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Transport Network aware Mobility for 5G
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Abstract

This document specifies a framework and mapping from slices in 5G mobile systems to transport slices in IP and Layer 2 transport networks. Slices in 5G systems are characterized by latency bounds, reservation guarantees, jitter, data rates, availability, mobility speed, usage density, criticality and priority should be mapped to transport slice characteristics that include bandwidth, latency and criteria such as isolation, directionality and disjoint routes. Mobile slice criteria need to be mapped to the appropriate transport slice and capabilities offered in backhaul, midhaul and fronthaul connectivity segments between radio side network functions and user plane function (gateway).

This document describes how mobile network functions map its slice criteria to identifiers in IP packets that transport segments use to grant transport layer services. This is based on mapping between mobile and IP transport underlays (IPv6, MPLS, IPv4, Segment Routing). Applicability of this framework and a new transport network underlay routing mechanism, Preferred Path Routing (PPR), which brings slice properties and works with any underlying transport (L2, IPv4, SR and MPLS) is also discussed.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC2119 [RFC2119].

Status of This Memo

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1. Introduction

The 3GPP architecture for 5GS is defined in [TS.23.501-3GPP], [TS.23.502-3GPP] and [TS.23.503-3GPP]. The architecture defines a comprehensive set of functions for access mobility, session handling and related functions for subscription management, authentication and policy among others. These network functions (NF) are defined using a service-based architecture (SBA) that allows NFs to expose their functions via an API and common service framework.

UPFs are the data forwarding entities in the 5GC architecture. The architecture allows the placement of Branching Point (BP) and Uplink Classifier (ULCL) UPFs closer to the access network (5G-AN). The 5G-AN can be a radio access network or any non-3GPP access network, for example, WLAN. The IP address is anchored by a PDU session anchor UPF (PSA UPF). 3GPP slicing and RAN aspects are further described in (Appendix A.1).

5GS allows more than one UPF on the path for a PDU (Protocol Data Unit) session that provides various functionality including session anchoring, uplink classification and branching point for a multihomed IPv6 PDU session. The interface between the BP/ULCL UPF and the PSA UPF is called N9 [TS.23.501-3GPP]. 3GPP has adopted GTP-U for the N9 and N3 interface between the various UPF instances and the (R)AN and also for the F1-U interface between the DU and the CU in the RAN. 3GPP has specified control and user plane aspects in [TS.23.501-3GPP] to provide slice and QoS support. 3GPP has defined three broad slice types to cover enhanced mobile broadband (eMBB) communications,

ultra-reliable low latency communications(URLLC) and massive internet of things (mIoT). ATIS [ATIS075] has defined an additional slice type for V2X services. There may be multiple instances of a slice type to satisfy some characteristics like isolation. The slice details in 3GPP, ATIS or NGMN do not specify how slice characteristics for QoS, hard /soft isolation, protection and other aspects should be satisfied in IP transport networks. This is explored further in this document.

1.1. Problem Statement

[TS.23.501-3GPP] and [TS.23.502-3GPP] define network slicing as one of the core capability of 5GC with slice awareness from Radio and 5G Core (5GC) network. The 5G System (5GS) as defined, does not consider the resources and functionalities needed from transport network for the selection of UPF. This is seen as independent functionality and currently not part of 5GS.

However, the lack of underlying Transport Network (TN) awareness may lead to selection of sub-optimal UPF(s) and/or 5G-AN during 5GS various procedures (e.g., session establishment, mobility). Meeting the specific slice characteristics on the F1-U, N3, N9 interfaces depends on the IP transport underlay providing these resources and capabilities. This could also lead to the inability in meeting SLAs for real-time, mission-critical or latency sensitive services. 5GS procedures including but not limited to Service Request, PDU Session Establishment, or UE mobility need same service level characteristics from the Transport Network (TN) for the Protocols Data Unit (PDU) session, similar to as provided in Radio and 5GC for the various Slice Service Types (SST) and 5QI's defined in [TS.23.501-3GPP].

The 5GS provides slices to its clients (UEs). The UE's PDU session spans the access network (radio network including the F1-U) and N3 and N9 transport segments which have an IP transport underlay. The 5G operator needs to obtain slice capability from the IP transport provider. Several UE sessions that match a slice may be mapped to an IP transport segment. Thus there needs to be a mapping between the slice capability offered to the UE (S-NSSAI) and what is provided by the IP transport.

1.2. Solution Approach

This document specifies an approach to fulfil the needs of 5GS to transport user plane traffic from 5G-AN to UPF for all service continuity modes [TS.23.501-3GPP] in an optimized fashion. This is done by, keeping establishment and mobility procedures aware of underlying transport network along with slicing requirements.

(Section 2) describes in detail on how TN aware mobility can be built irrespective of underlying TN technology used. Using Preferred Path Routing (PPR), applicable to any transport network underlay (IPv6, MPLS and IPv4) is detailed in (Section 3.1). How other IETF TE technologies applicable for this draft is specified in (Section 3.2). At the end, (Appendix B) further describes the applicability and procedures of PPR with 5G SSC modes on F1-U, N3 and N9 interfaces.

