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    Co-existence of 3GPP 5GS and Identifier-Locator Separation Architecture
                draft-homma-dmm-5gs-id-loc-coexistence-03

Abstract

   This document describes an approach to introduce Identifier Locator
   Separation architecture into 3GPP 5GS with low-impact on its
   specifications, and shows the features and considerations of this
   approach.

Status of This Memo

   This Internet-Draft is submitted in full conformance with the
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   This Internet-Draft will expire on October 25, 2019.

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1. Introduction

   Identifier-Locator Separation (ID-LOC) architectures aim to simplify
   management of network, devices, and sessions by employing two
   namespaces: Identifier for device's identity, and Locator for its
   location in the network.

   An ID-LOC architecture can be implemented by a dedicated protocol
   such as LISP [I-D.ietf-lisp-rfc6833bis], ILA
   [I-D.herbert-intarea-ila], ILNP [RFC6740], etc. The control plane of
   such ID-LOC protocols can be combined with one of different
   encapsulation techniques such as GTP-U [TS.29281], SRv6
   [I-D.filsfils-spring-srv6-network-programming], MPLS [RFC3031], VXLAN
   [RFC7348], etc. at data plane to provide a customized solution.
   Furthermore, regarding control plane of ID-LOC, it can optionally
   even take advantage of enhanced PUB/SUB capable distributed databases
   to store ID-LOC mappings.

   ID-LOC protocols are also expected to be used for optimizing user-
   plane of mobile network
   [I-D.bogineni-dmm-optimized-mobile-user-plane]. Different
   alternatives to introduce ID-LOC architecture into 3GPP 5GS(5th
   Generation System), are under consideration in related IETF WG such
   as DMM WG.

   Introducing ID-LOC architecture into mobile network can involve
   modifications to 5GS architecture and specifications that might span
   over several 5GS releases.

   Therefore, an approach that enables the introduction of ID-LOC
   architecture into 5GS without change of its specifications and
   supports migration path toward a native ID-LOC network can be useful
   to operators. Here, ID-LOC native network refers to a network that
   employs the ID-LOC architecture as only mechanism for packet
   forwarding.

   The document aims to describe one such approach and clarify different
   features, and benefits.

2. Definition of Terms

   This section describes general terms of ID-LOC architecture. This
   document also refers definitions of 3GPP 5GS [TS.23.501-3GPP], and
   some of such terms which are used in this document are listed in this
   section.

   The LISP terms are described in [I-D.ietf-lisp-rfc6833bis].

The ILA terms are described in [I-D.herbert-intarea-ila].

The SRv6 terms are described in
[I-D.ietf-6man-segment-routing-header].

2.1. Terms of ID-LOC Protocols

Device Identifier (ID): An ID is an identifier of host or end point
   such as UE or network function including VM instance, container,
   etc. In ID-LOC architectures, an IP or MAC address is generally
   assigned to an end device as identifier. In this case, IDs are
   used as values for the source and destination IP/MAC address
   fields of packets sent from end points. Alternatively, other
   attributes of the end point, such as its Fully Qualified Domain
   Name (FQDN), can also be used as IDs.

Locator (LOC): A LOC is generally an address (e.g. IPv4, IPv6, MAC,
   etc) of the ID-LOC node. In the case of SRv6 it can be the ID-LOC
   node's local SID representing the segment for which the ID-LOC
   node is the segment termination node.

ID-LOC node; An ID-LOC node is a node that has at least one unique
   locator within a network domain, and has functionalities to obtain
   destination locator and to forward packets to the ID-LOC node
   which has the destination locator. This node has an ID-LOC
   mapping cache and obtains destination locator by looking up
   destination ID (destination address of a data packet) from the
   mapping cache. If ID of the received packet is not present in its
   own mapping cache, an ID-LOC node requests mapping information of
   the ID and the assigned locator to ID-to-LOC mapping system. Also
   an ID-LOC node forwards packet to a peered LOC node by
   encapsulation or conversion of the IP header field such as IP
   address field, and decapsulates or reconverts packets received
   from another ID-LOC node. Different implementations of ID-LOC
   architecture use different forwarding mechanisms. LISP data-
   plane, for example, uses IPv4/v6 header and LISP header for
   encapsulation, whereas ILA tightly couples itself with IPv6, and
   SRv6 uses IPv6 and SIDs (Segment Identifiers).

ID-to-LOC Mapping System: An ID-to-LOC mapping system is a database
   which contains all known ID-to-LOC mappings within an ID-LOC
   domain. The mapping information is updated when an end point
   moves to under another ID-LOC node. This database can be
   logically centralized, distributed across the ID-LOC nodes, or a
   combination of both. If the database is logically centralized,
   each ID-LOC node has an interface to the system to send a request
   and receive mapping information.

ID-to-LOC Mapping Cache: An ID-LOC mapping cache is a table in an
   ID-LOC node that stores ID-to-LOC mapping information and it is
   used for obtaining destination LOC from ID of received packet.
   ID-to-LOC mapping cache typically contains a small piece of
   database. The cache is updated when the ID-LOC node receives a
   new ID-to-LOC mapping information from ID-to-LOC mapping system.

2.2. Terms of 5GS

User Plane Function (UPF): An UPF handles the user plane paths. An
   UPF is connected to SMF with N4 interface. More detailed
   information is described in [TS.23.501-3GPP]. This document
   defines two types of UPF, Central UPF (cUPF) and Distributed UPF
   (dUPF). Their features are described in Section 3

Uplink Classifier (ULCL): An ULCL is an UPF functionality that aims
   at diverting Uplink traffic, based on filter rules provided by
   SMF, towards Data Network (DN).

Data Network (DN): A DN is a network where network functions and
   entities, including operator or 3rd party services, are deployed.
   This document defines two types of DN, Central DN (cDN) and
   Distributed DN (dDN). Their features are described in Section 3.

Radio Access Network (RAN): A RAN is an access network where radio
   bearer sent by UEs traverse. A RAN encapsulate users' packets
   with GTP-U.

Session Management Function (SMF): An SMF is a function which
   provides control plane functionalities for handling user traffic.

Application Function (AF): An AF is a control plane functionality
   and connected to SMF with Naf interfaces.

3. Mechanism on Data Plane

This approach achieves traffic forwarding with optimized path and
session continuity by using ID-LOC and ULCL for particular
communication including UE-to-UE or MEC (Mobile Edge Computing)
communication. ULCL is one of fundamental functions of 5GC Rel.15
and it provides functionalities of packet filtering and divert for
uplink packets sent by UEs.

