistent load

distribution even in non-ECMP friendly network topologies.

┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐

┌──────────┐ base NRP ┌──────────┐

│ ETN │ │ ETN │

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■◀───┐│ │ IETF Network Slice 1 │ │┌────▶■ │

│ │ │ │ ┌─────┐ ┌─────┐ │ │ │

■◀───┤│ │ │ P │ │ P │ │ │├────▶■ │

├ ┼ ─ ─├────▶□◀──────▶□◀───▶□◀──────▶□────▶□◀──────▶□◀───┤─ ─ ─│─

■◀───┤│ │ │ │ │ │ │ │├────▶■ │

│ │ │ │ └─────┘ └─────┘ │ │ │

■◀───┘│ │ IETF Network Slice 2 │ │└────▶■ │

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■ fine-grained QoS (dedicated resources per IETF NS)

□ coarse QoS, with resources shared by all IETF NSes

Figure 8: Resource Allocation in with single NRP Slicing Model

The 5G control plane relies upon 32-bit identifier called S-NSSAI (Single Network Slice

Selection Assistance Information) as 5G network slice

identification. The S-NSSAI is not visible to the transport domain,

so instead, 5G functions can expose the 5G network slices to the transport

domain by mapping it to explicit L2/L3 identifiers such as VLAN-ID, IP

addresses, or Differentiated Services Code Point (DSCP) as documented

in [I-D.gcdrb-teas-5g-network-slice-application].

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4.1. IETF Network Slice Mapping using VLAN Hand-off

In this option, the IETF Network Slice, fulfilling connectivity

between SDPS of NFs , is realized by L2 or L3 services and the identification of the 5G network slice is mapped

by a VLAN, or double VLANs (commonly known as QinQ). Each VLAN can

represent a distinct logical interface on the attachment circuits,

hence it provides the possibility to place these logical interfaces

in distinct L2 or L3 service instances and implement separation

between 5G network slices via service instances. Since the 5G interfaces are IP

based interfaces (the only exception could be the F2 fronthaul-

interface, where eCPRI with Ethernet encapsulation is used), this

VLAN is typically not transported across the TN domain. Typically,

it has only local significance at a particular SDP. For

simplification it is recommended to rely on a same VLAN identifier

for all ACs, when possible. However, SDPs for a same IETF network slice at

different locations may also use different VLAN values. Therefore, a

VLAN to IETF Network Slice mapping table MUST be maintained for each

AC, and the VLAN allocation MUST be coordinated between TN

orchestration and local segment orchestration. Thus, while VLAN

hand-off is simple from the NF point of view, it adds complexity due

to the requirement of maintaining mapping tables for each SDP.

VLANs representing slices VLANs representing slices

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│ ●───────●■ │ │ ■●───────● ●───────● │

│ NF1 ●───────●■ ETN│ │ETN ■●───────●L2/L3●───────● NF2 │

│ ●───────●■ │ │ ■●───────● ●───────● │

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└────────┘└────────────────────┘└─────────────────────┘

Local TN Local

Segment Segment Segment

<---------------IETF Network Slice ----------------->

● – logical interface represented by VLAN on physical interface

■ - Service Demarcation Point

Figure 9: 5G Network Slice with VLAN Hand-off

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4.2. IETF Network Slice Mapping using IP Hand-off

In this option, the IETF network slices in the transport domain are instantiated

by IP tunnels (for example, IPsec, GTP-U tunnel) established between

NFs. The transport for a single 5G network slice is constructed with

multiple such tunnels, since a typical 5G network slice contains many NFs -

especially DUs and CUs. If a shared NF (i.e., an NF that serves

multiple slices, for example a shared DU) is deployed, multiple

tunnels from shared NF are established, each tunnel representing a

single slice. As opposed to the VLAN hand-off case, there is no

logical interface representing slice on the PE, hence all slices are

handled within single service instance. Similar to

to the VLAN hand-off case, a mapping table tracking IP to IETF

Network Slice mapping is required on NF1 and NF2.

Tunnels representing slices

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│ ○════════════■════════════════■══════════════════════════○ │

│ NF ├───────┤ ETN │ │ ETN ├───────┤L2/L3├───────┤ NF │

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Local TN Local

Segment Segment Segment

<---------------IETF Network Slice ----------------->

○ – tunnel (IPsec, GTP-U, ...) termination point

■ - Service Demarcation Point

Figure 10: 5G Slice with IP Hand-off

The mapping table can be simplified if for example IPv6 addressing is used

to address NFs. The identification of the 5G network slice (which is 32-bit number called S-NSSAI) can be embedded into the 128-bit IPv6 address and make IP to 5G network slice mapping table unnecessary.

~~is a 128-bit long field, while the~~

~~S-NSSAI is a 32-bit field: Slice/Service Type (SST): 8 bits, Slice~~

~~Differentiator (SD): 24 bits. 32 bits, out of 128 bits of the IPv6~~

~~address, may be used to encode the S-NSSAI, which makes an IP to~~

~~Slice mapping table unnecessary~~. This mapping is simply a local

allocation method to allocate IPv6 addresses to NF loopbacks, without

redefining IPv6 semantic. Different IPv6 address allocation schemes

following this mapping approach may be used, with one example

allocation showed in Figure 11.

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Note that this addressing scheme is local to a node; intermediary

nodes are not required to associate any additional semantic with IPv6

address.

One benefit of embedding the S-NSSAI in the IPv6 address is providing

a very easy way of identifying the packet as belonging to given

S-NSSAI at any place in the transport domain. This might be used,

for example, to selectively enable per S-NSSAI monitoring, or any

other per S-NSSAI handling, if required.

NF specific reserved

(not slice specific) for S-NSSAI

◀───────────────────────────▶ ◀───────▶

┌────┬────┬────┬────┬────┬────┬────┬────┐

│2001:0db8:xxxx:xxxx:xxxx:xxxx:ttdd:dddd│

└─────────┴─────────┴─────────┴─────────┘

tt - SST (8 bits)

dddddd - SD (24 bits)

Figure 11: An Example of S-NSSAI embedded into IPv6

In the example shown in Figure 11, the most significant 96 bits of

the IPv6 address are unique to NF, but do not carry any slice-

specific information, while the least significant 32 bits are used to

embed the S-NSSAI information. The 96-bit part of the address may be

further divided based, for example, on the geographical location or

the DC identification.

Figure 12 shows an example of 5G network slice deployment, where S-NSSAI is

embedded into IPv6 addresses used by NFs. NF-A has a set of tunnel

termination points, with unique per-slice IP addresses allocated from

the 2001:db8::a:0:0/96 prefix, while NF-B uses set of tunnel

termination points with per-slice IP addresses allocated from

2001:db8::b:0:0/96. This example shows two slices: eMBB (SST=1) and

MIoT (SST=3). Therefore, for eMBB the tunnel IP addresses are auto-

derived (without the need for a mapping table) as {2001:db8::a:100:0,

2001:db8::b:100:0}, while for MIoT (SST=3) tunnel uses

{2001:db8::a:300:0, 2001:db8::b:300:0}.

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2001:db8::a:0:0/96 (NF-A) 2001:db8::b:0:0/96 (NF-B)

2001:db8::a:100:0/128 ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ 2001:db8::b:100:0/128

│ │ │

┌────▼─┐ eMBB (SST=1) │ Transport ┌─▼────┐

│ ○═══════════════════■════════════════■═══════════════════○ │

│ NF-A │ │ │ │ NF-B │

│ ○═══════════════════■════════════════■═══════════════════○ │

└────▲─┘ MIoT (SST=3) │ Network └─▲────┘

│ │ │

2001:db8::a:300:0/128 └ ─ ─ ─ ─ ─ ─ ─ ─ ─ 2001:db8::b:300:0/128

└──────────────────┘└────────────────┘└──────────────────┘

Local Segment TN Segment Local Segment

○ – tunnel (IPsec, GTP-U, ...) termination point

■ - Service Demarcation Point

<------------------IETF Network Slice ------------------->

Figure 12: Deployment example with S-NSSAI embedded into IPv6

4.3. IETF Network Slice Mapping using MPLS Label Hand-off

In this option, an MPLS label is identification of the 5G network slice and attached to the traffic from NF1 to NF2, i.e., the service instances representing different 5G network slices

are created directly on the NF, or within the cloud infrastructure

hosting the NF, and attached to the TN domain. Therefore, the packet

is MPLS encapsulated outside the TN domain with native MPLS

encapsulation, or MPLSoUDP encapsulation, depending on the capability

of the NF or cloud infrastructure. ~~, with the service label depicting~~

~~the slice.~~

There are three major methods (based upon Section 10 of [RFC4364])

for interconnecting multiple service domains:

\* Option 10A (Section 4.3.1): VRF-to-VRF connections.

\* Option 10B (Section 4.3.2): redistribution of labeled VPN routes

with next-hop change at domain boundaries.

\* Option 10C (Section 4.3.3): redistribution of labeled VPN routes

without next-hop change + redistribution of labeled transport

routes with next-hop change at domain boundaries.

4.3.1. Option 10A

In this option, MPLS is not used in VRF-to-VRF hand-offs, since

services are terminated at the boundary of each domain, and VLAN

hand-off is in place between the domains. Thus, this option is the

same as VLAN hand-off, described in Section 4.1.

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4.3.2. Option 10B

In this option, L3VPN service instances for different IETF Network

Slice Services are instantiated outside the TN domain. These L3VPN

service instances could be instantiated either on the compute,

hosting mobile network functions (Figure 13, left hand side), or

within the cloud infrastructure itself (e.g., on the top of the rack

or leaf switch within cloud IP fabric (Figure 13, right hand side)).

On the local segment connected to ETN packets are already MPLS

encapsulated (or MPLSoUDP encapsulated, if cloud or compute

infrastructure doesn't support native MPLS encapsulation).

Therefore, the PE uses neither a VLAN nor an IP address for slice

identification at the SDP, but instead uses the MPLS label.