1.3. Acronyms

5QI - 5G QoS Indicator

5G-AN - 5G Access Network

AMF - Access and Mobility Management Function (5G)

BP - Branch Point (5G)

CSR - Cell Site Router

CP - Control Plane (5G)

CU - Centralized Unit (5G, gNB)

DN - Data Network (5G)

DU - Distributed Unit (5G, gNB)

eMBB - enhanced Mobile Broadband (5G)

FRR - Fast ReRoute

gNB - 5G NodeB

GBR - Guaranteed Bit Rate (5G)

GTP-U - GPRS Tunneling Protocol - Userplane (3GPP)

IGP - Interior Gateway Protocols (e.g. IS-IS, OSPFv2, OSPFv3)

LFA - Loop Free Alternatives (IP FRR)

mIOT - Massive IOT (5G)

MPLS - Multi Protocol Label Switching

NSSMF - Network Slice Selection Management Function

QFI   - QoS Flow ID (5G)

PPR   - Preferred Path Routing

PDU   - Protocol Data Unit (5G)

PW   - Pseudo Wire

RAN   - Radio Access Network

RQI   - Reflective QoS Indicator (5G)

SBI   - Service Based Interface (5G)

SID   - Segment Identifier

SMF   - Session Management Function (5G)

SSC   - Session and Service Continuity (5G)

SST   - Slice and Service Types (5G)

SR   - Segment Routing

TE   - Traffic Engineering

ULCL   - Uplink Classifier (5G)

UP   - User Plane(5G)

UPF   - User Plane Function (5G)

URLLC   - Ultra reliable and low latency communications (5G)

2. Transport and Slice aware Mobility in 5G Networks

3GPP architecture [TS.23.501-3GPP], [TS.23.502-3GPP] describe slicing in 5GS. However, the application of 5GS slices in transport network for backhaul, mid-haul and front haul are not explicitly covered. To support specific characteristics in backhaul (N3, N9), mid-haul (F1) and front haul, it is necessary to map and provision corresponding resources in the transport domain. This section describes how to provision the mapping information in transport network and apply it so that user plane packets can be provided the transport resources (QoS, isolation, protection, etc.) expected by the 5GS slices.

TN Aware Mobility with optimized transport network functionality is explained below. How an underlay agnostic routing technology fits in