The overview of the assumed 5GC architecture of data plane where the
proposal approach works is shown in Figure 1. The details of
numbered interfaces in the figure are described in [TS.23.501-3GPP].

```
                          .--.
                         (    )-.
                        .'  cDN/  '
                       (  Internet )
                        (         -'
                         '-(     )
                            '---'
                             |N6
                      +-----+-----+
                      |   cUPF    |                       ===
                      +-----+-----+                        ^
                            |N9                            |
             ,---------------------+--------------------.  |
            /                                          \   |
            |           Transport Network              |   |
            \                                          /   |
             `----+------------------------+--------------'
                  |N9                       |N9          Connected
            +-----+-----+    ,-----.   +-----+-----+    ,-----.    with
            |   dUPF#1  |N6 /       \   |   dUPF#2  |N6 /       \   GTP-U
            |     [UL]+---| dDN#A |   |       [UL]+---| dDN#B |..
            |     [CL]|   \       /   |       [CL]|   \       /    |
            +-----+-----+    `-----'   +-----+-----+    `-----'    |
                  |N3                       |N3                    |
                                                                   |
               (( o ))                    (( o ))                  |
                  A                          A                     v
                 /-\   RAN                  /-\   RAN             ===
                /-|-\                      /-|-\

                  |                          |

               [ UE ] ..                  [ UE ] ..


                                      dUPF: Distributed UPF
                                      cUPF: Central UPF
                                       dDN: Distributed DN
                                       cDN: Central DN
```
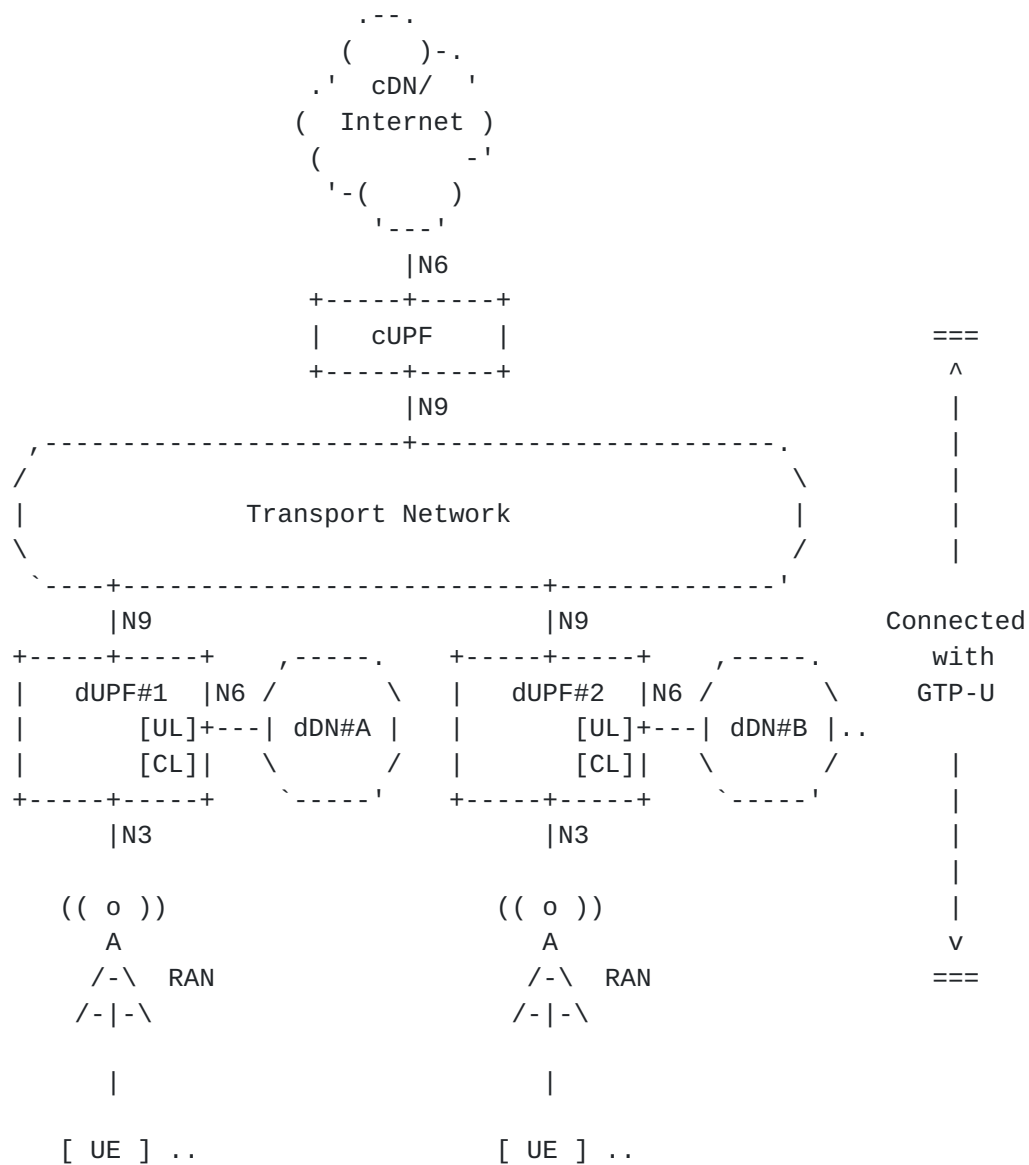
                Figure 1: Assumed 5GC Network Architecture

   This network has following features;

   o A Central UPF (cUPF) is deployed at a connecting point to Central
      DN (cDN). A cUPF becomes anchor point for UEs and it assigns IP

addresses (IDs) for each UE. The traffic transmitted from UEs are
basically sent to the cUPF.

o Distributed UPFs (dUPFs) and Distributed DNs (dDNs) are deployed
   and geographically distributed at user edge side. A unique
   address space (it's not necessarily globally unique) is assigned
   to dDN. When a dUPF forwards a UE's uplink packet, and if the
   subnet of the destination address is the same as the one assigned
   to dDN at proximity, then dUPF, with the help of ULCL, may divert
   the packet to that dDN. Here, the ULCL identifies each
   encapsulated uplink packet to be diverted, by checking if the
   destination of the inner packet is one of IP addresses assigned
   the dDN. A dUPF removes GTP-U header from the packets, and sends
   them to dDN via N6. When dUPF receives packets from dDN, dUPF
   encapsulates them with GTP-U header, and merges them into downlink
   packets from cUPF. An overview of behaviors of dUPF and ULCL is
   shown in Figure 2.

o Network topology between RAN and dUPF/cUPF adopts tree structure
   and the section between RAN and dUPF and the section between dUPF
   and cUPF are connected with GTP-U.

```
        GTP-U packets     GTP-U packets
         from cUPF           to cUPF


               |                 ^
               |      N9         |
               |                 |
          +----|------------|-----+
          |    |    dUPF    |     |           ,---------.
          |    v            |     | IP packet /           \
          |    o<---------------------------|           |
          |    |            |     |          |           |
          |    |            |     |    N6    |   dDN     |
          |    |         +------+ |          |           |
          |    |         | ULCL |------------>|           |
          |    |         +------+ | IP packet |           |
          |    |            ^     |           \         /
          +----|------------|-----+            `---------'
               |            |
               |            |
               |    N3      |
               v            |


        GTP-U packets     GTP-U packets
         to UE              from UE
```
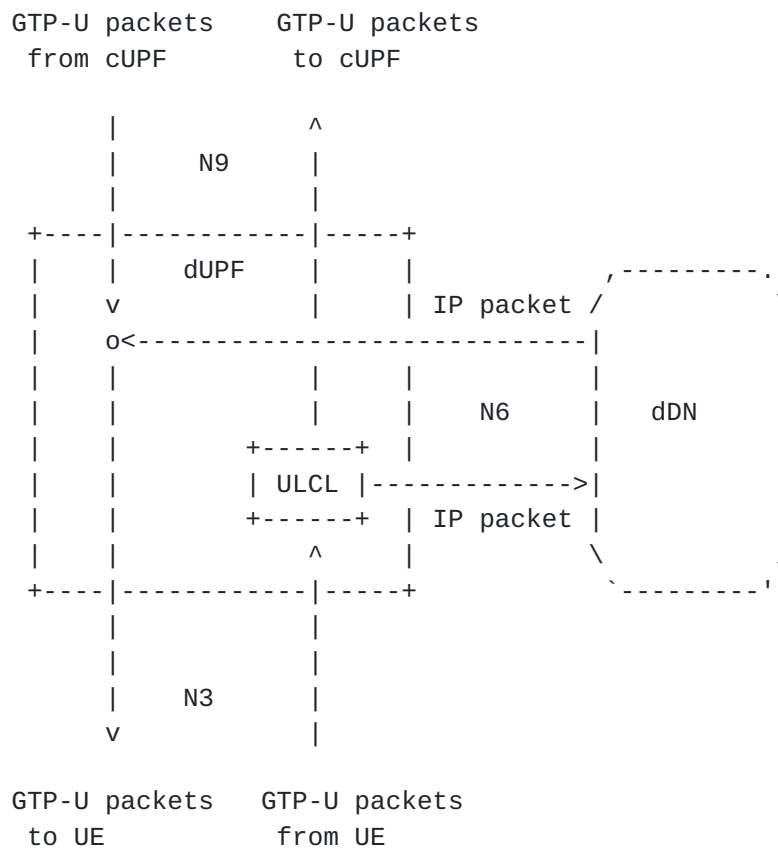
Figure 2: Behaviors of dUPF and ULCL