◁────── ◁────── ◁──────

BGP VPN BGP VPN BGP VPN

COM=1, L=A" COM=1, L=A' COM=1, L=A

COM=2, L=B" COM=2, L=B' COM=2, L=B

COM=3, L=C" COM=3, L=C' COM=3, L=C

◁─────────────▷◁────────────▷◁─────────────▷

nhs nhs nhs nhs

VLANs

service instances service instances representing

representing slices representing slices slices

│ ┌ ─ ─ ─ ─ ─ ─ ─ ─ │ │

│ Transport │ │ │

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│ ◙ │ │■ │ │ ■│ │ ◙………………●───────● │

│NF1 ◙ ├───────┤■ ETN│ │ETN ■├───────┤ ◙………………●───────● NF2 │

│ ◙ │ │■ │ │ ■│ │ ◙………………●───────● │

└──────┘ └┬────┘ └─────┘ └────────┘ └──────┘

Network │ L2/L3

└ ─ ─ ─ ─ ─ ─ ─ ─

└────────┘└──────────────────┘└───────────────────────┘

Local TN Local

Segment Segment Segment

<------------------IETF Network Slice ------------------->

● – logical interface represented by VLAN on physical interface

◙ - service instances (with unique MPLS label)

■ - Service Demarcation Point

Figure 13: MPLS Hand-off: Option B

MPLS labels are allocated dynamically, especially in Option 10B

deployments, where at the domain boundaries service prefixes are

reflected with next-hop self, and new label is dynamically allocated,

as visible in Figure 13 (e.g., labels A, A' and A" for the first

depicted slice). Therefore, for any slice-specific per hop behavior

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at the TN domain edge, the ETN must be able to determine which label

represents which slice. In the BGP control plane, when exchanging

service prefixes over local segment, each slice might be represented

by a unique BGP community, so tracking label assignment to the slice

is possible. For example, in Figure 13, for the slice identified

with COM=1, ETN advertises a dynamically allocated label A". Since,

based on the community, the label to slice association is known, ETN

can use this dynamically allocated label A" to identify incoming

packets as belonging to slice 1, and execute appropriate edge per hop

behavior.

It is worth noting that slice identification in the BGP control plane

might be at the prefix granularity. In extreme case, each prefix can

have different community representing a different slice. Depending

on the business requirements, each slice could be represented by a

different service instance, as outlined in Figure 13. In that case,

the route target extended community might be used as slice

differentiator. In another deployment, all prefixes (representing

different slices) might be handled by single 'mobile' service

instance, and some other BGP attribute (e.g., a standard community)

might be used for slice differentiation. Or there could be a

deployment that groups multiple slices together into a single service

instance, resulting in a handful of service instances. In any case,

fine-grained per-hop behavior at the edge of TN domain is possible.

4.3.3. Option 10C

\*\_for further study\_\*

5. QoS Mapping Models

The resources are managed via various QoS policies deployed in the

network. QoS mapping models to support 5G slicing connectivity

implemented over packet switched transport uses two layers of QoS

that are discussed in the following subsections.

5.1. 5G QoS Layer

QoS treatment is indicated in the 5G QoS layer by the 5QI (5G QoS

indicator), as defined in [TS-23.501]. A 5QI is an identifier (ID)

that is used as a reference to 5G QoS characteristics (e.g.,

scheduling weights, admission thresholds, queue management

thresholds, and link layer protocol configuration) in the RAN domain.

Given that 5QI applies to the RAN domain, it is not visible to the TN

domain. Therefore, if 5QI-aware treatment is desired in the TN

domain as well, 5G network functions might set DSCP with a value

representing 5QI so that differentiated treatment can implemented in

TN domain as well. Based on these DSCP values, at SDP of each TN

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segment used to construct transport for given 5G slice, very granular

QoS enforcement might be implemented.

The mapping between 5QI and DSCP is out of scope for this document.

Mapping recommendations are documented, e.g., in

[I-D.henry-tsvwg-diffserv-to-qci].

Each slice service might have flows with multiple 5QIs, thus there

could be many different 5QIs being deployed. 5QIs (or, more

precisely, corresponding DSCP values) are visible to the TN domain at

SDP (i.e., at the edge of the TN domain).

In this document, this layer of QoS will be referred as '5G QoS

Class' ('5G QoS' in short), or '5G DSCP'.

5.2. TN QoS Layer

Control of the TN resources on transit links, as well as traffic

scheduling/prioritization on transit links, is based on a flat (non-

hierarchical) QoS model in this IETF Network Slice realization. That

is, IETF Network Slices are assigned dedicated resources (e.g., QoS

queues) at the edge of the TN domain (at SDPs), while all IETF

Network Slices are sharing resources (sharing QoS queues) on the

transit links of the TN domain. Typical router hardware can support

up to 8 traffic queues per port, therefore the architecture assumes 8

traffic queues per port support in general.

At this layer, QoS treatment is indicated by QoS indicator specific

to the encapsulation used in the TN domain, and it could be DSCP or

MPLS Traffic Class (TC). This layer of QoS will be referred as 'TN

QoS Class', or 'TN QoS' for short, in this document.

5.3. QoS Realization Models

While 5QI might be exposed to the TN domain, via the DSCP value

(corresponding to specific 5QI value) set in the IP packet generated

by NFs, some 5G deployments might use 5QI in the RAN domain only,

without requesting per 5QI differentiated treatment from the TN

domain. This can be due to an NF limitation (e.g., no capability to

set DSCP), or it might simply depend on the overall slicing

deployment model. The O-RAN Alliance, for example, defines a phased

approach to the slicing, with initial phases utilizing only per

slice, but not per 5QI, differentiated treatment in the TN domain

(Annex F of [O-RAN.WG9.XPSAAS]).

Therefore, from a QoS perspective, the 5G slicing connectivity

realization architecture defines two high-level realization models

for slicing in the transport domain: a 5QI-unaware model and a 5QI-

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aware model. Both slicing models in the transport domain could be

used concurrently within the same 5G slice. For example, the TN

segment for 5G midhaul (F1-U interface) might be 5QI-aware, while at

the same time the TN segment for 5G backhaul (N3 interface) might

follow the 5QI-unaware model.

These models are further elaborated in the following two subsections.

5.4. 5QI-unaware Model

In 5QI-unaware mode, the DSCP values in the packets received from NF

at SDP are ignored. In the TN domain, there is no QoS

differentiation at the 5G QoS Class level. The entire IETF Network

Slice is mapped to single TN QoS Class, and, therefore, to a single

QoS queue on the routers in the TN domain. With a small number of

deployed 5G slices (for example only two 5G slices: eMBB and MIoT),

it is possible to dedicate a separate QoS queue for each slice on

transit routers. However, with introduction of private/enterprises

slices, as the number of 5G slices (and thus corresponding IETF

Network Slices) increases, a single QoS queue on transit links serves

multiple slices with similar characteristics. QoS enforcement on

transit links is fully coarse (single NRP, sharing resources among

all IETF Network Slices), as displayed in Figure 14.

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┏━━━━━━━━━━━━━━━━━┓ ETN │

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃

┃ SDP ┃ ┏━━━━━━━━━━━━━━━━━━━━━━━━━━━┫

┃│ ┌──────────┐ │┃ ┃ Transit link ┃

┃ │IETF NS 1 ├────────────┐ ┃┌────────────────────────┐ ┃

┃│ └──────────┘ │┃ ├─────▶ TN QoS Class 1 │ ┃

┃ ─ ─ ─ ─ ─ ─ ─ ─ ┃ │ ┃└────────────────────────┘ ┃

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ │ ┃┌────────────────────────┐ ┃

┃ SDP ┃ │ ┃│ TN QoS Class 2 │ ┃

┃│ ┌──────────┐ │┃ │ ┃└────────────────────────┘ ┃

┃ │IETF NS 2 ├────────┐ │ ┃┌────────────────────────┐ ┃

┃│ └──────────┘ │┃ │ │ ┃│ TN QoS Class 3 │ ┃

┃ ─ ─ ─ ─ ─ ─ ─ ─ ┃ │ │ ┃└────────────────────────┘ ┃

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ │ │ ┃┌────────────────────────┐ ┃

┃ SDP ┃ └─────────▶ TN QoS Class 4 │ ┃

┃│ ┌──────────┐ │┃ │ ┃└────────────────────────┘ ┃

┃ │IETF NS 3 ├────────────┘ ┃┌────────────────────────┐ ┃

┃│ └──────────┘ │┃ ┌─────────▶ TN QoS Class 5 │ ┃

┃ ─ ─ ─ ─ ─ ─ ─ ─ ┃ │ ┃└────────────────────────┘ ┃

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ │ ┃┌────────────────────────┐ ┃

┃ SDP ┃ │ ┃│ TN QoS Class 6 │ ┃

┃│ ┌──────────┐ │┃ │ ┃└────────────────────────┘ ┃

┃ │IETF NS 4 ├────────┤ ┃┌────────────────────────┐ ┃

┃│ └──────────┘ │┃ │ ┃│ TN QoS Class 7 │ ┃

┃ ─ ─ ─ ─ ─ ─ ─ ─ ┃ │ ┃└────────────────────────┘ ┃

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ │ ┃┌────────────────────────┐ ┃

┃ SDP ┃ │ ┃│ TN QoS Class 8 │ ┃

┃│ ┌──────────┐ │┃ │ ┃└────────────────────────┘ ┃

┃ │IETF NS 5 ├────────┘ ┃ Max 8 TN Classes ┃

┃│ └──────────┘ │┃ ┗━━━━━━━━━━━━━━━━━━━━━━━━━━━┛

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Fine-grained QoS enforcement Coarse QoS enforcement

(dedicated resources per (resources shared by

IETF Network Slice) multiple IETF NSs)

Figure 14: Slice to TN QoS Mapping (5QI-unaware Model)

When the IP traffic is handed over at the SDP from the local segment

to the TN domain, the PE encapsulates the traffic into MPLS (if MPLS

transport is used in the TN domain), or IPv6 - optionally with some

additional headers (if SRv6 transport is used in the TN domain), and

sends out the packets on the TN transit link.