this framework in detail along with other various TE technologies briefly are in (Section 3.1) and (Section 3.2) respectively.

```
                5G Control and Management Planes
    +------------------------------------------------------------------------+
    | +--------------------------------------------------------------------+ |
    | |                    (TNF)   5G Management Plane   (TNF)             | |
    | +----+-----------------+-------------+---------------+-----------+---+ |
    |      |                 |             |               |           |     |
    | +----+-----+           |   F1-C +----+-----+         |   N2 +----+---+ |
    | |          |----------(---------|gNB-CU(CP)|--------(-------| 5GC CP | |
    | |          |           |        +----+-----+         |      +----+---+ |
    +-|          |-----------|-------------|---------------|-----------|-----+
      |          |           |             |               |           |
      |          |           |             |               |           |
      |          |           | ACTN        |               | ACTN      |
      |          |       +---+---+         |           +---+---+       |
      |          |       |       |         |           |       |       |
      | gNB-DU   |       | SDN-C |         E1          | SDN-C |       |
      |          |       |       |         |           |       |       |
      |          |       +---+---+         |           +---+---+       |
      |          |           |             |               |           |
      |          |           |             |               |           |
      |          |        __ +__           |            ___+__         |
      |          |     __/      \__     +--+---+     __/      \__    +-+-+
      |          |    /      IP     \    | gNB  |    /      IP     \   |   |
 UE---|          |-(PE) Mid-haul (PE)---+CU(UP)+--(PE) Backhaul(PE)--+UPF|--DN
      +----------|    \__          __/    +------+    \__          __/   +---+
                         \______/                      \______/

                   |------ F1-U -------|        |------ N3 OR N9 ------|
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Figure 1: Backhaul and Mid-haul Transport Network for 5G

2.1. Backhaul and Mid-Haul Transport Network

Figure 1 depicts IP Xhaul network with SDN-C and PE (Provider Edge) routers provide IP transport service to 5GS user plane entities 5G-AN (e.g. gNB) and UPF. 5GS architecture with high level management, control and user plane entities and its interaction with the IP transport plane is shown here. The slice capability required in IP transport networks is estimated and provisioned by the functionality as specified in Section 2.4 (TNF) with support from various other control plane functions such as the Network Data Analytics Function (NWDAF), Network Function Repository Function (NRF) and Policy

Control Function (PCF). The TNF is only a logical function that maybe realized in a 3GPP management function such as Network Slice Selection Management Function (NSSMF) defined in [TS.28.533-3GPP]. The TNF requests the SDN-C to provision the IP XHaul network using ACTN [RFC8453].

The 5G management plane in Figure 1 interacts with the 5G control plane - the 5GC (5G Core), gNB-CU (5G NodeB Centralized Unit) and gNB-DU (5G Node B Distributed Unit). Non-access stratum (NAS) signaling from the UE for session management, mobility is handled by the 5GC. When a UE initiates session establishment, it indicates the desired slice type in the S-NSSAI (Specific Network Slice Selection Assistance Information) field. The AMF uses the S-NSSAI, other subscription information and configuration in the NSSF to select the appropriate SMF and the SMF in turn selects UPFs (User Plane Functions) that are able to provide the specified slice resources and capabilities.

The AMF, SMF, NSSF, PCF, NRF, NWDAF and other control functions in 5GC are described in [TS.23.501-3GPP] Some of the slice capabilities along the user plane path between the (R)AN and UPFs (F1-U, N3, N9 segments) such as a low latency path, jitter, protection and priority needs these to be provided by the IP transport network.

The 5G user plane from UE to DN (Data Network) includes a mid-haul segment (F1-U between gNB DU(UP), gNB CU(UP)) and backhaul (N3 between gNB - UPF; N9 between UPFs). If the RAN uses lower layer split architecture as specified by O-RAN alliance, then the user plane path from UE to DN also includes the fronthaul interface. The fronthaul interface carries the radio frames in the form of In-phase (I) and Quadrature (Q) samples using eCPRI encapsulation over Ethernet or UDP over IP.

The N3, N9 and F1 user planes use GTP-U [TS.29.281-3GPP] to transport UE PDUs (IPv4, IPv6, IPv4v6, Ethernet or Unstructured). For the front haul described further in Section 2.2, an Ethernet transport with VLANs can be expected to be the case in many deployments.

Figure 1 also depicts the PE router, where transport paths are initiated/terminated can be deployed separately with UPF or both functionalities can be in the same node. The TNF provisions this in the SDN-C of the IP XHaul network using ACTN [RFC8453]. When a GTP encapsulated user packet from the (R)AN (gNB) or UPF with the slice information traverses the F1U/N3/N9 segment, the PE router of the IP transport underlay can inspect the slice information and provide the provisioned capabilities. This is elaborated further in (Section 2.5).

2.2. Front Haul Transport Network

The O-RAN Alliance has specified the fronthaul interface between the O-RU and the O-DU in [ORAN-WG4.CUS-O-RAN]. The radio layer information, in the form of In-phase (I) and Quadrature (Q) samples are transported using Enhanced Common Public Radio Interface (eCPRI) framing over Ethernet or UDP. On the Ethernet based fronthaul interface, the slice information is carried in the Ethernet header through the VLAN tags. The Ethernet switches in the fronthaul transport network can inspect the slice information (VLAN tag) in the Ethernet header and provide the provisioned capabilities. The mapping of I and Q samples of different radio resources (radio resource blocks or carriers etc.,.) to different slices and to their respective VLAN tags on the fronthaul interface is controlled by the O-RAN fronthaul C-Plane and M-Plane interfaces. On UDP based fronthaul interface, the slice information is carried in the IP or UDP header. The PE routers of the fronthaul transport network can inspect the slice information in the IP or UDP header and provide the provisioned capabilities. The fronthaul transport network is latency and jitter sensitive. The provisioned slice capabilities in the fronthaul transport network MUST take care of the latency and jitter budgets of the specific slice for the fronthaul interface. The provisioning of the fronthaul transport network is handled by the SDN-C pertaining to the fronthaul transport.

2.3. Mobile Transport Network Context (MTNC) and Scalability

The MTNC represents a slice, QoS configuration for a transport path between two 3GPP user plane functions. The Mobile-Transport Network Context Identifier (MTNC-ID) is generated by the TNF to be unique for each path and per traffic class (including QoS and slice aspects). Thus, there may be more than one MTNC-ID for the same QoS and path if there is a need to provide isolation (slice) of the traffic. It should be noted that MTNC are per class/path and not per user session (nor is it per data path entity). The MTNC-IDs are configured by the TNF to be unique within a provisioning domain.

Since the MTNC-IDs are not generated per user flow or session, there is no need for unique MTNC-IDs per flow/session. In addition, since the traffic estimation not performed at the time of session establishment, there is no provisioning delay experienced during session setup. The MTNC-ID space scales as a square of the number sites between which 3GPP user plane functions require paths. If there are T traffic classes across N sites, the number of MTNC-IDs in a fully meshed network is (N*(N-1)/2) * T. For example, if there are 3 traffic classes between 25 sites, there would be at most 900 MTNC-IDs required. Multiple slices for the same QoS class that need to be