   In the proposed approach, IDs are assumed to be IP addresses and an
   ID-LOC node is installed between dUPF and dDN. ID-LOC nodes are
   connected with a IP mechanism such as IP tunnels or translation of
   destination IP field. As examples of such data plane protocols for
   providing connectivity between ID-LOC nodes, IPv4/v6 header with LISP
   header or SRv6 ([I-D.ietf-6man-segment-routing-header]) can be used.
   In addition, each ID-LOC node has connectivity with one or more
   Mapping Systems. The overview is shown in Figure 3.

```
                          .--.
                         (      )-.
                        .'  cDN/  '
                       (  Internet )
                       (          -'
                        '-(      )
                          '---'
                            |N6          ,---------.
                      +-----+-----+      | Mapping |
                      |   cUPF    |      | System  |
                      +-----+-----+      `---------'
                            |N9                 .
        ,---------------------+----------------.---------.
       / Transport Network   . . . . . . . . . . . . .  \
       |                   .                          .  |
       \             #=========================#===   /
        `----+-----------#--.-----------+-----------#--.-'
            |N9         #  .           |N9         #  .
      +-----+-----+   +-------+   +-----+-----+   +-------+
      |   dUPF#1  |N6 | ID-LOC|   |   dUPF#2  |N6 | ID-LOC|
      |      [UL]+---+ Node#1|   |      [UL]+---| Node#2|..
      |      [CL]|   |       |   |      [CL]|   |       |
      +-----+-----+   +---+---+   +-----+-----+   +---+---+
           |N3            |            |N3            |
                      ,-----.                      ,-----.
       (( o ))       /       \      (( o ))        /       \
          A         | dDN#A  |         A          | dDN#B  |
         /-\   RAN   \       /        /-\   RAN    \       /
        /-|-\         `-----'        /-|-\          `-----'

           |                           |

        [ UE ] ..                    [ UE ] ..


                              =====  : Connection between LOC nodes
                              . . .  : IF to Mapping System
```
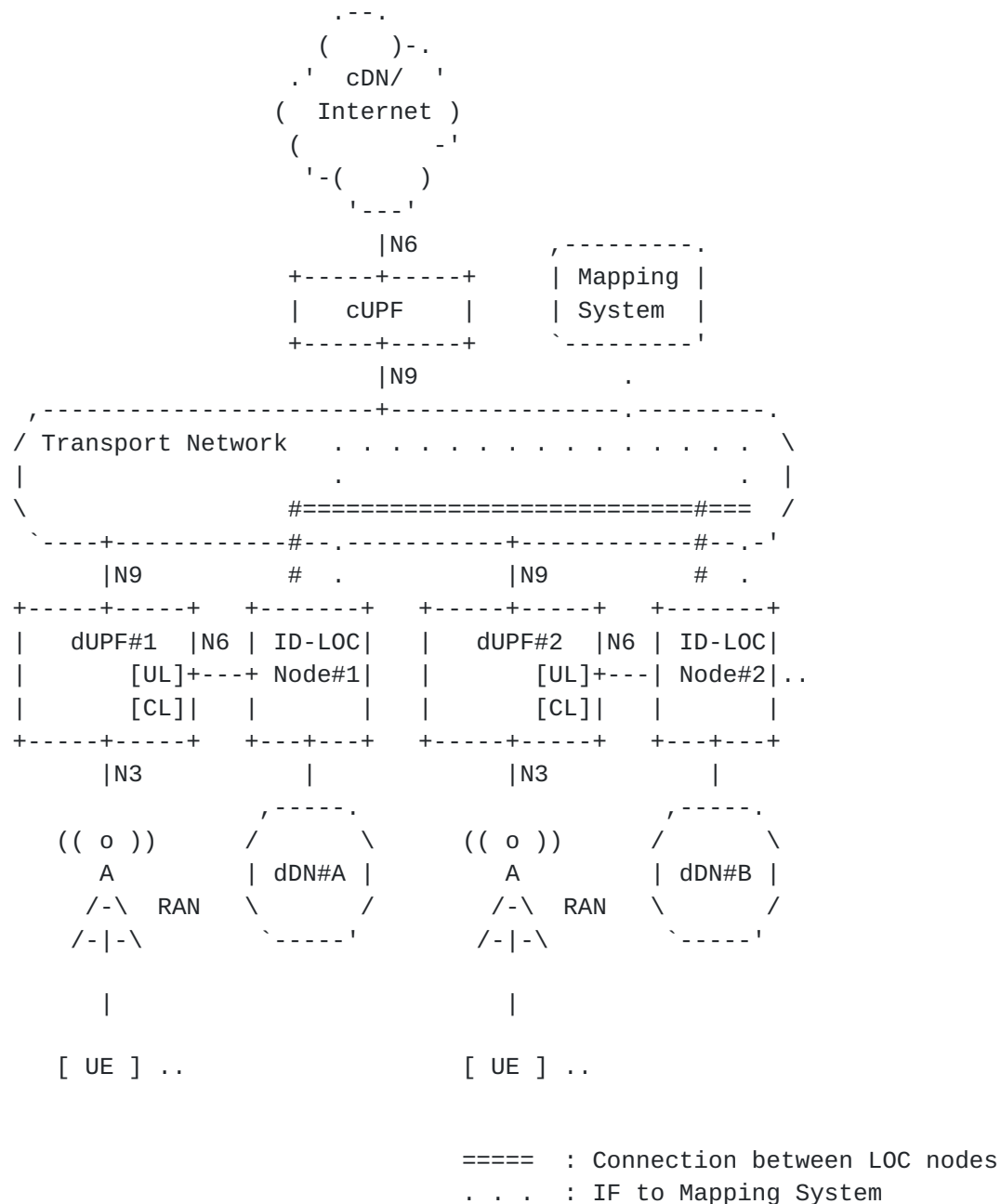
Figure 3: Proposal Network Architecture

Each dUPF has a filter table of ULCL. Each filter table is
configured to match the addresses of UEs within the network domain
(i.e., addresses for UEs assigned by the cUPF). Filter tables can
also be configured to match the address corresponding to the address
space (or part of) corresponding with the dDNs in the network domain.
UPFs monitor each uplink GTP-U packet with its ULCL and divert it to
the connected ID-LOC node with decapsulation of GTP-U if the

destination address of the inner packet (payload) matches the
filtering table. When ID-LOC node receives a packet from the dUPF,
it obtains LOC which the destination of the packet (ID) belongs to by
looking up its own ID-to-LOC mapping table or querying it from the
Mapping System according ID-LOC mechanism. Then it sends the packet
to peered ID-LOC node indicated by the LOC. The peered ID-LOC node
converts the received packet to appropriate form and forwards them
the destination by following its own forwarding table.

From such processes, forwarding paths of user traffic diverted by
ULCL from 5GC to ID-LOC node are optimized.

A cUPF is connected with dUPFs via N9 interface and packets are
forwarded with GTP-U encapsulation between cUPF and dUPF.

Some case studies of ID-LOC protocols are described in Appendix A and
Appendix B.

4. Mechanisms on Control Plane

For ID-LOC mechanism in mobile networks, a control plane mechanism is
required to manage location information of UEs and NFs in each dDN.
There are mainly three models to realize control plane mechanism for
ID-LOC as follows:

Model 1: Independent Control Planes

Model 2: Interworking Control Planes

Model 3: Integrated Control Planes

Some of models may require to use 5GS interfaces or add some
functionalities to functions of 5GC. 5GS architecture and the
service-based interfaces are shown in Figure 4. The details of
functions and interfaces are described in [TS.23.501-3GPP].

```
    +-----+  +-----+  +-----+      +-----+  +-----+  +-----+
    |NSSF |  | NEF |  | NRF |      | PCF |  | UDM |  | AF  |
    +--+--+  +--+--+  +--+--+      +--+--+  +--+--+  +--+--+
   Nnssf|    Nnef|    Nnrf|        Npcf|    Nudm|       |Naf
    ---+--------+--+-----+--+-------+--+-----+--------+-
             Nausf|    Namf|        Nsmf|
             +--+--+  +--+--+      +--+--+
             |AUSR |  | AMF |      | SMF |
             +-----+  +--+--+      +-----+
                        /|            |
   C-plane           N1/ |N2          |N4


  ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
   U-plane              /     |            |
                   N1 /      |N2          |N4
                     /       |            |
                 +-+-+  +--+--+ N3   +--+--+ N6   +----+
                 |UE +--+(R)AN+-----+ UPF +-----+ DN |
                 +---+  +-----+      ++---++      +----+
                                     |   |
                                     +---+
                                      N9
```
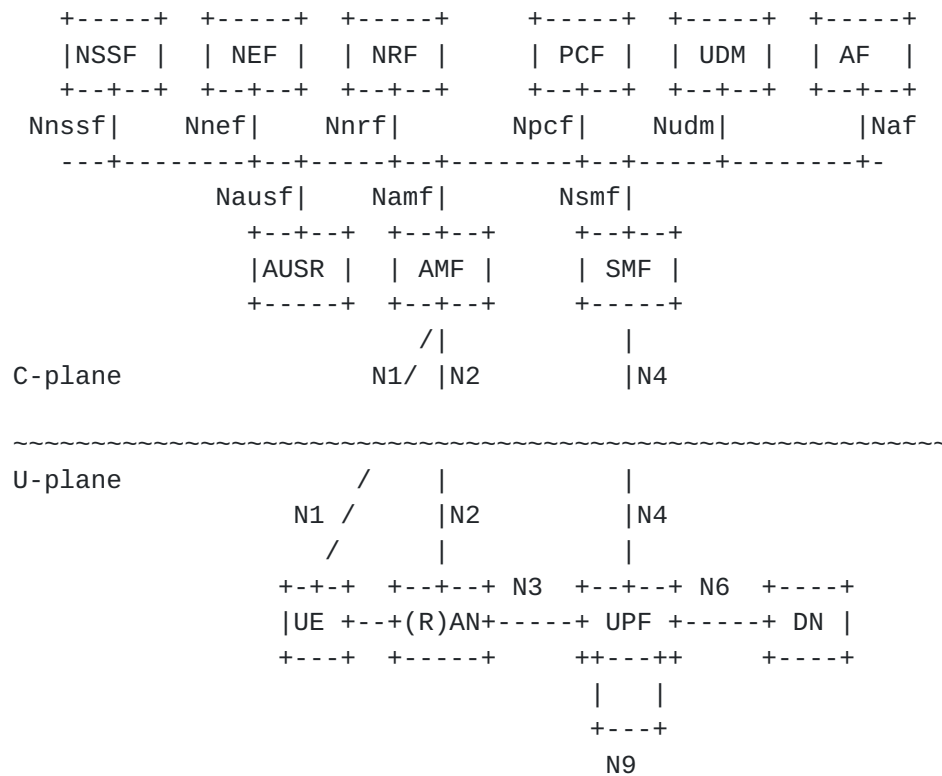
Figure 4: 5GS Architecture and Service-based Interfaces

4.1. Model 1: Independent Control Planes

In this model, control plane of 5GC and ID-to-LOC mapping mechanism
are completely separated. Information of a UE and an ID-LOC node
which the UE is attached is sent to a mapping system and registered
in the mapping database only when the ID-LOC node receives a packet
from the UE and the UE is not registered yet.