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The original IP header retains the DCSP marking (which is ignored in

5QI-unaware mode), while the new header (MPLS or IPv6) carries QoS

marking (MPLS Traffic Class bits for MPLS encapsulation, or DSCP for

SRv6/IPv6 encapsulation) related to TN CoS. Based on TN QoS Class

marking, per hop behavior for all IETF Network Slices is executed on

TN links. TN domain transit routers do not evaluate the original IP

header for QoS-related decisions. This model is outlined in

Figure 15 for MPLS encapsulation, and in Figure 16 for SRv6

encapsulation.

┌──────────────┐

│ MPLS Header │

├─────┬─────┐ │

│Label│TN TC│ │

┌──────────────┐ ─ ─ ─ ─ ─ ─ ─ ─ ├─────┴─────┴──┤

│ IP Header │ │╲ │ IP Header │

│ ┌───────┤ │ ╲ │ ┌───────┤

│ │5G DSCP│ ────────┘ ╲ │ │5G DSCP│

├──────┴───────┤ ╲ ├──────┴───────┤

│ │ ╲ │ │

│ │ ╲ │ │

│ │ ▏│ │

│ Payload │ ╱ │ Payload │

│(GTP-U/IPsec) │ ╱ │(GTP-U/IPsec) │

│ │ ╱ │ │

│ │ ────────┐ ╱ │ │

│ │ │ ╱ │ │

│ │ │╱ │ │

└──────────────┘ ─ ─ ─ ─ ─ ─ ─ ─ └──────────────┘

Figure 15: QoS with MPLS Encapsulation

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┌──────────────┐

│ IPv6 Header │

│ ┌───────┤

│ │TN DSCP│

├──────┴───────┤

optional

│ IPv6 │

headers

┌──────────────┐ ─ ─ ─ ─ ─ ─ ─ ─ ├──────────────┤

│ IP Header │ │╲ │ IP Header │

│ ┌───────┤ │ ╲ │ ┌───────┤

│ │5G DSCP│ ────────┘ ╲ │ │5G DSCP│

├──────┴───────┤ ╲ ├──────┴───────┤

│ │ ╲ │ │

│ │ ╲ │ │

│ │ ▏│ │

│ Payload │ ╱ │ Payload │

│(GTP-U/IPsec) │ ╱ │(GTP-U/IPsec) │

│ │ ╱ │ │

│ │ ────────┐ ╱ │ │

│ │ │ ╱ │ │

│ │ │╱ │ │

└──────────────┘ ─ ─ ─ ─ ─ ─ ─ ─ └──────────────┘

Figure 16: QoS with IPv6 Encapsulation

From the QoS perspective, both options are similar. However, there

is one difference between the two options. The MPLS TC is only 3

bits (8 possible combinations), while DSCP is 6 bits (64 possible

combinations). Hence, SRv6 [RFC8754] provides more flexibility for

TN CoS design, especially in combination with soft policing with in-

profile/ out-profile traffic, as discussed in Section 5.4.1.

Edge resources are controlled in a granular, fine-grained manner,

with dedicated resource allocation for each IETF Network Slice. The

resource control/enforcement happens at each SDP in two directions:

inbound and outbound.

5.4.1. Inbound Edge Resource Control

The main aspect of inbound edge resource control is per-slice traffic

capacity enforcement. This kind of enforcement is often called

'admission control' or 'traffic conditioning'. The goal of this

inbound enforcement is to ensure that the traffic above the

contracted rate is dropped or deprioritized, depending on the

business rules, right at the edge of TN domain. This, combined with

appropriate network capacity planning/management (Section 7) is

required to ensure proper isolation between slices in a scalable

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manner. As a result, traffic of one slice has no influence on the

traffic of other slices, even if the slice is misbehaving (e.g., DDoS

attacks or node/link failures) and generates traffic volumes above

the contracted rates.

The slice rates can be characterized with following parameters

[I-D.ietf-teas-ietf-network-slice-nbi-yang]:

\* CIR: Committed Information Rate (i.e., guaranteed bandwidth)

\* PIR: Peak Information Rate (i.e., maximum bandwidth)

These parameters define the traffic characteristics of the slice and

are part of SLO parameter set provided by the SMO to IETF NSC. Based

on these parameters the inbound policy can be implemented using one

of following options:

\* 1r2c (single-rate two-color) rate limiter

This is the most basic rate limiter, which meters at the SDP a

traffic stream of given slice and marks its packets as in-contract

(below contracted CIR) or out-of-contract (above contracted CIR).

In-contract packets are accepted and forwarded. Out-of contract

packets are either dropped right at the SDP (hard rate limiting),

or remarked (with different MPLS TC or DSCP TN markings) to

signify 'this packet should be dropped in the first place, if

there is a congestion' (soft rate limiting), depending on the

business policy of the operator. In the second case, while

packets above CIR are forwarded at the SDP, they are subject to

being dropped during any congestion event at any place in the TN

domain.

\* 2r3c (two-rate three-color) rate limiter

This was initially defined in [RFC2698], and its improved version

in [RFC4115]. In essence, the traffic is assigned to one of the

these three categories:

- Green, for traffic under CIR

- Yellow, for traffic between CIR and PIR

- Red, for traffic above PIR

An inbound 2r3c meter implemented with [RFC4115], compared to

[RFC2698], is more 'customer friendly' as it doesn't impose

outbound peak-rate shaping requirements on customer edge (CE)

devices. 2r3c meters in general give greater flexibility for edge

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enforcement regarding accepting the traffic (green), de-

prioritizing and potentially dropping the traffic during

congestion (yellow), or hard dropping the traffic (red).

Inbound edge enforcement model for 5QI-unaware model, where all

packets belonging to the slice are treated the same way in the TN

domain (no 5Q QoS Class differentiation in the TN domain) is outlined

in Figure 17.

Slice

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│ 2 │ i │

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│ e │ │

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└───┬──┘ │

└─────────┘

Figure 17: Ingress Slice Admission Control (5QI-unware Model)

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5.4.2. Outbound Edge Resource Control

While inbound slice admission control at the transport edge is

mandatory in the model, outbound edge resource control might not be

required in all use cases. Use cases that specifically call for

outbound edge resource control are:

\* Slices use both CIR and PIR parameters, and transport edge links

(attachment circuits) are dimensioned to fulfil the aggregate of

slice CIRs. If at any given time, some slices send the traffic

above CIR, congestion in outbound direction on the transport edge

link might happen. Therefore, fine-grained resource control to

guarantee at least CIR for each slice is required.

\* Any-to-Any (A2A) connectivity constructs are deployed, again

resulting in potential congestion in outbound direction on the

transport edge links, even if only slice CIR parameters are used.

This again requires fine-grained resource control per slice in

outbound direction at transport edge links.

As opposed to inbound edge resource control, typically implemented

with rate-limiters/policers, outbound resource control is typically

implemented with a weighted/priority queuing, potentially combined

with optional shapers (per slice). A detailed analysis of different

queuing mechanisms is out of scope for this document, but is provided

in [RFC7806].

Figure 18 outlines the outbound edge resource control model at the

transport network layer for 5QI-unaware slices. Each slice is

assigned a single egress queue. The sum of slice CIRs, used as the

weight in weighted queueing model, MUST NOT exceed the physical

capacity of the attachment circuit. Slice requests above this limit

MUST be rejected by the NSC, unless an already established slice with

lower priority, if such exists, is preempted.

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┌─────────┐ QoS output queues

│ ┌───┴──┐─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

│ │ S │ ╲│╱

│ │ l │ │

│ │ i │ │

│ A │ c │ │ weight=Slice-1-CIR

│ t │ e ┌─┴──────────────────────────┐ │ shaping=Slice-1-PIR

───┼──t──┼────▶ │ │

│ a │ 1 └─┬──────────────────────────┘ ╱│╲

│ c ├──────┤─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

│ h │ S │ ╲│╱

│ m │ l │ │

│ e │ i │ │

│ n │ c │ │ weight=Slice-2-CIR

│ t │ e ┌─┴──────────────────────────┐ │ shaping=Slice-2-PIR

───┼─────┼────▶ │ │

│ C │ 2 └─┬──────────────────────────┘ ╱│╲

│ i ├──────┤─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

│ r │ S │ ╲│╱

│ c │ l │ │

│ u │ i │ │

│ i │ c │ │ weight=Slice-3-CIR

│ t │ e ┌─┴──────────────────────────┐ │ shaping=Slice-3-PIR

───┼─────┼────▶ │ │

│ │ 3 └─┬──────────────────────────┘ ╱│╲

│ └───┬──┘─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

└─────────┘

Figure 18: Ingress Slice Admission control (5QI-unaware Model)

5.5. 5QI-aware Model

In the 5QI-aware model, potentially a large number of 5G QoS Classes,

represented via DSCP set by NFs (the architecture scales to thousands

of 5G slices) is mapped (multiplexed) to up to 8 TN QoS Classes used

in transport transit equipment, as outlined in Figure 19.