fully isolated, will add to the MTNC provisioning. An MTNC-ID space of 16 bits (65K+ identifiers) can be expected to be sufficient.

2.4. Transport Network Function (TNF)

Figure 1 shows a view of the functions and interfaces for provisioning the MTNC-IDs. The focus is on provisioning between the 3GPP management plane (NSSMF), transport network (SDN-C) and carrying the MTNC-IDs in PDU packets for the transport network to grant the provisioned resources.

In Figure 1, the TNF (logical functionality within the NSSMF) requests the SDN-C in the transport domain to program the TE path using ACTN [RFC 8453]. The SDN-C programs the Provider Edge (PE) routers and internal routers according to the underlay transport technology (e.g., PPR, MPLS, SRv6). The PE router inspects incoming PDU data packets for the MTNC-ID, classifies and provides the VN service provisioned across the transport network.

The detailed mechanisms by which the NSSMF provides the MTNC-IDs to the control plane and user plane functions are for 3GPP to specify. Two possible options are outlined below for completeness. The NSSMF may provide the MTNC-IDs to the 3GPP control plane by either providing it to the Session Management Function (SMF), and the SMF in turn provisions the user plane functions (UP-NF1, UP-NF2) during PDU session setup. Alternatively, the user plane functions may request the MTNC-IDs directly from the TNF/NSSMF. Figure 1 shows the case where user plane entities request the TNF/NSSMF to translate the Request and get the MTNC-ID. Another alternative is for the TNF to provide a mapping of the 3GPP Network Instance Identifier, described in (Section 2.7) and the MTNC-ID to the user plane entities via configuration.

The TNF should be seen as a logical entity that can be part of NSSMF in the 3GPP management plane [TS.28.533-3GPP]. The NSSMF may use network configuration, policies, history, heuristics or some combination of these to derive traffic estimates that the TNF would use. How these estimates are derived are not in the scope of this document. The focus here is only in terms of how the TNF and SDN-C are programmed given that slice and QoS characteristics across a transport path can be represented by an MTNC-ID. The TNF requests the SDN-C in the transport network to provision paths in the transport domain based on the MTNC-ID. The TNF is capable of providing the MTNC-ID provisioned to control and user plane functions in the 3GPP domain. Detailed mechanisms for programming the MTNC-ID should be part of the 3GPP specifications.

2.5. Transport Provisioning

Functionality of transport provisioning for an engineered IP transport that supports 3GPP slicing and QoS requirements in [TS.23.501-3GPP] is described in this section.

During a PDU session setup, the AMF using input from the NSSF selects a network slice and SMF. The SMF with user policy from Policy Control Function (PCF) sets 5QI (QoS parameters) and the UPF on the path of the PDU session. While QoS and slice selection for the PDU session can be applied across the 3GPP control and user plane functions as outlined in (Section 2), the IP transport underlay across F1-U, N3 and N9 segments do not have enough information to apply the resource constraints represented by the slicing and QoS classification. Current guidelines for interconnection with transport networks [IR.34-GSMA] provide an application mapping into DSCP. However, these recommendations do not take into consideration other aspects in slicing like isolation, protection and replication.

IP transport networks have their own slice and QoS configuration based on domain policies and the underlying network capability. Transport networks can enter into an agreement for virtual network services (VNS) with client domains using the ACTN [RFC8453] framework. An IP transport network may provide such slice instances to mobile network operators, CDN providers or enterprises for example. The 3GPP mobile network, on the other hand, defines a slice instance for UEs as are the mobile operator's 'clients'. The Network Slice Selection Management Function (NSSMF) [TS 28.533] that interacts with a TN controller like an SDN-C (that is out of scope of 3GPP).

The ACTN VN service can be used across the IP transport networks to provision and map the slice instance and QoS of the 3GPP domain to the IP transport domain. An abstraction that represents QoS and slice instance in the mobile domain and mapped to ACTN VN service in the transport domain is represented here as MTNC-IDs. Details of how the MTNC-IDs are derived are up to functions that can estimate the level of traffic demand.

The 3GPP network/5GS provides slices instances to its clients (UE) that include resources for radio and mobile core segments. The UE's PDU session spans the access network (radio) and F1-U/N3/N9 transport segments which have an IP transport underlay. The 5G operator needs to obtain slice capability from the IP transport provider since these resources are not seen by the 5GS. Several UE sessions that match a slice may be mapped to an IP transport segment. Thus, there needs to be a mapping between the slice capability offered to the UE (NSSAI) and what is provided by the IP transport.

When the 3GPP user plane function (5G-AN, UPF) does not terminate the transport underlay protocol (e.g., MPLS), it needs to be carried in the IP protocol header from end-to-end of the mobile transport connection (N3, N9). [I-D.ietf-dmm-5g-uplane-analysis] discusses these scenarios in detail.

2.6. MTNC-ID in the Data Packet

When the 3GPP user plane function (5G-AN, UPF) and transport provider edge is on different nodes, the PE router needs to have the means by which to classify the PDU packet. The mapping information is provisioned between the 5G provider and IP transport network and corresponding information should be carried in each IP packet on the F1-U, N3, N9 interface. To allow the IP transport edge nodes to inspect the transport context information efficiently, it should be carried in an IP header field that is easy to inspect. It may be noted that the F1-U, N3 and N9 interfaces in 5GS are IP interfaces. Thus, Layer 2 alternatives such as VLAN will fail if there are multiple L2 networks on the F1-U or N3 or N9 path. GTP (F1-U, N3, N9 encapsulation header) field extensions offer a possibility, however these extensions are hard for a transport edge router to parse efficiently on a per packet basis. Other IP header fields like DSCP are not suitable as it only conveys the QoS aspects (but not other aspects like isolation, protection, etc.)

IPv6 extension headers like SRv6 may be options to carry the MTNC-ID when such mechanism is a viable (if complete transport network is IPv6 based). To mininise the protocol changes are required and make this underlay tranport independent (IPv4/IPv6/MPLS/L2), an option is to provision a mapping of MTNC-ID to a UDP port range of the GTP encapsulated user packet. A simple mapping table between the MTNC-ID and the source UDP port number can be configured to ensure that ECMP /load balancing is not affected adversely by encoding the UDP source port with an MTNC-ID mapping. This mapping is configured in 3GPP user plane functions (5G-AN, UPF) and Provider Edge (PE) Routers that process MTNC-IDs.

PE routers can thus provision a policy based on the source UDP port number (which reflects the mapped MTNC-ID) to underlying transport path and then deliver the QoS/slice resource provisioned in the transport network. The source UDP port that is encoded is the outer IP (corresponding to GTP header) while the inner IP packet (UE payload) is unaltered. The source UDP port is encoded by the node that creates the GTP-U encapsulation and therefore, this mechanism has no impact to UDP checksum calculations.

3GPP network operators may use IPSec gateways (SEG) to secure packets between two sites - for example over an F1-U, N3 or N9 segment. The

MTNC identifier in the GTP-U packet should be in the outer IP source port even after IPSec encryption for PE transport routers to inspect and provide the level of service provisioned. Tunnel mode - which is the case for SEG/IPSec gateways - adds an outer IP header in both AH (Authenticated Header) and ESP (Encapsulated Security Payload) modes. The GTP-U / UDP source port with encoded MTNC identifier should be copied to the IPSec tunnel ESP header. One option is to use 16 bits from the SPI field of the ESP header to encode the MTNC identifier and use the remaining 16 bits in SPI field to identify an SA. Load balancing entropy for ECMP will not be affected as the MTNC encoding mechanism already accounts for this.