This model does not cause any impacts on 5GC architecture. However,
in this model, a UE cannot be accessed from other UEs within the same
network domain until a packet from the UE is diverted to the ID-LOC
node by the UPF which the UE is located and the ID and LOC are
registered to the Mapping System.

4.2. Model 2: Interworking Control Planes

In this model, a mapping system interworks with an SMF which manages
sessions of each UE. A scheme to inform, that a UE moves and is
relocated to another UPF, from SMF to AF via Naf interface is defined
in 5GS ([TS.23.502-3GPP])*. A Mapping System is installed as an AF
and obtains mobility information of UEs with the above scheme.

   * The stage 3 of discussion of 5GS has not been fixed yet and the
   specification may be changed.

   This model would not cause any impacts on 5GS architecture, and a
   mapping system can always keep the current mobility information of
   each UE.

4.3. Model 3: Integrated Control Planes

   In this model, SMF functionalities are integrated into a mapping
   system. In other words, the mapping system becomes a part of 5GS.
   In 5GS architecture, an SMF has a role of session management of UEs,
   and it updates its own mapping database depending on movement of a
   UE.

   This approach enables to always keep mapping databases the latest
   status, however, it obviously requires extension or replacement of
   SMF actually deployed in 5GS network.

5. Features Analysis

5.1. Benefits

   o This approach provides a mechanism for introducing ID-LOC
      architecture into 5GS with no or nominal impact, and achieves
      optimized forwarding with session continuity in the assumed use
      cases such as UE-to-UE or UE-to-dDN communications.

   o Regarding communication to the cDN, this approach can keep
      scalability because it does not change the current mechanism of
      5GS.

5.2. Issues

   o dUPF and ID-LOC node are separated, and thus an extra hop may
      occur against the optimized forwarding. However, it can be
      resolved by implementing dUPF and ID-LOC node within a same box or
      application.

6. Security Considerations

   TBD

7. IANA Considerations

   This memo includes no request to IANA.

8. Acknowledgement

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Appendix A. Case Studies on Use of LISP

   This Appendix describes detailed processes of the proposal approach
   with LISP mechanism in the following types of communications.

   1. UE-to-UE Communication

   2. UE-to-dDN Communication

   3. UE-to-cDN/Internet Communication

   In the following description of case studies, ID and Locator are
   called EID (End-point Identifier) and RLOC (Routing Locator) in LISP
   terms. Mapping Server has the master of EID-to-RLOC mapping
   database, and each xTR (Ingress/Egress Tunnel Router) has EID-to-RLOC
   mapping cache. An xTR obtains the destination RLOC from its own

cache by looking up the destination EID of received packet. They
obtain mappings from the mapping system if an EID looked up is not
registered in the cache. Packets are passed between xTRs with some
tunnel protocols.

A.1. **UE-to-UE Communication**

In the current architecture, a cUPF becomes an anchor point for UEs,
and all packets between UEs even those which are located to the same
dUPF are transferred through the anchor point. This may cause
communication delay and inefficient resource usage. In the proposed
procedure, packets can be transferred without going through an anchor
point, and low latency and efficient resource usage can be achieved.

The UE-to-UE communications include communications between UEs
located to different dUPFs (Case 1), and communication between UEs
located to the same dUPF (Case 2). In this section, the detailed
procedures of the cases are described.

Moreover, in a mobile network, a UE may move during communications.
This section describes considerations about UE's handover in such
case.

A.1.1. **Case A-1: UEs allocated different dUPF**

```
                        +-------+
                        |Mapping|
                        |System |
                        +-------+
                           .
                           .
                           .
                    (3) .     #========================#
                        .  #             (4)           #
                        .  #                            V
        +-------+          +-------+     +-------+      +-------+
        | dUPF#1|          | xTR#1 |     | dUPF#2|      | xTR#2 |
        |       |          | RLOC=X|     |+------|<-----| RLOC=Y|
        |   [UL]|          |       |     || [UL]|  (5) |       |
        |   [CL]|------>|           |     |v  [CL]|      |       |
        +-------+  (2)  +-------+     +-------+      +-------+
           ^                              |
           | (1)                         |(6)
           |                              v

         [UE#1]                        [UE#2]
          EID=a-1                       EID=a-2
```
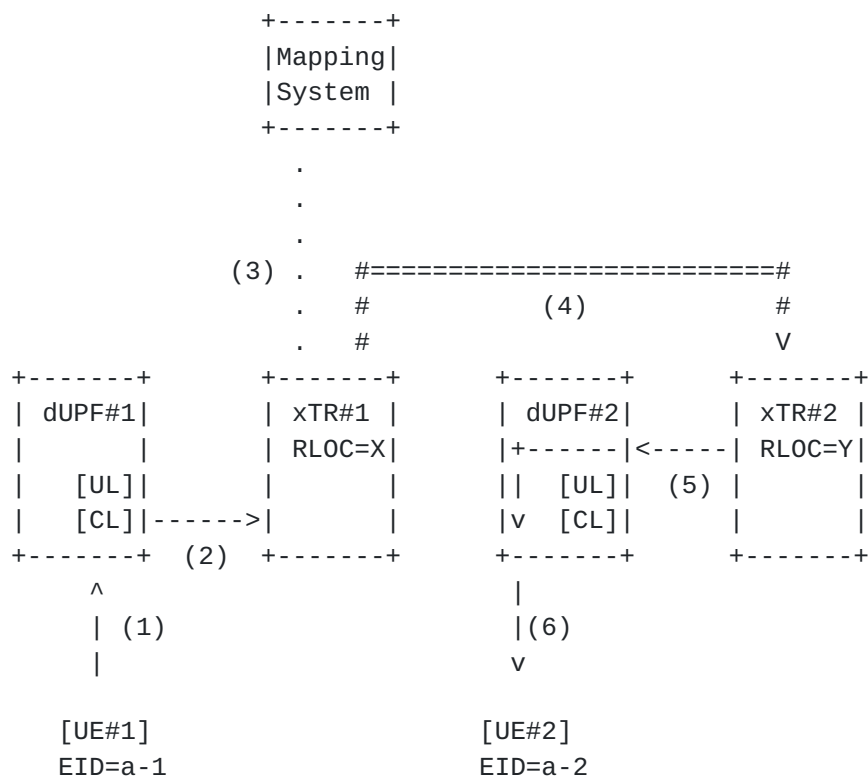
Figure 5: Procedure in Case A-1

(0) Within this network, addresses are assigned to UEs from a
     address space [A]. These addresses are described as a-n
     (n=1,2,..). EID=a-1 and a-2 are assigned to UE#1 and UE#2.

(1) UE#1 sends packets to UE#2 with setting EID=a-2 as the
     destination IP address.

(2) dUPF#1 monitors inner packet of received GTP-U packet and divert
     it to xTR#1 with decapsulation if the destination address is one
     of address space [A].

(3) xTR#1 updates own EID-to-RLOC mapping cache by interaction with
     Mapping System (if needed).

(4) xTR#1 obtains the RLOC(=Y) of EID=a-2 from the EID-to-RLOC
     mapping cache, and sends the packets to the xTR#2 with a tunnel
     with RLOC=Y as the destination address.

(5) xTR#2 decapsulate the packets, and sends them to dUPF#2.

(6) dUPF#2 encapsulate packets with GTP-U header, and sends them to
     UE#2.

A.1.2. Case A-2: UEs allocated the same xTR

```
                      +-------+
                      |Mapping|
                      |System |
                      +-------+




    +-------+        +-------+       +-------+      +-------+
    | dUPF#1|  (3)   | xTR#1 |       | dUPF#2|      | xTR#2 |
    |+------|<-----  | RLOC=X|       |       |      | RLOC=Y|
    ||  [UL]|        |       |       |  [UL]|       |       |
    |v  [CL]||------>|       |       |  [CL]|       |       |
    +-------+  (2)   +-------+       +-------+      +-------+
     |      ^
  (4) |     | (1)
     v      |


   [UE#2]  [UE#1]
  EID=a-2  EID=a-1
```
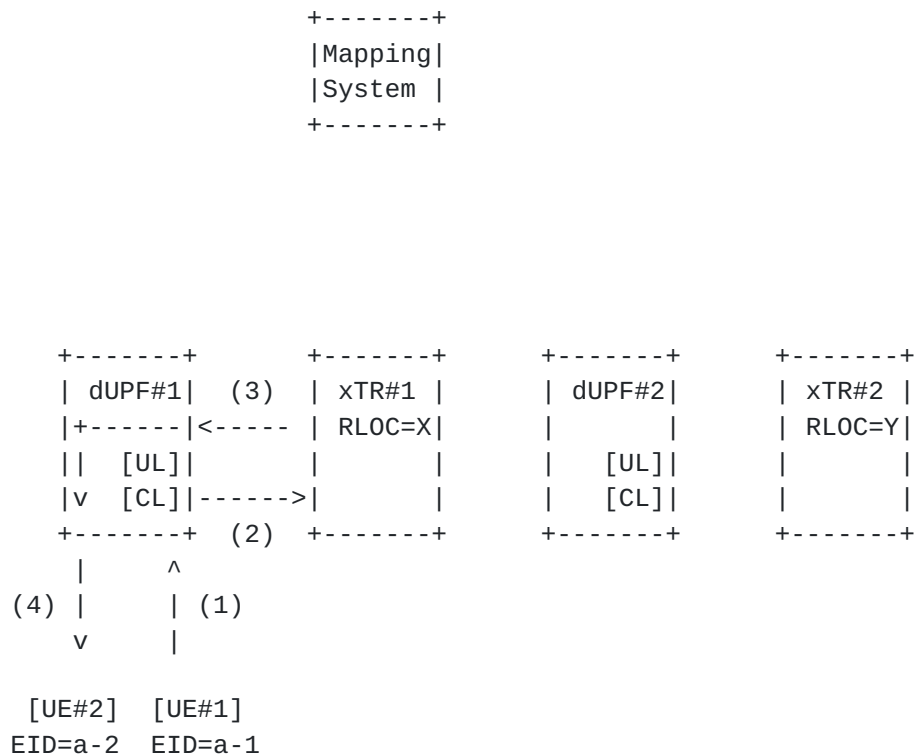
                  Figure 6: Procedure in Case A-2

   (0) Within this network, addresses are assigned to UEs from a
        address space [A]. These addresses are described as a-n
        (n=1,2,..). EID=a-1 and a-2 are assigned to UE#1 and UE#2.