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┏━━━━━━━━━━━━━━━━━┓ ETN │

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃

┃ SDP ┃ ┏━━━━━━━━━━━━━━━━━━━━━━━━━━━┫

┃│ ┌──────────┐ │┃ ┃ Transit link ┃

┃ │5G DSCP A ├───────────────┐ ┃┌────────────────────────┐ ┃

I ┃│ └──────────┘ │┃ ├──▶ TN QoS Class 1 │ ┃

E ┃ ┌──────────┐ ┃ │ ┃└────────────────────────┘ ┃

T ┃│ │5G DSCP B ├───────────┐ │ ┃┌────────────────────────┐ ┃

F ┃ └──────────┘ ┃ │ │ ┃│ TN QoS Class 2 │ ┃

┃│ ┌──────────┐ │┃ │ │ ┃└────────────────────────┘ ┃

N ┃ │5G DSCP C ├──╋─────┐ │ │ ┃┌────────────────────────┐ ┃

S ┃│ └──────────┘ │┃ │ │ │ ┃│ TN QoS Class 3 │ ┃

┃ ┌──────────┐ ┃ │ │ │ ┃└────────────────────────┘ ┃

1 ┃│ │5G DSCP D ├─────┐ │ │ │ ┃┌────────────────────────┐ ┃

┃ └──────────┘ ┃ │ │ ├──────▶ TN QoS Class 4 │ ┃

┃└ ─ ─ ─ ─ ─ ─ ─ ┘┃ │ │ │ │ ┃└────────────────────────┘ ┃

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ │ │ │ │ ┃┌────────────────────────┐ ┃

┃ ┌──────────┐ ┃ │ ├─────────▶ TN QoS Class 5 │ ┃

┃│ │5G DSCP A ├─────│──│──│───┘ ┃└────────────────────────┘ ┃

I ┃ └──────────┘ ┃ │ │ │ ┃┌────────────────────────┐ ┃

E ┃│ ┌──────────┐ │┃ │ │ │ ┃│ TN QoS Class 6 │ ┃

T ┃ │5G DSCP E ├─────│──│──┘ ┃└────────────────────────┘ ┃

F ┃│ └──────────┘ │┃ │ │ ┃┌────────────────────────┐ ┃

┃ ┌──────────┐ ┃ │ │ ┃│ TN QoS Class 7 │ ┃

N ┃│ │5G DSCP F ├─────│──┘ ┃└────────────────────────┘ ┃

S ┃ └──────────┘ ┃ │ ┃┌────────────────────────┐ ┃

┃│ ┌──────────┐ │┃ ├────────────▶ TN QoS Class 8 │ ┃

2 ┃ │5G DSCP G ├─────┘ ┃└────────────────────────┘ ┃

┃│ └──────────┘ │┃ ┃ Max 8 TN Classes ┃

┃ SDP ┃ ┗━━━━━━━━━━━━━━━━━━━━━━━━━━━┛

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Fine-grained QoS enforcement Coarse QoS enforcement

(dedicated resources per (resources shared by

IETF Network Slice) multiple IETF NSs)

Figure 19: Slice 5Q QoS to TN QoS Mapping (5QI-aware Model)

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Given that in large scale deployments (large number of 5G slices),

the number of potential 5G QoS Classes is much higher than the number

of TN QoS Classes, multiple 5G QoS Classes with similar

characteristics - potentially from different slices - would be

grouped with common operator-defined TN logic and mapped to a same TN

QoS Class when transported in the TN domain. That is, common per hop

behavior (PHB) is executed on transit TN routers for all packets

grouped together. An example of this approach is outlined in

Figure 20.

> Please note that the numbers indicated in {{figure-34}} (S-NSSAI, 5QI, DSCP, queue, etc.) are provided for illustration purposes only and shoudl not be considered as deployment guidance.

┌───────────── ETN ─────────────────┐

┌────── NF-A ──────┐ │ │

│ │ │ ┌ ─ ─ ─ ─ ┐ │

│ 3GPP S-NSSAI 100 │ │ SDP │

│┌──────┐ ┌───────┐│ │ │┌───────┐│ │

││5QI=1 ├─▶DSCP=46├──────▶DSCP=46├───┐ │

│└──────┘ └───────┘│ │ │└───────┘│ │ │

│┌──────┐ ┌───────┐│ │ ┌───────┐ │ │

││5QI=65├─▶DSCP=46├──────▶DSCP=46├┼──┤ │

│└──────┘ └───────┘│ │ └───────┘ │ │

│┌──────┐ ┌───────┐│ │ │┌───────┐│ │ │

││5QI=7 ├─▶DSCP=10├──────▶DSCP=10──────┐ ┌──────────────┐ │

│└──────┘ └───────┘│ │ │└───────┘│ │ │ │TN QoS Class 5│ │

└──────────────────┘ │ ─ ─ ─ ─ ─ ├─│──▶ Queue 5 │ │

│ │ │ └──────────────┘ │

┌────── NF-B ──────┐ │ │ │ │

│ │ │ ┌ ─ ─ ─ ─ ┐ │ │ │

│ 3GPP S-NSSAI 200 │ │ SDP │ │ │

│┌──────┐ ┌───────┐│ │ │┌───────┐│ │ │ │

││5QI=1 ├─▶DSCP=46├──────▶DSCP=46├───┤ │ ┌──────────────┐ │

│└──────┘ └───────┘│ │ │└───────┘│ │ │ │TN QoS Class 1│ │

│┌──────┐ ┌───────┐│ │ ┌───────┐ │ ├──▶ Queue 1 │ │

││5QI=65├─▶DSCP=46├──────▶DSCP=46├┼──┘ │ └──────────────┘ │

│└──────┘ └───────┘│ │ └───────┘ │ │

│┌──────┐ ┌───────┐│ │ │┌───────┐│ │ │

││5QI=7 ├─▶DSCP=10├──────▶DSCP=10├─────┘ │

│└──────┘ └───────┘│ │ │└───────┘│ │

└──────────────────┘ │ ─ ─ ─ ─ ─ │

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Figure 20: Example of 3GPP QoS Mapped to TN QoS

In current SDO progress of 3GPP (Rel.17) and O-RAN the mapping of 5QI

to DSCP is not expected in per-slice fashion, where 5QI to DSCP

mapping may vary from 3GPP slice to 3GPP slice, hence the mapping of

5G QoS DSCP values to TN QoS Classes may be rather common.

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Like in 5QI-unaware model, the original IP header retains the DCSP

marking corresponding to 5QI (5G QoS Class), while the new header

(MPLS or IPv6) carries QoS marking related to TN QoS Class. Based on

TN QoS Class marking, per hop behavior for all aggregated 5G QoS

Classes from all IETF Network Slices is executed on TN links. TN

domain transit routers do not evaluate original IP header for QoS

related decisions. The original DSCP marking retained in the

original IP header is used at the PE for fine-grained per slice and

per 5G QoS Class inbound/outbound enforcement on the AC.

In 5QI-aware model, compared to 5QI-unware model, edge resources are

controlled in an even more granular, fine-grained manner, with

dedicated resource allocation for each IETF Network Slice and

dedicated resource allocation for number of traffic classes (most

commonly up 4 or 8 traffic classes, depending on the HW capability of

the equipment) within each IETF Network Slice.

5.5.1. Inbound Edge Resource Control

Compared to the 5QI-unware model, admission control (traffic

conditioning) in the 5QI-aware model is more granular, as it enforces

not only per slice capacity constraints, but may as well enforce the

constraints per 5G QoS Class within each slice.

5G slice using multiple 5QIs can potentially specify rates in one of

the following ways:

\* Rates per traffic class (CIR or CIR+PIR), no rate per slice (sum

of rates per class gives the rate per slice).

\* Rate per slice (CIR or CIR+PIR), and rates per prioritized

(premium) traffic classes (CIR only). Best effort traffic class

uses the bandwidth (within slice CIR/PIR) not consumed by

prioritized classes.

In the first option, the slice admission control is executed with

traffic class granularity, as outlined in Figure 21. In this model,

if a premium class doesn't consume all available class capacity, it

cannot be reused by non-premium (i.e., Best Effort) class.

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Class ┌─────────┐

policer ┌──┴───┐ │

│ │ │

5Q-QoS-A: CIR-1A ──────◇────────────┼──▶ S │ │

5Q-QoS-B: CIR-1B ──────◇────────────┼──▶ l │ │

5Q-QoS-C: CIR-1C ──────◇────────────┼──▶ i │ │

│ c │ │

│ e │ │

BE CIR/PIR-1D ──────◇────────────┼──▶ │ A │

│ 1 │ t │

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├──────┤ a │

│ │ c │

5Q-QoS-A: CIR-2A ──────◇────────────┼─▶ S │ h │

5Q-QoS-B: CIR-2B ──────◇────────────┼─▶ l │ m │

5Q-QoS-C: CIR-2C ──────◇────────────┼─▶ i │ e │

│ c │ n │

│ e │ t │

BE CIR/PIR-2D ──────◇────────────┼─▶ │ │

│ 2 │ C │

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│ │ c │

5Q-QoS-A: CIR-3A ──────◇────────────┼─▶ S │ u │

5Q-QoS-B: CIR-3B ──────◇────────────┼─▶ l │ i │

5Q-QoS-C: CIR-3C ──────◇────────────┼─▶ i │ t │

│ c │ │

│ e │ │

BE CIR/PIR-3D───────◇────────────┼─▶ │ │

│ 3 │ │

│ │ │

└──┬───┘ │

└─────────┘

Figure 21: Ingress Slice Admission Control (5QI-aware Model)

The second model combines the advantages of 5QI-unaware model (per

slice admission control) with the per traffic class admission

control, as outlined in Figure 21. Ingress admission control is at

class granularity for premium classes (CIR only). Non-premium class

(i.e., Best Effort) has no separate class admission control policy,

but it is allowed to use the entire slice capacity, which is

available at any given moment. I.e., slice capacity, which is not

consumed by premium classes. It is a hierarchical model, as depicted

in Figure 22.