If the RAN uses O-RAN lower layer split architecture, then a fronthaul network is involved. On an Ethernet based fronthaul transport network, VLAN tag may be an option to carry the MTNC-ID. The VLAN ID provides a 12 bit space and is sufficient to support up to 4096 slices on the fronthaul transport network. The mapping of fronthaul traffic to corresponding network slice is based on the radio resource for which the fronthaul carries the I and Q samples. The mapping of fronthaul traffic to the VLAN tag corresponding to the network slice is specified in Section 2.2. On UDP based fronthaul transport network, the UDP source port can be used to carry the MTNC-ID.

2.7. Functionality for E2E Management

With the TNF functionality in 5GS Service Based Interface, the following additional functionalities are required for end-2-end slice management including the transport network:

- o The Specific Network Slice Selection Assistance Information (S-NSSAI) of PDU session SHOULD be mapped to the assigned transport VPN and the TE path information for that slice.

- o For transport slice assignment for various SSTs (eMBB, URLLC, MIoT) corresponding underlay paths need to be created and monitored from each transport end point (CSR and PE@UPF).

- o During PDU session creation, apart from radio and 5GC resources, transport network resources needed to be verified matching the characteristics of the PDU session traffic type.

- o The TNF MUST provide an API that takes as input the source and destination 3GPP user plane element address, required bandwidth, latency and jitter characteristics between those user plane elements and returns as output a particular TE path's identifier, that satisfies the requested requirements.

o Mapping of PDU session parameters to underlay SST paths need to be done. One way to do this to let the SMF install a Forwarding Action Rule (FAR) in the UPF via N4 with the FAR pointing to a "Network Instance" in the UPF. A "Network Instance" is a logical identifier for an underlying network. The "Network Instance" pointed by the FAR can be mapped to a transport path (through L2/L3 VPN). FARs are associated with Packet Detection Rule (PDR). PDRs are used to classify packets in the uplink (UL) and the downlink (DL) direction. For UL procedures specified in (Section 2.5), (Section 2.6) can be used for classifying a packet belonging to a particular slice characteristics. For DL, at a PSA UPF, the UE IP address is used to identify the PDU session, and hence the slice a packet belongs to and the IP 5 tuple can be used for identifying the flow and QoS characteristics to be applied on the packet at UPF. If a PE is not co-located at the UPF then mapping to the underlying TE paths at PE happens based on the encapsulated GTP-US packet as specified in (Section 2.6).

o If any other form of encapsulation (other than GTP-U) either on N3 or N9 corresponding QFI information MUST be there in the encapsulation header.

o In some SSC modes (Appendix B), if segmented path (CSR to PE@staging/ULCL/BP-UPF to PE@anchor-point-UPF) is needed, then corresponding path characteristics MUST be used. This includes a path from CSR to PE@UL-CL/BP UPF [TS.23.501-3GPP] and UL-CL/BP UPF to eventual UPF access to DN.

o Continuous monitoring of the underlying transport path characteristics should be enabled at the endpoints (technologies for monitoring depends traffic engineering technique used as described in (Section 3.1) and (Section 3.2)). If path characteristics are degraded, reassignment of the paths at the endpoints should be performed. For all the affected PDU sessions, degraded transport paths need to be updated dynamically with similar alternate paths.

o During UE mobility event similar to 4G/LTE i.e., gNB mobility (Xn based or N2 based), for target gNB selection, apart from radio resources, transport resources MUST be factored. This enables handling of all PDU sessions from the UE to target gNB and this require co-ordination of gNB, AMF, SMF with the TNF module.

Integrating the TNF as part of the 5GS Service Based Interfaces, provides the flexibility to control the allocation of required characteristics from the TN during a 5GS signaling procedure (e.g. PDU Session Establishment). If TNF is seen as part of management plane, this real time flexibility is lost. Changes to detailed

signaling to integrate the above for various 5GS procedures as defined in [TS.23.502-3GPP] is beyond the scope of this document.

3. Transport Network Underlays

Apart from the various flavors of IETF VPN technologies to share the transport network resources and capacity, TE capabilities in the underlay network is an essential component to realize the 5G TN requirements. This section focuses on various transport underlay technologies (not exhaustive) and their applicability to realize Midhaul/Backhaul transport networks. Focus is on the user/data plane i.e., F1-U/N3/N9 interfaces as laid out in the framework Figure 1.

3.1. Using PPR as TN Underlay

In a network implementing source routing, packets may be transported through the use of Segment Identifiers (SIDs), where a SID uniquely identifies a segment as defined in [I-D.ietf-spring-segment-routing]. Section 5.3 [I-D.bogineni-dmm-optimized-mobile-user-plane] lays out all SRv6 features along with a few concerns in Section 5.3.7 of the same document. Those concerns as well as need for underlay agnostic (L2/IPv4/IPv6/MPLS) TE requirements are addressed by a new XHaul routing mechanism called Preferred Path Routing (PPR), of which this section provides an overview.

With PPR, the label/PPR-ID refer not to individual segments of which the path is composed, but to the identifier of a path that is deployed on network nodes. The fact that paths and path identifiers can be computed and controlled by a controller, not a routing protocol, allows the deployment of any path that network operators prefer, not just shortest paths. As packets refer to a path towards a given destination and nodes make their forwarding decision based on the identifier of a path, not the identifier of a next segment node, it is no longer necessary to carry a sequence of labels. This results in multiple benefits including significant reduction in network layer overhead, increased performance and hardware compatibility for carrying both path and services along the path.

Details of the IGP extensions for PPR are provided here:

o IS-IS - [I-D.chunduri-lsr-isis-preferred-path-routing]

o OSPF - [I-D.chunduri-lsr-ospf-preferred-path-routing]

3.1.1. PPR on F1-U/N3/N9 Interfaces

PPR does not remove GTP-U, unlike some other proposals laid out in [I-D.bogineni-dmm-optimized-mobile-user-plane]. Instead, PPR works with the existing cellular user plane (GTP-U) for F1-U/N3 and any approach selected for N9 (encapsulation or no-encapsulation). In this scenario, PPR will only help providing TE benefits needed for 5G slices from transport domain perspective. It does so for any underlying user/data plane used in the transport network (L2/IPv4/IPv6/MPLS). This is achieved by:

- For 3 different SSTs, 3 PPR-IDs can be signaled from any node in the transport network. For Uplink traffic, the 5G-AN will choose the right PPR-ID of the UPF based on the S-NSSAI the PDU Session belongs to and/or the UDP Source port (corresponds to the MTNC-ID (Section 2.5)) of the GTP-U encapsulation header. Similarly in the Downlink direction matching PPR-ID of the 5G-AN is chosen based on the S-NSSAI the PDU Session belongs to. The table below shows a typical mapping:

GTP/UDP SRC PORT	SST in S-NSSAI	Transport Path Info	Transport Path Characteristics
Range Xx - Xy X1, X2(discrete values)	MIOT (massive IOT)	PW ID/VPN info, PPR-ID-A	GBR (Guaranteed Bit Rate) Bandwidth: Bx Delay: Dx Jitter: Jx
Range Yx - Yy Y1, Y2(discrete values)	URLLC (ultra-low latency)	PW ID/VPN info, PPR-ID-B	GBR with Delay Req. Bandwidth: By Delay: Dy Jitter: Jy
Range Zx - Zy Z1, Z2(discrete values)	EMBB (broadband)	PW ID/VPN info, PPR-ID-C	Non-GBR Bandwidth: Bx

Figure 2: Mapping of PPR-IDs on N3/N9