   (1) UE#1 sends packets to UE#2 with setting EID=a-2 as the
        destination IP address.

   (2) dUPF#1 monitors inner packets of received GTP-U traffic and
        divert it to xTR#1 with decapsulation if the destination address
        is one of address space [A].

   (3) Since xTR#1 serves UE#2, it locally routes the traffic for
        EID=a-2. xTR#1 sends the received packets back to dUPF#1.

   (4) dUPF#1 encapsulate packets with GTP-U, and sends them to UE#2.

A.1.3. Consideration of Case that UE Moves to under Another xTR

   When a UE moves to a serving area of another dUPF during
   communication with another UE, EID-to-RLOC mapping database of a
   Mapping System and the tables of the xTR and the peered xTR must be
   updated. Unless some of the mechanism described below are in place,
   the xTRs can't send packets to the appropriate xTR during the
   updating, and thus packet drop or stalling may occur.

   For example, a mechanism that immediately advertise the update of
   location of UEs to Mapping System and the appropriate xTRs depending
   on movement of each UE might be required. Some documents (e.g.,
   [I-D.ietf-lisp-eid-mobility], [I-D.ietf-lisp-pubsub]) discuss such
   mechanisms. Alternatively, a mechanism that replicates packets to
   both the old and new location while the UE is in transit could also
   be used. This approach is discussed in detail in
   [I-D.ietf-lisp-predictive-rlocs].

A.2. UE-to-dDN Communication

   The UE-to-dDN communications basically correspond the communication
   between a UE and neighbor dDN (Case3). On the other hand, if a UE
   moved under another dUPF during usage of a stateful application, or
   the application is not uniformly deployed in every dDN, the UE needs
   to continue to communicate with the previous dDN (Case4).

   In such cases, in the current architecture, all packets are needed to
   go through the anchor point or dynamic GTP tunnel reconfiguration
   between dUPF is required. The former solution causes additional
   communication delay and inefficient resource usage. The latter
   solution increase the cost of 5GS control plane to dynamically update
   the GTP tunnel with multiple UPFs and their ULCL filter tables along
   with the movement of the UE. The proposed approach achieves
   appropriate packet transfer in such cases.

   In this section, the detailed procedures of communications between a
   UE and neighbor dDN and communications between a UE and non-neighbor
   dDN

A.2.1. Case A-3: UE communicates with neighbor dDN

```
                      +-------+
                      |Mapping|
                      |System |
                      +-------+
                          .
                          .
                          .
                 (3) .
                          .
                          .
      +-------+        +-------+        +-------+        +-------+
      | dUPF#1|  (6)   | xTR#1 |        | dUPF#2|        | xTR#2 |
      |+------|<-----  | RLOC=X|        |       |        | RLOC=Y|
      ||  [UL]|        |       |        |  [UL]|        |       |
      |v  [CL]||------>|       |        |  [CL]|        |       |
      +-------+  (2)   +-------+        +-------+        +-------+
       |    ^           |    ^
    (7) |     | (1)    (4)|  | (5)
        v     |           v  |
                   ,-------.
      [UE#1]      /  dDN#B  \
      EID=a1     |  |   ^   |
                 |  v   |   |
                 | [APL#1] |
                 \ EID=b-1 /
                  `-------'
```

                   Figure 7: Procedure in Case A-3

   (0) Within this network, UEs are assigned their addresses from an
        address space [A]. These addresses are described as a-n
        (n=1,2,...). Also, applications in dDN#B are assigned their
        addresses from a address space [B]. These addresses are described
        as b-n (n=1,2,..). EID=a-1 and b-1 assigned to UE#1 and APL#1
        which is located in dDN#B.

   [Uplink Processes]

   (1) UE#1 sends packets to dDN#B with setting EID=b-1 as the
        destination IP address.

   (2) dUPF#1 monitors inner of received GTP-U packets and divert it to
        xTR#1 with decapsulation if the destination IP address is one of
        address space [B].

(3) xTR#1 updates own EID-to-RLOC mapping cache by interaction with
     Mapping System (if needed). Or xTR#1 may update its own cache by
     a Map-Notify message when an APL is deployed or deleted in dDB#B.

(4) Since xTR#1 serves dDN#B, it locally routes the traffic for
     EID=b-1. xTR#1 sends the packets to the dDN#B.

[Downlink Processes]

(5) APL#1 in dDN#B sends packets to UE#1 with setting EID=a-1 as the
     destination IP address.

(6) Since xTR#1 serves UE#1, it locally routes the traffic for
     EID=a-1. xTR#1 sends packets to dUPF#1.

(7) dUPF#2 encapsulates packets with GTP-U, and sends them to UE#1.

A.2.2. Case A-4: UE communicates with non-neighbor dDN

```
                        +-------+
                        |Mapping|
                        |System |
                        +-------+
                           .
                           .                   (7)
                           . #=============================#
                      (3) . # #========================# #
                           . # #            (4)         # #
                           . V #                        V #
          +-------+      +-------+      +-------+      +-------+
          | dUPF#1|  (8) | xTR#1 |      | dUPF#2|      | xTR#2 |
          |+------|<-----| RLOC=X|      |       | (0)  | RLOC=Y|
          || [UL]||      |       |      |  [UL]||<---->|       |
          |v  [CL]||----->|      |      |  [CL]||      |       |
          +-------+  (2)  +-------+      +-------+      +-------+
           |   ^                          ^            |   ^
        (9) |   | (1)                     | (0)    (5)| | (6)
            v   |                         |           v   |
                     (0)                  v         ,-------.
        [UE#1] <= = = = = = = = = = =[UE#1]       /  dDN#C  \
        EID=a-1 UE#1 moves to the serving area of  |  | ^   |
              dUPF#1 from the serving area of UPF#2 |  v  |   |
                                                  | [APL#2] |
                                                  \ EID=c-1 /
                                                   `-------'
```
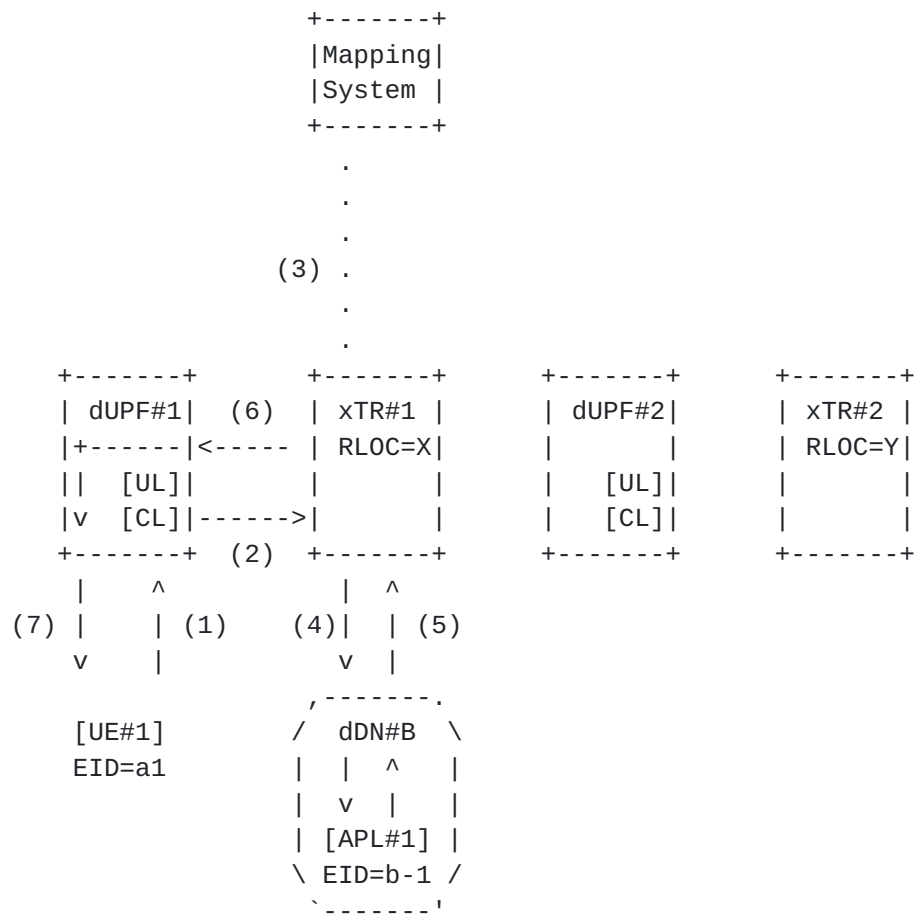
Figure 8: Procedure in Case A-4

(0) Within this network, UEs are assigned their addresses from an
     address space [A]. These addresses are described as a-n
     (n=1,2,..). And applications in dDN#C are assigned their
     addresses from an address space [C]. These addresses are
     described as c-n (n=1,2,..). EID=a-1 and c-1 assigned to UE#1 and
     APL#2 which is located in dDN#C. UE#1 has moved to the serving
     area of dUPF#1 from the serving area of UPF#2 while communicating
     to APL#2.