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Slice

policer ┌─────────┐

Class . ┌──┴───┐ │

policer ; : │ │ │

5Q-QoS-A: CIR-1A ────◇─────────┤─┼──┼──▶ S │ │

5Q-QoS-B: CIR-1B ────◇─────────┤─┼──┼──▶ l │ │

5Q-QoS-C: CIR-1C ────◇─────────┤─┼──┼──▶ i │ │

│ │ │ c │ │

│ │ │ e │ │

BE CIR/PIR-1D ──────────────┤─┼──┼──▶ │ A │

│ │ │ 1 │ t │

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. ├──────┤ a │

; : │ │ c │

5Q-QoS-A: CIR-2A ────◇─────────┤─┼──┼──▶ S │ h │

5Q-QoS-B: CIR-2B ────◇─────────┤─┼──┼──▶ l │ m │

5Q-QoS-C: CIR-2C ────◇─────────┤─┼──┼──▶ i │ e │

│ │ │ c │ n │

│ │ │ e │ t │

BE CIR/PIR-2D ──────────────┤─┼──┼──▶ │ │

│ │ │ 2 │ C │

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; : │ │ c │

5Q-QoS-A: CIR-3A ────◇─────────┤─┼──┼──▶ S │ u │

5Q-QoS-B: CIR-3B ────◇─────────┤─┼──┼──▶ l │ i │

5Q-QoS-C: CIR-3C ────◇─────────┤─┼──┼──▶ i │ t │

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BE CIR/PIR-3D ──────────────┤─┼──┼──▶ │ │

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Figure 22: Ingress Slice Admission Control (5QI-aware) - Hierarchical

5.5.2. Outbound Edge Resource Control

Figure 23 outlines the outbound edge resource control model at the

transport network layer for 5QI-aware slices. Each slice is assigned

multiple egress queues. The sum of queue weights (equal to 5Q QoS

CIRs within the slice) CIRs MUST NOT exceed the CIR of the slice

itself. And, similarly to the 5QI-aware model, the sum of slice CIRs

MUST NOT exceed the physical capacity of the attachment circuit.

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┌─────────┐ QoS output queues

│ ┌───┴──┐─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

│ │ ┌─┴──────────────────────────┐ ╲│╱

───┼─────┼────▶ 5Q-QoS-A: w=5Q-QoS-A-CIR │ │

│ │ S └─┬──────────────────────────┘ │

│ │ l ┌─┴──────────────────────────┐ │

───┼─────┼─i──▶ 5Q-QoS-B: w=5Q-QoS-B-CIR │ │

│ │ c └─┬──────────────────────────┘ │ weight=Slice-1-CIR

│ │ e ┌─┴──────────────────────────┐ │ shaping=Slice-1-PIR

───┼─────┼────▶ 5Q-QoS-C: w=5Q-QoS-C-CIR │ │

│ │ 1 └─┬──────────────────────────┘ │

│ │ ┌─┴──────────────────────────┐ │

───┼─────┼────▶ Best Effort (remainder) │ │

│ │ └─┬──────────────────────────┘ ╱│╲

│ A ├──────┤─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

│ t │ ┌─┴──────────────────────────┐ ╲│╱

│ t │ │ │ │

│ a │ └─┬──────────────────────────┘ │

│ c │ S ┌─┴──────────────────────────┐ │

│ h │ l │ │ │

│ m │ i └─┬──────────────────────────┘ │ weight=Slice-2-CIR

│ e │ c ┌─┴──────────────────────────┐ │ shaping=Slice-2-PIR

│ n │ e │ │ │

│ t │ └─┬──────────────────────────┘ │

│ │ 2 ┌─┴──────────────────────────┐ │

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│ r ├──────┤─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

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│ │ i │ │ │

│ │ c └─┬──────────────────────────┘ │ weight=Slice-3-CIR

│ │ e ┌─┴──────────────────────────┐ │ shaping=Slice-3-PIR

│ │ │ │ │

│ │ 3 └─┬──────────────────────────┘ │

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Figure 23: Egress Slice Admission Control (5QI-aware)

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5.6. Transit Resource Control

Transit resource control is much simpler than Edge resource control.

As outlined in Figure 19, at the edge, 5Q QoS Class marking

(represented by DSCP related to 5QI set by mobile network functions

in the packets handed off to the TN) is mapped to the TN QoS Class.

Based in TN QoS Class, when the packet is encapsulated with outer

header (MPLS or IPv6), TN QoS Class marking (MPLS TC or IPv6 DSCP in

outer header, as depicted in Figure 15 and Figure 16) is set in the

outer header. PHB on transit is based exclusively on that TN QoS

Class marking, i.e., original 5G QoS Class DSCP is not taken into

consideration on transit.

Transit resource control does not use any inbound interface policy,

but only outbound interface policy, which is based on priority queue

combined with weighted or deficit queuing model, without any shaper.

The main purpose of transit resource control is to ensure that during

network congestion events, for example caused by network failures and

temporary rerouting, premium classes are prioritized, and any drops

only occur in traffic that was de-prioritized by ingress admission

control Section 5.4.1 or in non-premium (best-effort) classes.

Capacity planning and management, as described in Section 7, ensures

that enough capacity is available to fulfill all approved slice

requests.

6. Transport Planes Mapping Models

A network operator might define various tunnel groups, where each

tunnel group is created with specific optimization criteria and

constraints. This document refers to such tunnel groups as

'transport planes'. For example, a transport plane "A" might

represent tunnels optimized for latency, and transport plane "B"

represent tunnels optimized for high capacity.

Figure 24 depicts an example of a simple network with two transport

planes. These transport planes might be realized via various IP/MPLS

techniques, for example Flex-Algo or RSVP/SR traffic engineering

tunnels with or without PCE, and with or without bandwidth

reservations.

Section 7 discusses in detail different bandwidth models that can be

deployed in the transport network. However, discussion about how to

realize or orchestrate transport planes is out of scope for this

document.

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┌───────────────┐ ┌──────┐

│ Ingress PE │ ╔═══════════════════════════════▶│ PE-A │

│ │ ║ ╔═══════════════════════════▷│ │

│ ┌ ─ ─ ─ ─ ┐ │ ║ ╚═════════════════════╗ └──────┘

│ ●══════╝ ╔═════════════════════╝

│ │Transport●════════════════════════════════╗ ┌──────┐

│ Plane A ●═════════════╗ ╚═════▶│ PE-B │

│ │ ●═══════╗ ║ ║ ╔═══╗ ╔═══╗ ╔═════▷│ │

│ ─ ─ ─ ─ ─ │ ║ ║ ║ ║ ║ ║ ║ ║ └──────┘

│ │ ║ ║ ║ ║ ╚═══╝ ╚═══╝

│ ┌ ─ ─ ─ ─ ┐ │ ║ ║ ║ ║ ┌──────┐

│ ○═══════║══╝ ╚════════════════════════▶│ PE-C │

│ │Transport○═══════║════════╝ ╔═════▷│ │

│ Plane B ○═══════║═════════════════╗ ║ └──────┘

│ │ ○═════╗ ╚═══════════════╗ ║ ║

│ ─ ─ ─ ─ ─ │ ║ ╔═╗ ╔═╗ ╔═╗ ╔═╗ ║ ╚══════╝ ┌──────┐

│ │ ║ ║ ║ ║ ║ ║ ║ ║ ║ ╚══════════════▶│ PE-D │

└───────────────┘ ╚═╝ ╚═╝ ╚═╝ ╚═╝ ╚════════════════▷│ │

└──────┘

●════════▶ Tunnels of Transport Plane A

○════════▷ Tunnels of Transport Plane B

Figure 24: Transport Planes

Note that there could be multiple tunnels within a single transport

plane between any pair of PEs. For readibility, Figure 24 shows only

single tunnel per transport plane for [ingress PE, egress PE] pair.

Similar to the QoS mapping models discussed in Section 5, for mapping

to transport planes at the ingress PE, both 5QI-unaware and 5QI-aware

modes are defined. In essence, entire slices can be mapped to

transport planes without 5G QoS consideration (5QI-unaware mode), or

flows with different 5G QoS Classes, even if they are from the same

slice, might be mapped to different transport planes (5QI-aware

mode).

6.1. 5QI-unaware Model

As discussed in Section 5.4, in the 5QI-unware model, the TN domain

doesn't take into account 5G QoS during execution of per-hop

behavior. The entire slice is mapped to single TN QoS Class,

therefore the entire slice is subject to the same per-hop behavior.

Similarly, in 5QI-unaware transport plane mapping model, the entire

slice is mapped to a single transport plane, as depicted in

Figure 25.

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┃ Attach. Circuit ┃ PE router

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ │

┃ SDP ┃

┃│ ┌──────────┐ │┃ │

┃ │IETF NS 1 ├──────────┐

┃│ └──────────┘ │┃ │ │

┃ ─ ─ ─ ─ ─ ─ ─ ─ ┃ │

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ │ ┌─────────┐ │

┃ SDP ┃ │ │ │

┃│ ┌──────────┐ │┃ │ │Transport│ │

┃ │IETF NS 2 ├──────┐ ├───▶ Plane │

┃│ └──────────┘ │┃ │ │ │ A │ │

┃ ─ ─ ─ ─ ─ ─ ─ ─ ┃ │ │ │ │

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ │ │ └─────────┘ │

┃ SDP ┃ │ │

┃│ ┌──────────┐ │┃ │ │ │

┃ │IETF NS 3 ├──────┤ │

┃│ └──────────┘ │┃ │ │ ┌─────────┐ │

┃ ─ ─ ─ ─ ─ ─ ─ ─ ┃ │ │ │ │

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ │ │ │Transport│ │

┃ SDP ┃ ├───│───▶ Plane │

┃│ ┌──────────┐ │┃ │ │ │ B │ │

┃ │IETF NS 4 ├──────┘ │ │ │

┃│ └──────────┘ │┃ │ └─────────┘ │

┃ ─ ─ ─ ─ ─ ─ ─ ─ ┃ │

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ │ │

┃ SDP ┃ │

┃│ ┌──────────┐ │┃ │ │

┃ │IETF NS 5 ├──────────┘

┃│ └──────────┘ │┃ │

┃ ─ ─ ─ ─ ─ ─ ─ ─ ┃

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Figure 25: Slice to Transport Plane Mapping (5QI-unaware Model)

It is worth noting that there is no strict correlation between TN QoS

Classes and Transport Planes. The TN domain can be operated with

e.g., 8 TN QoS Classes (representing 8 hardware queues in the

routers), and 2 Transport Planes (e.g., latency optimized transport

plane using link latency metrics for path calculation, and transport

plane following IGP metrics). TN QoS Class determines the per-hop

behavior when the packets are transiting through the TN domain, while

Transport Plane determines the path, optimized or constrained based

on operator's business criteria, that the packets use to transit

through the TN domain.