- It is possible to have a single PPR-ID for multiple input points through a PPR tree structure separate in UL and DL direction.

- Same set of PPRs are created uniformly across all needed 5G-ANs and UPFs to allow various mobility scenarios.

- Any modification of TE parameters of the path, replacement path and deleted path needed to be updated from TNF to the relevant ingress points. Same information can be pushed to the NSSF, and/or SMF as needed.

- PPR can be supported with any native IPv4 and IPv6 data/user planes ((Section 3.1.2)) with optional TE features ((Section 3.1.3)) . As this is an underlay mechanism it can work with any overlay encapsulation approach including GTP-U as defined currently for N3 interface.

3.1.2. Path Steering Support to native IP user planes

PPR works in fully compatible way with SR defined user planes (SR-MPLS and SRv6) by reducing the path overhead and other challenges as listed in Section 5.3.7 of [I-D.bogineni-dmm-optimized-mobile-user-plane]. PPR also expands the source routing to user planes beyond SR-MPLS and SRv6 i.e., L2, native IPv6 and IPv4 user planes.

This helps legacy transport networks to get the immediate path steering benefits and helps in overall migration strategy of the network to the desired user plane. Some of these benefits with PPR can be realized with no hardware upgrade except control plane software for native IPv6 and IPv4 user planes.

3.1.3. Service Level Guarantee in Underlay

PPR also optionally allows to allocate resources that are to be reserved along the preferred path. These resources are required in some cases (for some 5G SSTs with stringent GBR and latency requirements) not only for providing committed bandwidth or deterministic latency, but also for assuring overall service level guarantee in the network. This approach does not require per-hop provisioning and reduces the OPEX by minimizing the number of protocols needed and allows dynamism with Fast-ReRoute (FRR) capabilities.

3.2. Other TE Technologies Applicability

RSVP-TE [RFC3209] provides a lean transport overhead for the TE path for MPLS user plane. However, it is perceived as less dynamic in some cases and has some provisioning overhead across all the nodes in N3 and N9 interface nodes. Also, it has another drawback with excessive state refresh overhead across adjacent nodes and this can be mitigated with [RFC8370].

SR-TE [I-D.ietf-spring-segment-routing] does not explicitly signal bandwidth reservation or mechanism to guarantee latency on the nodes/links on SR path. But SR allows path steering for any flow at the ingress and particular path for a flow can be chosen. Some of the issues around path overhead/tax, MTU issues are documented at Section 5.3 of [I-D.bogineni-dmm-optimized-mobile-user-plane]. SR-MPLS allows reduction of the control protocols to one IGP (with out needing for LDP and RSVP-TE).

However, as specified above with PPR ((Section 3.1)), in the integrated transport network function (TNF) a particular RSVP-TE path for MPLS or SR path for MPLS and IPv6 with SRH user plane, can be supplied to SMF for mapping a particular PDU session to the transport path.

4. Acknowledgements

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5. IANA Considerations

This document has no requests for any IANA code point allocations.

6. Security Considerations

This document does not introduce any new security issues.

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Appendix A. New Control Plane and User Planes

A.1. Slicing Framework and RAN Aspects

The 3GPP architecture defines slicing aspects where the Network Slice Selection Function (NSSF) assists the Access Mobility Manager (AMF) and Session Management Function (SMF) to assist and select the right entities and resources corresponding to the slice requested by the User Equipment (UE). The User Equipment (UE) indicates information regarding the set of slices it wishes to connect, in the Network Slice Selection Assistance Information (NSSAI) field during network registration procedure (Attach) and the specific slice the UE wants to establish an IP session, in the Specific NSSAI (S-NSSAI) field during the session establishment procedure (PDU Session Establishment). The AMF selects the right SMF and the SMF in turn selects the User Plane Functions (UPF) so that the QoS and capabilities requested can be fulfilled.

The architecture for the Radio Access Network (RAN) is defined in [TS.38.300-3GPP] and [TS.38.401-3GPP]. The 5G RAN architecture allows disaggregation of the RAN into a Distributed Unit (DU) and a Centralized Unit (CU). The CU is further split into control plane (CU-CP) and user plane (CU-UP). The interface between CU-UP and the DU for the user plane traffic is called the F1-U and between the CU-CP and DU for the control plane traffic is called the F1-C. The F1-C and the F1-U together are called the mid-haul interfaces. The DU does not have a CP/UP split. Apart from 3GPP, O-RAN Alliance has specified further disaggregation of the RAN at the lower layer (physical layer). The DU is disaggregated into a ORAN DU (O-DU) which runs the upper part of the physical layer, MAC and RLC and the ORAN Radio Unit (O-RU) which runs the lower part of the physical layer. The interface between the O-DU and the O-RU is called the Fronthaul interface and is specified in [ORAN-WG4.CUS-O-RAN].

A.2. Slice aware Mobility: Discrete Approach

In this approach transport network functionality from the 5G-AN to UPF is discrete and 5GS is not aware of the underlying transport network and the resources available. Deployment specific mapping function is used to map the GTP-U encapsulated traffic at the 5G-AN (e.g. gNB) in UL and UPF in DL direction to the appropriate transport slice or transport Traffic Engineered (TE) paths. These TE paths can be established using RSVP-TE [RFC3209] for MPLS underlay, SR [I-D.ietf-spring-segment-routing] for both MPLS and IPv6 underlay or PPR [I-D.chunduri-lsr-isis-preferred-path-routing] with MPLS, IPv6 with SRH, native IPv6 and native IPv4 underlays.

As per [TS.23.501-3GPP] and [TS.23.502-3GPP] the SMF controls the user plane traffic forwarding rules in the UPF. The UPFs have a concept of a "Network Instance" which logically abstracts the underlying transport path. When the SMF creates the packet detection rules (PDR) and forwarding action rules (FAR) for a PDU session at the UPF, the SMF identifies the network instance through which the packet matching the PDR has to be forwarded. A network instance can be mapped to a TE path at the UPF. In this approach, TNF as shown in (Figure 1) need not be part of the 5G Service Based Interface (SBI). Only management plane functionality is needed to create, monitor, manage and delete (life cycle management) the transport TE paths/ transport slices from the 5G-AN to the UPF (on N3/N9 interfaces). The management plane functionality also provides the mapping of such TE paths to a network instance identifier to the SMF. The SMF uses this mapping to install appropriate FARs in the UPF. This approach provide partial integration of the transport network into 5GS with some benefits.

One of the limitations of this approach is the inability of the 5GS procedures to know, if underlying transport resources are available for the traffic type being carried in PDU session before making certain decisions in the 5G CP. One example scenario/decision could be, a target 5G-AN selection during a N2 mobility event, without knowing if the target 5G-AN is having a underlay transport slice resource for the S-NSSAI and 5QI of the PDU session. The Integrated approach specified below can mitigate this.

Appendix B. PPR with various 5G Mobility procedures

PPR fulfills the needs of 5GS to transport the user plane traffic from 5G-AN to UPF in all 3 SSC modes defined [TS.23.501-3GPP]. This is done in keeping the backhaul network at par with 5G slicing requirements that are applicable to Radio and virtualized core network to create a truly end-to-end slice path for 5G traffic. When UE moves across the 5G-AN (e.g. from one gNB to another gNB), there is no transport network reconfiguration required with the approach above.

SSC mode would be specified/defaulted by SMF. No change in the mode once connection is initiated and this property is not altered here.

B.1. SSC Mode1