[Uplink Processes]

(1) UE#1 sends packets to APL#2 with setting EID=c-1 as the
     destination IP address.

(2) dUPF#1 monitors each inner packet of received GTP-U traffic and
     divert it to xTR#1 with decapsulation if the destination address
     is one of address space [C].

(3) xTR#1 updates own EID-to-RLOC mapping cache by interaction with
     Mapping System (if needed).

(4) xTR#1 obtains RLOC(=Y) of EID=c-1 from the EID-to-RLOC mapping
     cache, and sends the packet to the xTR#2 with a tunnel with RLOC=Y
     as the destination address.

(5) xTR#2 decapsulates the packets received from xTR#1, and sends
     them to dDN#C depending on its forwarding table.

[Downlink Processes]

(6) APL#2 sends packets to UE#1 with setting EID=a-1 as the
     destination IP address.

(7) xTR#2 obtains RLOC(=X) of EID=a-1 from the EID-to-RLOC mapping
     cache, and sends the packets to the xTR#1 with a tunnel with
     RLOC=X as the destination address.

(8) xTR#1 decapsulates the packets received from xTR#2m and sends
     them to the dUPF#1 depending on its forwarding table.

(9) dUPF#1 encapsulates the packets with GTP-U and sends packets to
     UE#1.

A.3. UE-to-cDN/Internet Communication

UE-to-cDN/Internet communication is achieved by GTP-U mechanism
originally equipped in 3GPP 5GS architecture. In this section, we

describe processes of UE-to-cDN communication in the proposal
architecture as an example.

A.3.1. Case A-5: UE communicates with cDN

```
                            ,------------.
                           /     cDN      \
                           |              |
                           |    EID=d-1   |
                           |    [APL#3]   |
                           |     |  ^     |
                           \     |  |    /
                            `------------'
                           (4) |  | (3)
                               v  |
                           +-----------+
                           |    cUPF   |
                           +-----------+
                               |  ^
                   (5)         |  |
             +------------------+  |
             |   +-------------------+
             |   |       (2)
             V   |
          +-------+       +-------+
          | dUPF#1|       | xTR#1 |
          |       |       | RLOC=X|
          |   [UL]|       |       |
          |   [CL]|       |       |
          +-------+       +-------+
             |  ^
         (6) |  | (1)
             v  |

           [UE#1]
           EID=a-1
```

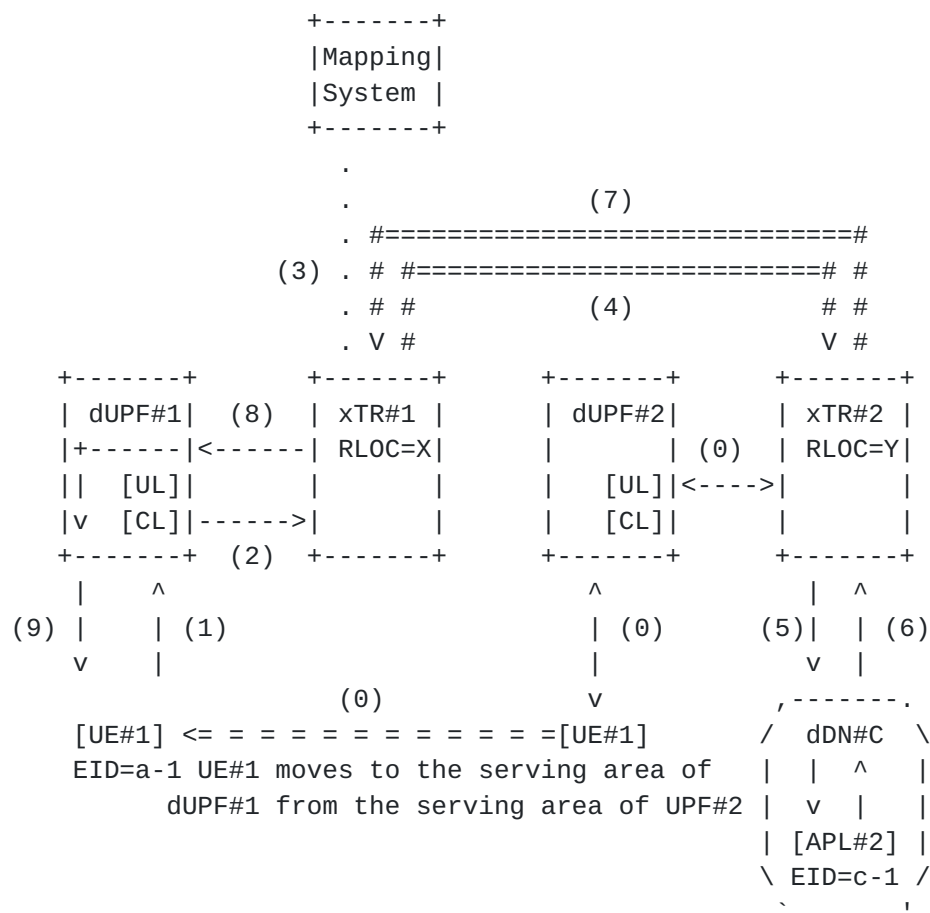   Figure 9: Procedure in Case A-5
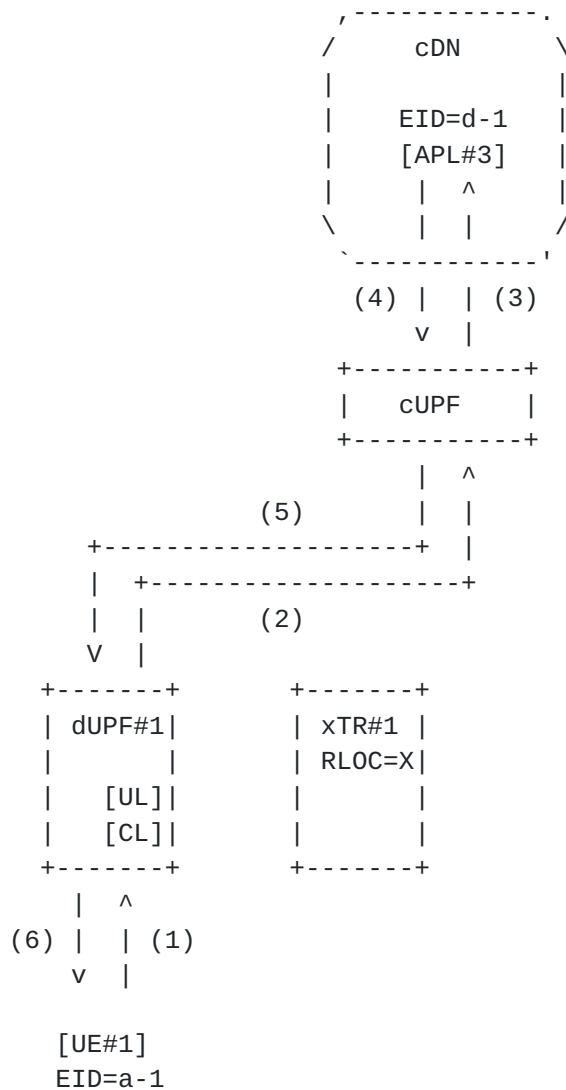
   (0) Within this network, UEs are assigned their addresses from an
        address space [A]. These addresses are described as a-n
        (n=1,2,..). And applications in cDN are assigned their addresses
        from an address space [D]. These addresses are described as d-n
        (n=1,2,..). EID=a-1 and d-1 assigned to UE#1 and APL#3 which is
        located in cDN.

[Uplink Processes]

(1) UE#1 sends packets to cDN with setting EID=d-1 as the
     destination IP address.

(2) dUPF#1 monitors inner of received GTP-U packets. Since the
     destination IP address (EID=d-1) does not hit the filter of ULCL,
     dUPF#1 re-encapsulates the packet to another GTP-U connecting to
     cUPF and forwards to cUPF.