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6.2. 5QI-aware Model

In 5QI-aware model, the traffic can be mapped to transport planes at

the granularity of 5G QoS Class. Given that the potential number of

transport planes is limited, packets from multiple 5G QoS Classes

with similar characteristics are mapped to a common transport plane,

as depicted in Figure 26.

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┃ Attach. Circuit ┃ │

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ PE router

┃ SDP ┃ │

┃│ ┌──────────┐ │┃

┃ │ 5G QoS A ├──────┐ │

I ┃│ └──────────┘ │┃ │

E ┃ ┌──────────┐ ┃ │ │

T ┃│ │ 5G QoS B ├──────┤

F ┃ └──────────┘ ┃ │ ┌─────────┐ │

┃│ ┌──────────┐ │┃ │ │ │

N ┃ │ 5G QoS C ├───────────┐ │Transport│ │

S ┃│ └──────────┘ │┃ ├────│────▶ Plane │

┃ ┌──────────┐ ┃ │ │ │ A │ │

1 ┃│ │ 5G QoS D ├───────────┤ │ │

┃ └──────────┘ ┃ │ │ └─────────┘ │

┃└ ─ ─ ─ ─ ─ ─ ─ ┘┃ │ │

┃┌ ─ ─ ─ ─ ─ ─ ─ ┐┃ │ │ │

┃ ┌──────────┐ ┃ │ │

┃│ │ 5G QoS A ├──────┤ │ ┌─────────┐ │

I ┃ └──────────┘ ┃ │ │ │ │

E ┃│ ┌──────────┐ │┃ │ │ │Transport│ │

T ┃ │ 5G QoS E ├──────┘ ├────▶ Plane │

F ┃│ └──────────┘ │┃ │ │ B │ │

┃ ┌──────────┐ ┃ │ │ │

N ┃│ │ 5G QoS F ├───────────┤ └─────────┘ │

S ┃ └──────────┘ ┃ │

┃│ ┌──────────┐ │┃ │ │

2 ┃ │ 5G QoS G ├───────────┘

┃│ └──────────┘ │┃ │

┃ SDP ┃

┃└ ─ ─ ─ ─ ─ ─ ─ ┘┃ │

┗━━━━━━━━━━━━━━━━━┛

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Figure 26: Slice to Transport Plane mapping (5QI-aware Model)

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7. Capacity Planning/Management

This section describes the information conveyed by the SMO to the

transport controller with respect to slice bandwidth requirements.

Figure 27 shows three DCs that contain instances of network

functions. Also shown are PEs that have links to the DCs. The PEs

belong to the transport network. Other details of the transport

network, such as P-routers and transit links are not shown. Also

details of the DC infrastructure such as switches and routers are not

shown.

The SMO is aware of the existence of the network functions and their

locations. However, it is not aware of the details of the transport

network. The transport controller has the opposite view - it is

aware of the transport infrastructure and the links between the PEs

and the DCs, but is not aware of the individual network functions.

┌ ─ ─ ─ ─ DC 1─ ─ ─ ─ ┌ ─ ─ ─ ─ ─ ─ ─ ─ ┐ ┌ ─ ─ ─ ─ DC 2─ ─ ─ ─

┌──────┐ │ ┌────┐ ┌────┐ ┌──────┐ │

│ │ NF1A │ ───■PE1A│ │PE2A■──┤ │ NF2A │

└──────┘ │ └────┘ └────┘ └──────┘ │

│ ┌──────┐ │ │ │ ┌──────┐

│ NF1B │ │ │ NF2B │ │

│ └──────┘ │ │ │ └──────┘

┌──────┐ │ ┌────┐ ┌────┐ ┌──────┐ │

│ │ NF1C │ ───■PE1B│ │PE2B■──┤ │ NF2C │

└──────┘ │ └────┘ └────┘ └──────┘ │

└ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ │ Transport │ └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

│ Network │ ┌ ─ ─ ─ ─ DC 3─ ─ ─ ─

┌────┐ ┌──────┐ │

│ │PE3A■──┤ │ NF3A │

└────┘ └──────┘ │

│ │ │ ┌──────┐

│ NF3B │ │

│ │ │ └──────┘

┌────┐ ┌──────┐ │

│ │PE3B■──┤ │ NF3C │

└────┘ └──────┘ │

└ ─ ─ ─ ─ ─ ─ ─ ─ ┘ └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

■ - SDP, with fine-grained QoS (dedicated resources per IETF NS)

Figure 27: An Example of Multi-DC Architecture

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Let us consider 5G Slice "X" that uses some of the network functions

in the three DCs. If this slice has latency requirements, the SMO

will have taken those into account when deciding which NF instances

in which DC is to be invoked for this slice. As a result of such a

placement decision, the three DCs shown are involved in 5G Slice "X",

rather than other DCs. For its decision-making, the SMO needs

information from the NSC about the observed latency between DCs.

Preferably, the NSC would present the topology in an abstracted form,

consisting of point-to-point abstracted links between pairs of DCs

and associated latency and optionally delay variation and link loss

values. It would be valuable to have a mechanism for the SMO to

inform the NSC which DC-pairs are of interest for these metrics -

there may be of order thousands of DCs, but the SMO will only be

interested in these metrics for a small fraction of all the possible

DC-pairs, i.e. those in the same region of the network. The

mechanism for conveying the information will be discussed in a future

version of this document.

Figure 28 shows the matrix of bandwidth demands for 5G slice "X".

Within the slice, multiple network function instances might be

sending traffic from DCi to DCj. However, the SMO sums the

associated demands into one value. For example, NF1A and NF1B in DC1

might be sending traffic to multiple NFs in DC2, but this is

expressed as one value in the traffic matrix: the total bandwidth

required for 5G Slice X from DC1 to DC2 (8 units). Each row in the

right-most column in the traffic matrix shows the total amount of

traffic going from a given DC into the transport network, regardless

of the destination DC. Note that this number can be less than the

sum of DC-to-DC demands in the same row, on the basis that not all

the network functions are likely to be sending at their maximum rate

simultaneously. For example, the total traffic from DC1 for Slice X

is 11 units, which is less than the sum of the DC-to-DC demands in

the same row (13 units). Note, as described in Section 5, a slice

may have per-QoS class bandwidth requirements, and may have CIR and

PIR limits. This is not included in the example, but the same

principles apply in such cases.

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To┌──────┬──────┬──────┬──────────────┐

From │ DC 1 │ DC 2 │ DC 3 │Total from DC │

┌──────┼──────┼──────┼──────┼──────────────┤

│ DC 1 │ n/a │ 8 │ 5 │ 11.0 │

├──────┼──────┼──────┼──────┼──────────────┤

│ DC 2 │ 1 │ n/a │ 2 │ 2.5 │

├──────┼──────┼──────┼──────┼──────────────┤

│ DC 3 │ 4 │ 7 │ n/a │ 10.0 │

└──────┴──────┴──────┴──────┴──────────────┘

Slice X

To┌──────┬──────┬──────┬──────────────┐

From │ DC 1 │ DC 2 │ DC 3 │Total from DC │

┌──────┼──────┼──────┼──────┼──────────────┤

│ DC 1 │ n/a │ 4 │ 2.5 │ 6.0 │

├──────┼──────┼──────┼──────┼──────────────┤

│ DC 2 │ 0.5 │ n/a │ 0.8 │ 1.0 │

├──────┼──────┼──────┼──────┼──────────────┤

│ DC 3 │ 2.6 │ 3 │ n/a │ 5.1 │

└──────┴──────┴──────┴──────┴──────────────┘

Slice Y

Figure 28: Inter-DC Traffic Demand Matrix

[I-D.ietf-teas-ietf-network-slice-nbi-yang] can be used to convey all

of the information in the traffic matrix to the IETF NSC. The IETF

NSC applies policers corresponding to the last column in the traffic

matrix to the appropriate PE routers, in order to enforce the

bandwidth contract. For example, it applies a policer of 11 units to

PE1A and PE1B that face DC1, as this is the total bandwidth that DC1

sends into the transport network corresponding to Slice X. Also, the

controller may apply shapers in the direction from the TN to the DC,

if otherwise there is the possibility of a link in the DC being

oversubscribed. Note that a peer NF endpoint of an AC can be

identified using 'peer-sap-id' as defined in [I-D.ietf-opsawg-sap].

Depending on the bandwidth model used in the network (Section 7.1),

the other values in the matrix, i.e., the DC-to-DC demands, may not

be directly applied to the transport network. Even so, the

information may be useful to the IETF NSC for capacity planning and

failure simulation purposes. If, on the other hand, the DC-to-DC

demand information is not used by the IETF NSC, the IETF YANG Data

Model for L3VPN Service Delivery [RFC8299] or the IETF YANG Data

Model for L2VPN Service Delivery [RFC8466] could be used instead of

[I-D.ietf-teas-ietf-network-slice-nbi-yang], as they support

conveying the bandwidth information in the right-most column of the

traffic matrix.

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The transport network may be implemented in such a way that it has

various types of paths, for example low-latency traffic might be

mapped onto a different transport path to other traffic (for example

a particular flex-algo or a particular set of TE LSPs), as discussed

in Section 5. The SMO can use

[I-D.ietf-teas-ietf-network-slice-nbi-yang] to request low-latency

transport for a given slice if required. However, [RFC8299] or

[RFC8466] do not support requesting a particular transport-type,

e.g., low-latency. One option is to augment these models to convey

this information. This can be achieved by reusing the 'underlay-

transport' construct defined in [RFC9182] and [RFC9291].