```
                           +--------------+
             +---+----+    |NSSMF +-----+ | +-----------------+
             |  AMF   |    |      | TNF | | |      SMF        |
             +---+--+-+    |      +-+-+-+ | +-----+-----------+
                N1  |      +--------+-+---+       |
                 |  |               | |           |
                 |  |          +---+-+---+        |
                 |  |          | SDN-C  |         |
                 |  |          +---+-+---+        |
                 |  |               | |           |
        +--------+  N2    +---------+ + ---+      |
        |           |     |                |      |
        +    +---+--+   +--++            +---+ +-+---+     +-----+
        UE1  |gNB|======|CSR|---N3--------|PE |-|UPF |-N6--| DN |
        ==   +---+      +---+            +---+ +-----+     +-----+
```

Figure 3: SSC Mode1 with integrated Transport Slice Function

After UE1 moved to another gNB in the same UPF serving area

```
                           +---------------+
             +---+----+    |NSSMF +-----+ | +----------------+
             |  AMF   |    |      | TNF | | |      SMF       |
             +------+-+    |      +-+-+-+ | +-----+----------+
                    |      +--------+-+----+      |
                    |               | |           |
                    |           +---+-+---+       |
                    |           | SDN-C  |        |
                    |           +---+-+---+       |
                    |               | |           |
                    N2    +---------+ + ---+      |
                    |     |                |      |
             +---+--+   +--++             +---+ +-+--+     +----+
             |gNB|======|CSR|---N3--------|PE |-|UPF |-N6--| DN |
             +---+      +---+             +-+-+ +----+     +----+
                                            |
                                            |
                                            |
                                            |
            +----+      +---+               |
       UE1  |gNB2|======|CSR|------N3-------+
       ==   +----+      +---+
```

Figure 4: SSC Mode1 with integrated Transport Slice Function

In this mode, IP address at the UE is preserved during mobility events. This is similar to 4G/LTE mechanism and for respective slices, corresponding PPR-ID (TE Path) has to be assigned to the packet at UL and DL direction. During Xn mobility as shown above, source gNB has to additionally ensure transport path's resources from TNF are available at the target gNB apart from radio resources check (at decision and request phase of Xn/N2 mobility scenario).

B.2. SSC Mode2

In this case, if IP Address is changed during mobility (different UPF area), then corresponding PDU session is released. No session continuity from the network is provided and this is designed as an application offload and application manages the session continuity, if needed. For PDU Session, Service Request and Mobility cases mechanism to select the transport resource and the PPR-ID (TE Path) is similar to SSC Mode1.

B.3. SSC Mode3

In this mode, new IP address may be assigned because of UE moved to another UPF coverage area. Network ensures UE suffers no loss of 'connectivity'. A connection through new PDU session anchor point is established before the connection is terminated for better service continuity. There are two ways in which this happens.

- o Change of SSC Mode 3 PDU Session Anchor with multiple PDU Sessions.

- o Change of SSC Mode 3 PDU Session Anchor with IPv6 multi-homed PDU Session.

In the first mode, from user plane perspective, the two PDU sessions are independent and the use of PPR-ID by gNB and UPFs is exactly similar to SSC Mode 1 described above. The following paragraphs describe the IPv6 multi-homed PDU session case for SSC Mode 3.