(3) cUPF decapusalates GTP-U packets and forwards them to APL#3 in
     cDN depending on its own forwarding table.

[Downlink Processes]

(4) APL#3 in cDN sends packets to UE#1 with setting EID=a-1 as the
     destination IP address.

(5) cUPF encapsulates the packets received from APL#3 and forwards
     them to dUPF#1 depending on its own forwarding table.

(6) dUPF re-encapsulates the packets to another GTP-U and forwards
     to UE#1.

Appendix B. Case Studies on Use of ILA

This Appendix describes detailed processes of the proposal approach
with ILA mechanism in the following types of communications.

1. UE-to-UE Communication

2. UE-to-dDN Communication

3. UE-to-cDN/Internet Communication

Each ILA node has ID-to-LOC mapping table. Mappings are propagated
amongst ILA routers or hosts in a network using mapping propagation
protocols.

In the following description of case studies, a mapping system,
called ILA resolver in ILA terms, has the master of ID-to-LOC mapping
database, and each ILA node obtains mappings from the mapping system.
In some cases, each ILA node has an ID-to-LOC mapping database.

In ILA, an SIR address expressed by composition of SIR prefix and
identifier is assigned to each UE or VM instance. An SIR prefix and
an identifier are described SIR_prefix_n and id_m (n=1,2,...,
m=1,2,...), and an SIR address is expressed as SIR_addr_x =[n,m]

(x=1,2,...) in the following description. Also, each ILA-Nodes are
assigned unique Locators, which is a network prefix that routes to a
host. Locators are described as loc_n (n=1,2,..).

B.1. UE-to-UE Communications

The overview of this communication type is described in A.1.

B.1.1. Case B-1: UEs allocated different dUPF
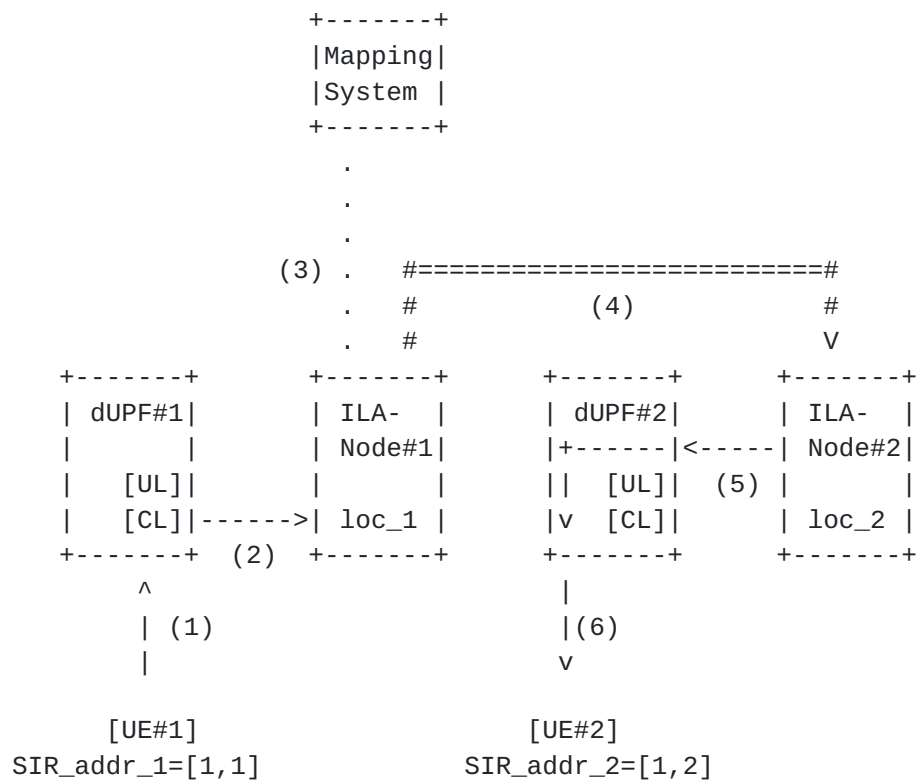
```
                         +-------+
                         |Mapping|
                         |System |
                         +-------+
                            .
                            .
                            .
                     (3) .    #=========================#
                         .   #            (4)           #
                         .   #                           V
       +-------+     +-------+     +-------+     +-------+
       | dUPF#1|     | ILA-  |     | dUPF#2|     | ILA-  |
       |       |     | Node#1|     |+------|<-----| Node#2|
       |   [UL]|     |       |     || [UL]|  (5) |       |
       |   [CL]|------>| loc_1 |     |v  [CL]|     | loc_2 |
       +-------+  (2)  +-------+     +-------+     +-------+
           ^                             |
           | (1)                         |(6)
           |                             v

         [UE#1]                       [UE#2]
     SIR_addr_1=[1,1]            SIR_addr_2=[1,2]


              Legend: SIR_addr_x=[(SIR_Prefix), (Identifier)]



                 Figure 10: Procedure in Case B-1
```

(0) Within this network, UEs are belonged to the same ILA domain,
     and the same SIR prefix is assigned to UEs. SIR_addr_1=[1,1] and
     SIR_addr_2=[1,2] are assigned to UE#1 and UE#2.

(1) UE#1 sends packets to UE#2 with setting SIR_addr_2 as the
     destination IP address.

(2) dUPF#1 monitors inner packet of received GTP-U packet and
     diverts it to ILA-Node#1 with decapsulation if the prefix of the
     destination address is SIR_prefix_1.

(3) ILA-Node#1 updates own ID-to-LOC mapping table by interaction
     with the mapping system (if needed).

(4) ILA-Node#1 obtains loc_2 as Locator of the ILA node#2 from the
     ID-to-LOC mapping table. ILA-Node#1 converts the prefixes of the
     source and destination addresses to loc_1 (Locator of id_1) and
     loc_2 (Locator of id_2). ILA-Node#1 sends the packet to the ILA-
     Node#2.

(5) ILA-Node#2 receives the packet and converts the prefixes of the
     source and destination addresses to SIR_prefix_1, and then sends
     packets to dUPF#2.

(6) dUPF#2 encapsulate packets with GTP-U header, and sends them to
     UE#2.

B.1.2. Case B-2: UEs allocated the same ILA node

```
                          +-------+
                          |Mapping|
                          |System |
                          +-------+
                             .
                             .
                             .
                             .
                      (3)  .
                             .
                             .
                             .
         +-------+        +-------+       +-------+       +-------+
         | dUPF#1|  (4)   | ILA-  |       | dUPF#2|       | ILA-  |
         |+------|<-----  | Node#1|       |       |       | Node#2|
         ||  [UL]|        |       |       |  [UL]|       |       |
         |v  [CL]||------>| loc_1 |       |  [CL]|       | loc_2 |
         +-------+  (2)   +-------+       +-------+       +-------+
          |       ^
     (5) |       | (1)
          v       |

      [UE#2]    [UE#1]
   SIR_addr_2   SIR_addr_1
   =[1,2]       =[1,1]
```

Legend: SIR_addr_x=[(SIR_Prefix), (Identifier)]

Figure 11: Procedure in Case B-2

(0) Within this network, UEs are belonged to the same ILA domain,
     and the same SIR prefix is assigned to UEs. SIR_addr_1=[1,1] and
     SIR_addr_2=[1,2] are assigned to UE#1 and UE#2.

(1) UE#1 sends packets to UE#2 with setting SIR_addr_2 as the
     destination IP address.

(2) dUPF#1 monitors inner packet of received GTP-U packet and
     diverts it to ILA-Node#1 with decapsulation if the prefix of the
     destination address is SIR_prefix_1.

(3) ILA-node#1 updates own ID-to-LOC mapping table by interaction
     with Mapping System (if needed).

(4) ILA-Node#1 obtains loc_1 as Locator of ILA node#2 from the ID-
     to-LOC mapping table. Since loc_1 indicates itself, ILA-Node#1
     sends the packets back to dUPF#1.

(5) dUPF#1 encapsulate packets with GTP-U, and sends them to UE#2.

B.2. UE-to-dDN Communication

The overview of this communication type is described in A.2.