7.1. Bandwidth Models

This section describes three bandwidth management schemes that could

be employed in the transport network. Many variations are possible,

but each example describes the salient points of the corresponding

scheme. Schemes 2 and 3 use TE; other variations on TE are possible

as described in [I-D.ietf-teas-rfc3272bis].

7.1.1. Scheme 1: Shortest Path Forwarding (SPF)

Shortest path forwarding is used according to the IGP metric. Given

that some slices are likely to have latency SLOs, the IGP metric on

each link can be set to be in proportion to the latency of the link.

In this way, all traffic follows the minimum latency path between

endpoints.

In Scheme 1, although the operator provides bandwidth guarantees to

the slice customers, there is no explicit end-to-end underpinning of

the bandwidth SLO, in the form of bandwidth reservations across the

transport network. Rather, the expected performance is achieved via

capacity planning, based on traffic growth trends and anticipated

future demands, in order to ensure that network links are not over-

subscribed. This scheme is analogous to that used in many existing

business VPN deployments, in that bandwidth guarantees are provided

to the customers but are not explicitly underpinned end to end across

the transport network.

A variation on the scheme is that Flex-Algo, defined in

[I-D.ietf-lsr-flex-algo], is used, for example one Flex-Algo could

use latency-based metrics and another Flex-Algo could use the IGP

metric. There would be a many-to-one mapping of slices to Flex-

Algos.

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While Scheme 1 is technically feasible, it is vulnerable to

unexpected changes in traffic patterns and/or network element

failures resulting in congestion. This is because, unlike Schemes 2

and 3 that employ TE, traffic cannot be diverted from the shortest

path.

7.1.2. Scheme 2: TE LSPs with Fixed Bandwidth Reservations

Scheme 2 uses RSVP-TE or SR-TE LSPs with fixed bandwidth

reservations. By "fixed", we mean a value that stays constant over

time, unless the SMO communicates a change in slice bandwidth

requirements, due to the creation or modification of a slice. Note

that the "reservations" would be in the mind of the transport

controller - it is not necessary (or indeed possible for SR-TE) to

reserve bandwidth at the network layer. The bandwidth requirement

acts as a constraint whenever the controller (re)computes the path of

an LSP. There could be a single mesh of LSPs between endpoints that

carry all of the traffic types, or there could be a small handful of

meshes, for example one mesh for low-latency traffic that follows the

minimum latency path and another mesh for the other traffic that

follows the minimum IGP metric path, as described in Section 5.

There would be a many-to-one mapping of slices to LSPs.

The bandwidth requirement from DCi to DCj is the sum of the DCi-DCj

demands of the individual slices. For example, if only Slice X and

Slice Y are present, then the bandwidth requirement from DC1 to DC2

is 12 units (8 units for Slice X and 4 units for Slice Y). When the

SMO requests a new slice, the transport controller, in its mind,

increments the bandwidth requirement according to the requirements of

the new slice. For example, in Figure 27, suppose a new slice is

instantiated that needs 0.8 Gbps from DC1 to DC2. The transport

controller would increase its notion of the bandwidth requirement

from DC1 to DC2 from 12 Gbps to 12.8 Gbps to accommodate the

additional expected traffic.

In the example, each DC has two PEs facing it for reasons of

resilience. The transport controller needs to determine how to map

the DC1 to DC2 bandwidth requirement to bandwidth reservations of TE

LSPs from DC1 to DC2. For example, if the routing configuration is

arranged such that in the absence of any network failure, traffic

from DC1 to DC2 always enters PE1A and goes to PE2A, the controller

reserves 12.8 Gbps of bandwidth on the LSP from PE1A to PE2A. If, on

the other hand, the routing configuration is arranged such that in

the absence of any network failure, traffic from DC1 to DC2 always

enters PE1A and is load-balanced across PE2A and PE2B, the controller

reserves 6.4 Gbps of bandwidth on the LSP from PE1A to PE2A and 6.4

Gbps of bandwidth on the LSP from PE1A to PE2B. It might be tricky

for the transport controller to be aware of all conditions that

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change the way traffic lands on the various PEs, and therefore know

that it needs to change bandwidth reservations of LSPs accordingly.

For example, there might be an internal failure within DC1 that

causes traffic from DC1 to land on PE1B, rather than PE1A. The

transport controller may not be aware of the failure and therefore

may not know that it now needs to apply bandwidth reservations to

LSPs from PE1B to PE2A/PE2B.

7.1.3. Scheme 3: TE LSPs without Bandwidth Reservation

Like Scheme 2, Scheme 3 uses RSVP-TE or SR-TE LSPs. There could be a

single mesh of LSPs between endpoints that carry all of the traffic

types, or there could be a small handful of meshes, for example one

mesh for low-latency traffic that follows the minimum latency path

and another mesh for the other traffic that follows the minimum IGP

metric path, as described in Section 5. There would be a many-to-one

mapping of slices to LSPs.

The difference between Scheme 2 and Scheme 3 is that Scheme 3 does

not have fixed bandwidth reservations for the LSPs. Instead, actual

measured data-plane traffic volumes are used to influence the

placement of TE LSPs. One way of achieving this is to use

distributed RSVP-TE with auto-bandwidth. Alternatively, the

transport controller can use telemetry-driven automatic congestion

avoidance. In this approach, when the actual traffic volume in the

data plane on given link exceeds a threshold, the controller, knowing

how much actual data plane traffic is currently travelling along each

RSVP or SR-TE LSP, can tune the paths of one or more LSPs using the

link such that they avoid that link.

It would be undesirable to move a minimum-latency LSP rather than

another type of LSP in order to ease the congestion, as the new path

will typically have a higher latency, if the minimum-latency LSP is

currently following the minimum-latency path. This can be avoided by

designing the algorithms described in the previous paragraph such

that they avoid moving minimum-latency LSPs unless there is no

alternative.

8. IANA Considerations

This document does not make any IANA request.

9. Security Considerations

IETF Network Slices considerations are discussed in Section 6 of

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

TBC.

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Appendix A. Acronyms and Abbreviations

3GPP: 3rd Generation Partnership Project

5GC: 5G Core

5QI: 5G QoS Indicator

A2A: Any-to-Any

AC: Attachment Circuit

AMF: Access and Mobility Management Function

AUSF: Authentication Server Function

BBU: Baseband Unit

BH: Backhaul

BS: Base Station

CE: Customer Edge

CIR: Committed Information Rate

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CN: Core Network

CoS: Class of Service

CP: Control Plane

CSP: Communication Service Provider

CU: Centralized Unit

CU-CP: Centralized Unit Control Plane

CU-UP: Centralized Unit User Plane

DC: Data Center

DDoS: Distributed Denial of Services

DN: Data Network

DSCP: Differentiated Services Code Point

DU: Distributed Unit

eCPRI: enhanced Common Public Radio Interface

FH: Fronthaul

FIB: Forwarding Information Base

GPRS: Generic Packet Radio Service

gNB: gNodeB

GTP: GPRS Tunneling Protocol

GTP-U: GPRS Tunneling Protocol User plane

HW: Hardware

ID: Identifier

IGP: Interior Gateway Protocol

IP: Internet Protocol

L2VPN: Layer 2 Virtual Private Network

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L3VPN: Layer 3 Virtual Private Network

LSP: Label Switched Path

MH: Midhaul

MIoT: Massive Internet of Things

MPLS: Multiprotocol Label Switching

NF: Network Function

NR: New Radio

NRF: Network Function Repository

NRP: Network Resource Partition

NSC: Network Slice Controller

NSS: Network Slice Subnet

PE: Provider Edge

PIR: Peak Information Rate

PLMN: Public Land Mobile Network

PSTN: Public Switched Telephony Network

QoS: Quality of Service

RAN: Radio Access Network

RF: Radio Frequency

RIB: Routing Information Base

RSVP: Resource Reservation Protocol

RU: Radio Unit

SD: Slice Differentiator

SDP: Service Demarcation Point

SLA: Service Level Agreement

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SLO: Service Level Objective

SMF: Session Management Function

SMO: Service Management and Orchestration

S-NSSAI: Single Network Slice Selection Assistance Information

SST: Slice/Service Type

SR: Segment Routing

SRv6: Segment Routing version 6

TC: Traffic Class

TE: Traffic Engineering

TN: Transport Network

TS: Technical Specification

UDM: Unified Data Management

UE: User Equipment

UP: User Plane

UPF: User Plane Function

URLLC: Ultra Reliable Low Latency Communication

VLAN: Virtual Local Area Network

VNF: Virtual Network Function

VPN: Virtual Private Network

VRF: Virtual Routing and Forwarding

VXLAN: Virtual Extensible Local Area Network

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Appendix B. An Overview of 5G Networking

This section provides a brief introduction to 5G mobile networking

with a perspective on the Transport Network. This section does not

intend to replace or define 3GPP architecure, it just provides a

brief overview for readers that do not have a mobile background. For

more comprehensive information, refer to [TS-23.501].

B.1. Key Building Blocks

[TS-23.501] defines the Network Functions (UPF, AMF, etc.) that

compose the 5G System (5GS) Architecture together with related

interfaces (e.g., N1, N2). This architecture has native Control and

User Plane separation, and the Control Plane leverages a service-

based architecture. Figure 29 outlines an example 5GS architecture

with a subset of possible network functions and network interfaces.

┌─────┐ ┌─────┐ ┌─────┐ ┌─────┐ ┌─────┐ ┌─────┐

│NSSF │ │ NEF │ │ NRF │ │ PCF │ │ UDM │ │ AF │

└──┬──┘ └──┬──┘ └──┬──┘ └──┬──┘ └──┬──┘ └──┬──┘

Nnssf│ Nnef│ Nnrf│ Npcf│ Nudm│ │Naf

───┴────────┴──┬─────┴──┬───────┴───┬────┴────────┴────

Nausf│ Namf│ Nsmf│

┌──┴──┐ ┌──┴──┐ ┌──┴──────┐

│AUSR │ │ AMF │ │ SMF │

└─────┘ └──┬──┘ └──┬──────┘

╱ │ │ ╲

Control Plane N1 ╱ │N2 │N4 ╲N4

════════════════════════════════════════════════════════════

User Plane ╱ │ │ ╲

┌───┐ ┌──┴──┐ N3 ┌──┴──┐ N9 ┌─────┐ N6 .───.