```
                          +--------------+
            +---+----+    |NSSMF +-----+ | +----------------+
            |  AMF   |    |      | TNF | | |      SMF       |
            +---+--+-+    |      +-+-+-+ | +-+-----------+--+
                |  |      +--------+-+---+   |           |
               N1  |               | |       |           |
                |  |           +---+-+--+    |           |
                |  |           | SDN-C  |    |           |
                |  |           +---+-+--+    |           |
                |  |               | |       |           |
      to-UE+----+  N2  +-----------+ |       N4        N4|
               +---+   |             |       |           |
               |       |             |       |           |
           +---+   +---++        +---+ +-------+--+    +---+ +---+
           |gNB|===|CSR |---N3---|PE |-| BP UPF   |-N9-|PE |-|UPF|-N6->
           +---+   +----+        +---+ +-------+--+    +---+ +---+ to DN
                                               | +----+
                                               +-| DN |
                                             N6  +----+
```

Figure 5: SSC Mode3 and Service Continuity

In the uplink direction for the traffic offloading from the Branching Point UPF, packet has to reach to the right exit UPF. In this case packet gets re-encapsulated by the BP UPF (with either GTP-U or the

chosen encapsulation) after bit rate enforcement and LI, towards the anchor UPF. At this point packet has to be on the appropriate VPN/PW to the anchor UPF. This mapping is done based on the S-NSSAI the PDU session belongs to and/or with the UDP source port (corresponds to the MTNC-ID (Section 2.5)) of the GTP-U encapsulation header to the PPR-ID of the exit node by selecting the respective TE PPR-ID (PPR path) of the UPF. If it's a non-MPLS underlay, destination IP address of the encapsulation header would be the mapped PPR-ID (TE path).

In the downlink direction for the incoming packet, UPF has to encapsulate the packet (with either GTP-U or the chosen encapsulation) to reach the BP UPF. Here mapping is done based on the S-NSSAI the PDU session belongs, to the PPR-ID (TE Path) of the BP UPF. If it's a non-MPLS underlay, destination IP address of the encapsulation header would be the mapped PPR-ID (TE path). In summary:

- Respective PPR-ID on N3 and N9 has to be selected with correct transport characteristics from TNF.

- For N2 based mobility SMF has to ensure transport resources are available for N3 Interface to new BP UPF and from there the original anchor point UPF.

- For Service continuity with multi-homed PDU session same transport network characteristics of the original PDU session (both on N3 and N9) need to be observed for the newly configured IPv6 prefixes.

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