│UE ├──┤(R)AN├─────┤ UPF ├────┤ UPF ├────( DN )

└───┘ └─────┘ └─────┘ └─────┘ `───'

Figure 29: 5GS Architecture and Service-based Interfaces

Similar to previous versions of 3GPP mobile networks [RFC6459], a 5G

mobile network is split into the following four major domains

(Figure 30):

\* UE, MS, MN, and Mobile:

The terms UE (User Equipment), MS (Mobile Station), MN (Mobile

Node), and mobile refer to the devices that are hosts with the

ability to obtain Internet connectivity via a 3GPP network. An MS

is comprised of the Terminal Equipment (TE) and a Mobile Terminal

(MT). The terms UE, MS, MN, and mobile are used interchangeably

within this document.

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\* Radio Access Network (RAN):

Provides wireless connectivity to the UE devices via radio. It is

made up of the Antenna that transmits and receives signals to the

UE and the Base Station that digitizes the signal and converts the

RF data stream to IP packets.

\* Core Network (CN):

Controls the CP of the RAN and provides connectivity to the Data

Network (e.g., the Internet or a private VPN). The Core Network

hosts dozens of services such as authentication, phone registry,

charging, access to PSTN and handover.

\* Transport Network (TN):

Provides connectivity between sites where 5G Network Functions are

located. The TN may connect sites from the RAN to the Core

Network, as well as sites within the RAN or within the CN. This

connectivity is achieved using IP.

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│ │ │ │ │

│ ┌────┐ │ │ │ │ .───────.

│ UE ├──────┤ RAN │ │ CN ├────( DN )

│ └────┘ │ │ │ │ `───────'

│ │ │ │ │

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│ │ │

│ │ │

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│ ┌─────┴─────────────────┴────┐

│ │ │

│ │ │

│ Transport Network │ │

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│ └────────────────────────────┘

│

│ 5G System

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└ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

Figure 30: Building Blocks of 5G Architecture (A High-Level

Representation)

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B.2. Core Network (CN)

The 5G Core Network (5GC) is made up of a set of NFs which fall into

two main categories (Figure 31):

\* 5GC User Plane:

The User Plane Function (UPF) is the interconnect point between

the mobile infrastructure and the Data Network (DN). It

interfaces with the RAN via the N3 interface by encapsulating/

decapsulating the User Plane Traffic in GTP Tunnels (aka GTP-U or

Mobile User Plane).

\* 5GC Control Plane:

The 5G Control Plane is made up of a comprehensive set of Network

Functions. An exhaustive list and description of these entities

is out of the scope of this document. The following NFs and

interfaces are worth mentioning, since their connectivity may rely

on the Transport Network:

- the AMF (Access and Mobility Function) connects with the RAN

control plane over the N2 interface

- the SMF controls the 5GC UPF via the N4 interface

┌ ─ ─ ─ ─ ┐ ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐

RAN 5G Core (5GC)

│ │ │ │

│ │ │ [AUSF] [NRF] [UDM] etc. │

│ │ │ (Service Based) │

( Architecture)

│ │ │ │

N2 ┌─────┐ N11 ┌─────┐

│ CP ───────────┤ AMF ├─────┤ SMF │ │

└─────┘ └──┬──┘

│ │ │ │ │

│ Control Plane

═══════════════════════════════════════════════════════════

│ User Plane

│ │ │ │ N4 │

N3 ┌──┴──┐ N6 .───────.

│ UP ───────────────────────┤ UPF ├───────▶( DN )

└─────┘ `───────'

│ │ │ │

─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

Figure 31: 5G Core Network (CN)

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B.3. Radio Access Network (RAN)

The RAN connects cellular wireless devices to a mobile Core Network.

The RAN is made up of three components, which form the Radio Base

Station:

\* The Baseband Unit (BBU) provides the interface between the Core

Network and the Radio Network. It connects to the Radio Unit and

is responsible for the baseband signal processing to packet.

\* The Radio Unit (RU) is located close to the Antenna and controlled

by the BBU. It converts the Baseband signal received from the BBU

to a Radio frequency signal.

\* The Antenna converts the electric signal received from the RU to

radio waves

The 5G RAN Base Station is called a gNodeB (gNB). It connects to the

Core Network via the N3 (User Plane) and N2 (Control Plane)

interfaces.

The 5G RAN architecture supports RAN disaggregation in various ways.

Notably, the BBU can be split into a DU (Distributed Unit) for

digital signal processing and a CU (Centralized Unit) for RAN Layer 3

processing. Furthermore, the CU can be itself split into Control

Plane (CU-CP) and User Plane (CU-UP).

Figure 32 depicts a disaggregated RAN with NFs and interfaces.

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┌─────────────────────────────────┐ ┌ ─ ─ ─ ─ ─ ┐

│ │ N3

┌────┐ NR │ ├────┤ 5G Core │

│ UE ├──────┤ gNodeB │

└────┘ │ ├────┤ (5GC) │

│ │ N2

└─────────────────────────────────┘ └ ─ ─ ─ ─ ─ ┘

│ │

│ │

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┌─────────────────────────────────┐ ┌ ─ ─ ─ ─ ─ ┐

│ ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐ │

│ │ │ │

┌────┐ NR │ ┌────┐ F2 │┌────┐ F1-U ┌─────┐│ │ N3 ┌─────┐

│ UE ├────────┤ RU ├─────┤ DU ├──────┤CU-UP├──────────┤ UPF │ │

└────┘ │ └────┘ │└────┘ └──┬──┘│ │ └─────┘

│ ╲ │ │ │ │

│ │ ╲ │ │ │

│ ╲ │ │ │ │

│ │ ╲ │E1 │ │

│ F1-C ╲ │ │ │ │

│ │ ╲ │ │ │

│ ╲ │ │ │ │

│ │ ╲ │ │ │

│ ┌──┴──┐ │ N2 │ ┌─────┐ │

│ │ │CU-CP├──────────┤ AMF │

│ └─────┘ │ │ └─────┘ │

│ │ │ │

│ BBU split │ │ 5G Core │

│ └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘ │

│ │ │ (5GC) │

│ disaggregated gNodeB │

└─────────────────────────────────┘ └ ─ ─ ─ ─ ─ ┘

Figure 32: RAN Disaggregation

B.4. Transport Network (TN)

The 5G transport architecture defines three main segments for the

Transport Network, which are commonly referred to as Fronthaul (FH),

Midhaul (MH), and Backhaul (BH) [TR-GSTR-TN5G]:

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\* Fronthaul happens before the BBU processing. In 5G, this

interface is based on eCPRI (Enhanced CPRI) with native Ethernet

or IP encapsulation.

\* Midhaul is optional: this segment is introduced in the BBU split

presented in Appendix B.3, where Midhaul network refers to the DU-

CU interconnection (i.e., F1 interface). At this level, all

traffic is encapsulated in IP (signaling and user plane).

\* Backhaul happens after BBU processing. Therefore, it maps to the

interconnection between the RAN and the Core Network. All traffic

is also encapsulated in IP.

Figure 33 illustrates the different segments of the Transport Network

with the relevant Network Functions.

┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐

│ Transport Network │

│ │

TN Segment 1 TN Segment 2 TN Segment 3

│ (Fronthaul) (Midhaul) (Backhaul) │

┌───────────┐ ┌────────────┐ ┌───────────┐

│ │ │ │ │ │ │ │

─ ┼ ─ ─ ─ ─ ─ ┼ ┼ ─ ─ ─ ─ ─ ─│─│─ ─ ─ ─ ─ ─│─ ─ ─ ─ ─ ─ ─

┌─┴──┐ ┌─┴─┴┐ ┌─┴─┴┐ ┌──┴──┐ .───.

│ RU │ │ DU │ │ CU │ │ UPF ├────( DN )

└────┘ └────┘ └────┘ └─────┘ `───'

Figure 33: 5G Transport Segments

It is worth mentioning that a given part of the transport network can

carry several 5G transport segments concurrently, as outlined in

Figure 34. This is because different types of 5G network functions

might be placed in the same location (e.g., the UPF from one slice

might be placed in the same location as the CU-UP from another

slice).

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┌ ─ ─ ─ ─ ┐

┌────┐ Colocated

││RU-1│ │ RU/DU

└─┬──┘

│ │ FH-1 │

┌─┴──┐

││DU-1│ │ ┌────┐ ┌─────┐ .───.

└─┬──┘ │CU-1│ │UPF-1├────────( DN )

└ ─│─ ─ ─ ┘ └─┬─┬┘ └─┬───┘ `───'

┌ ─│─ ─ ─ ─ ─ ─│─│─ ─ ─ ─ ─ ─ ┼ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

│ MH-1 │ │ BH-1 │ Transport Network │

│ └───────────┘ └────────────┘

┌───────────┐ ┌────────────┐ ┌───────────┐ │

│ │ FH-2 │ │ MH-2 │ │ BH-2 │

─ ┼ ─ ─ ─ ─ ─ ┼ ┼ ─ ─ ─ ─ ─ ─│─│─ ─ ─ ─ ─ ─│─ ─ ─ ─ ─ ─ ─ ┘

┌─┴──┐ ┌─┴─┴┐ ┌─┴─┴┐ ┌─┴───┐ .───.

│RU-2│ │DU-2│ │CU-2│ │UPF-2├────( DN )

└────┘ └────┘ └────┘ └─────┘ `───'

Figure 34: Concurrent 5G Transport Segments

Acknowledgments

The authors would like to thank Adrian Farrel, Joel Halpern and Tarek

Saad for their reviews of this document and for providing valuable

feedback on it.

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