B.2.1. Case B-3: UE communicates with neighbor dDN

```
                         +-------+
                         |Mapping|
                         |System |
                         +-------+
                             .
                             .
                             .
                             .
                      (3)  .
                             .
                             .
          +-------+       +-------+      +-------+      +-------+
          | dUPF#1|  (6)  | ILA-  |      | dUPF#2|      | ILA-  |
          |+------|<----- | Node#1|      |       |      | Node#2|
          ||  [UL]|       |       |      |  [UL]||      |       |
          |v  [CL]|------>| loc_1 |      |  [CL]||      | loc_2 |
          +-------+  (2)  +-------+      +-------+      +-------+
           |   ^           |   ^
       (7) |   | (1)    (4)|   | (5)
           v   |           v   |
                        ,---------.
          [UE#1]       /   dDN#B     \
     SIR_addr_1=[1,1]  |  |    ^     |
                       |  v    |     |
                       | [APL#1]     |
                       |SIR_addr_2   |
                       \ =[2,2]     /
                        `---------'
```

Legend: SIR_addr_x=[(SIR_Prefix), (Identifier)]
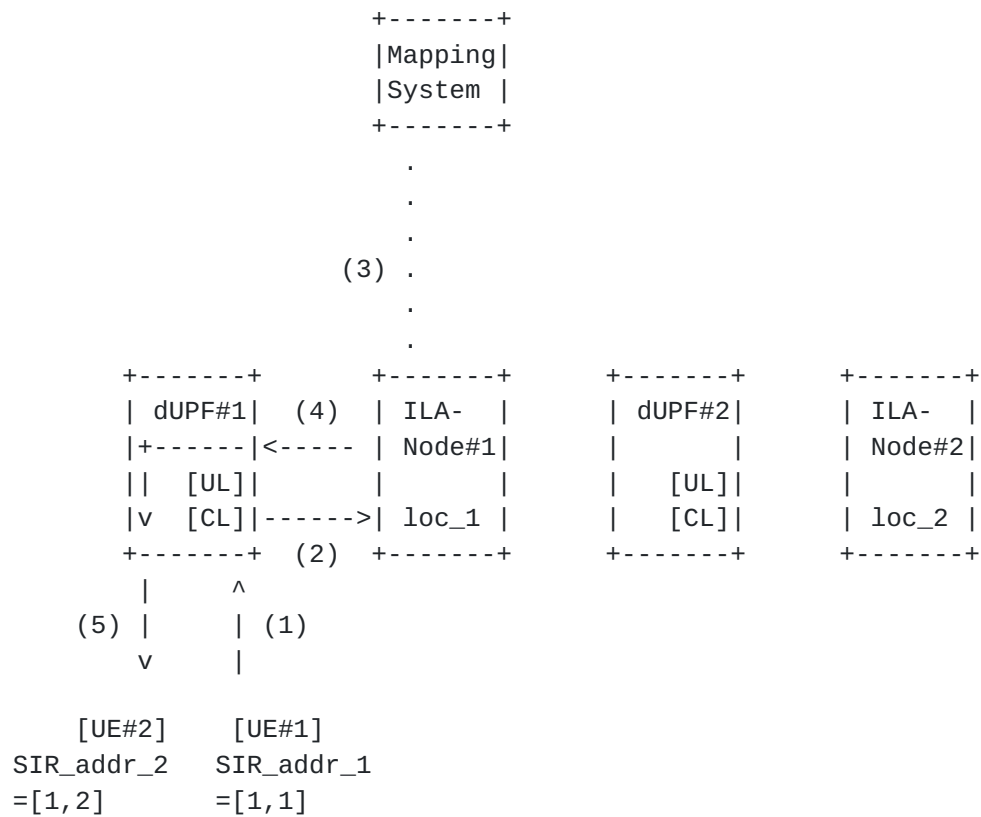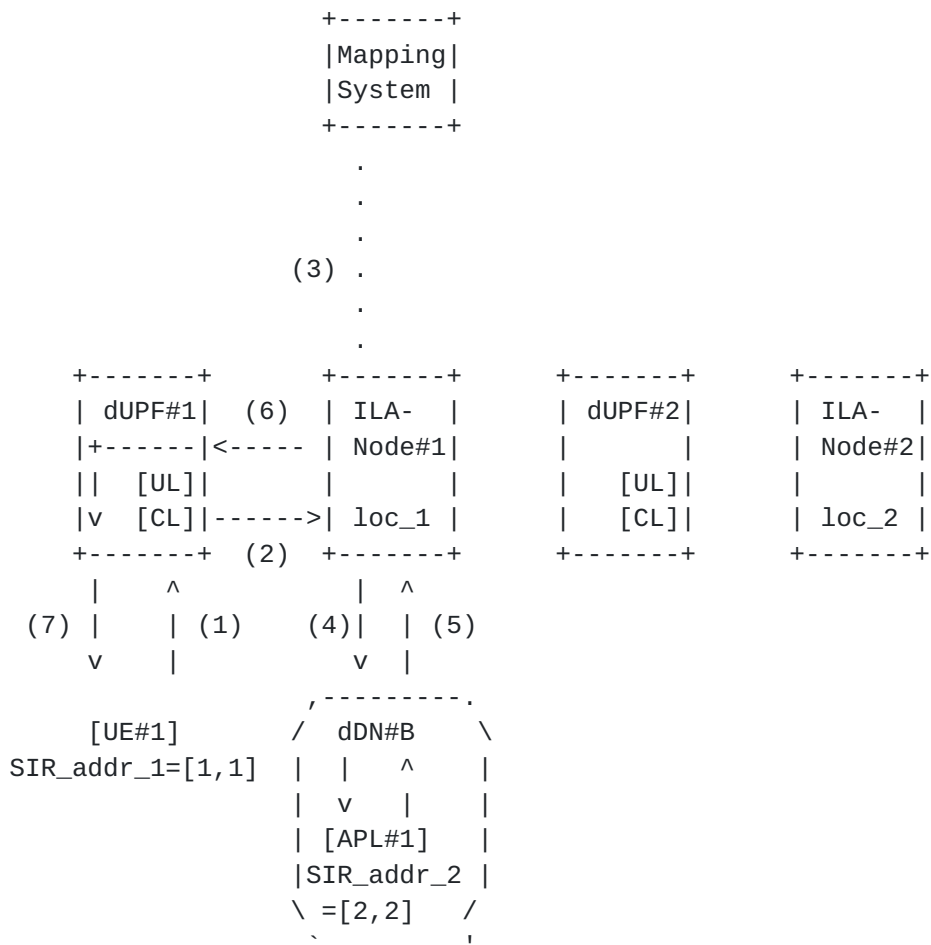
Figure 12: Procedure in Case B-3

(0) Within this network, UEs are belonged to the same ILA domain,
     and the same SIR prefix (SIR_prefix_1) are assigned to UEs.
     Applications in dDN#B are belonged to different ILA domain. and
     different SIR prefix (SIR_prefix_2) is assigned to these
     applications. SIR_addr_1=[1,1] and SIR_addr_2=[2,2] are assigned
     to UE#1 and APL#1. APL#1 is located in dDN#B.

Uplink Processes

(1) UE#1 sends packets to APL#1 with setting SIR_addr_2 as the
     destination IP address.

(2) dUPF#1 monitors inner packet of received GTP-U packet and
     diverts it to ILA-Node#1 with decapsulation if the prefix of the
     destination address is SIR_prefix_2.

(3) ILA-Node#1 updates own ID-to-LOC mapping table by interaction
     with a mapping system (if needed). Or ILA-Node#1 may update its
     own table by a Map-Notify message when an APL is deployed or
     deleted in dDB#B.

(4) ILA-Node#1 obtains loc_1 as Locator of id_2 from the ID-to-LOC
     mapping table. Since loc_1 indicates itself, ILA-Node#1 sends the
     packets to the dDN#B.

Downlink Processes

(5) APL#1 in dDN#B sends packets to UE#1 with setting SIR_address_1
     as the destination IP address.

(6) ILA-Node#1 obtains loc_1 as Locator of id_1 from the ID-to-LOC
     mapping table. Since loc=1 indicates itself, ILA-Node#1 sends
     packets to dUPF#1.

(7) dUPF#2 encapsulates packets with GTP-U, and sends them to UE#1.

B.2.2. Case B-4: UE communicates with non-neighbor dDN

```
                      +-------+
                      |Mapping|
                      |System |
                      +-------+
                       .
                       .                     (7)
                       . #===============================#
                  (3) . # #===========================# #
                       . # #              (4)          # #
                       . V #                           V #
         +-------+       +-------+       +-------+       +-------+
         | dUPF#1|  (8)  | ILA-  |       | dUPF#2|       | ILA-  |
         |+------|<------| Node#1|       |       | (0)   | Node#2|
         ||  [UL]|       |       |       |   [UL]|<---->|       |
         |v  [CL]||------>| loc_1 |       |   [CL]|       | loc_2 |
         +-------+  (2)  +-------+       +-------+       +-------+
          |    ^                           ^             |  ^
      (9) |    | (1)                       | (0)     (5)| | (6)
          v    |                           |             v  |
                      (0)                  v        ,--------.
         [UE#1] <= = = = = = = = = = = =[UE#1]     /  dDN#C   \
       SIR_addr_1  UE#1 moves to the serving area of | |   ^   |
       =[1,1]    dUPF#1 from the serving area of UPF#2 | v   |   |
                                                    | [APL#2]  |
                                                    |SIR_adrr_3|
                                                    \ =[3,3]   /
                                                     `--------'
```

Legend: SIR_addr_x=[(SIR_Prefix), (Identifier)]

Figure 13: Procedure in Case B-4

(0) Within this network, UEs are belonged to the same ILA domain,
     and the same SIR prefix (SIR_prefix_1) are assigned to UEs.
     Applications in dDN#C are belonged to different ILA domain. and
     different SIR prefix (SIR_prefix_3) is assigned to these
     applications. SIR_addr_1=[1,1] and SIR_addr_3=[3,3] are assigned
     to UE#1 and APL#2. APL#2 is located in dDN#C. UE#1 has moved to
     the serving area of dUPF#1 from the serving area of UPF#2 while
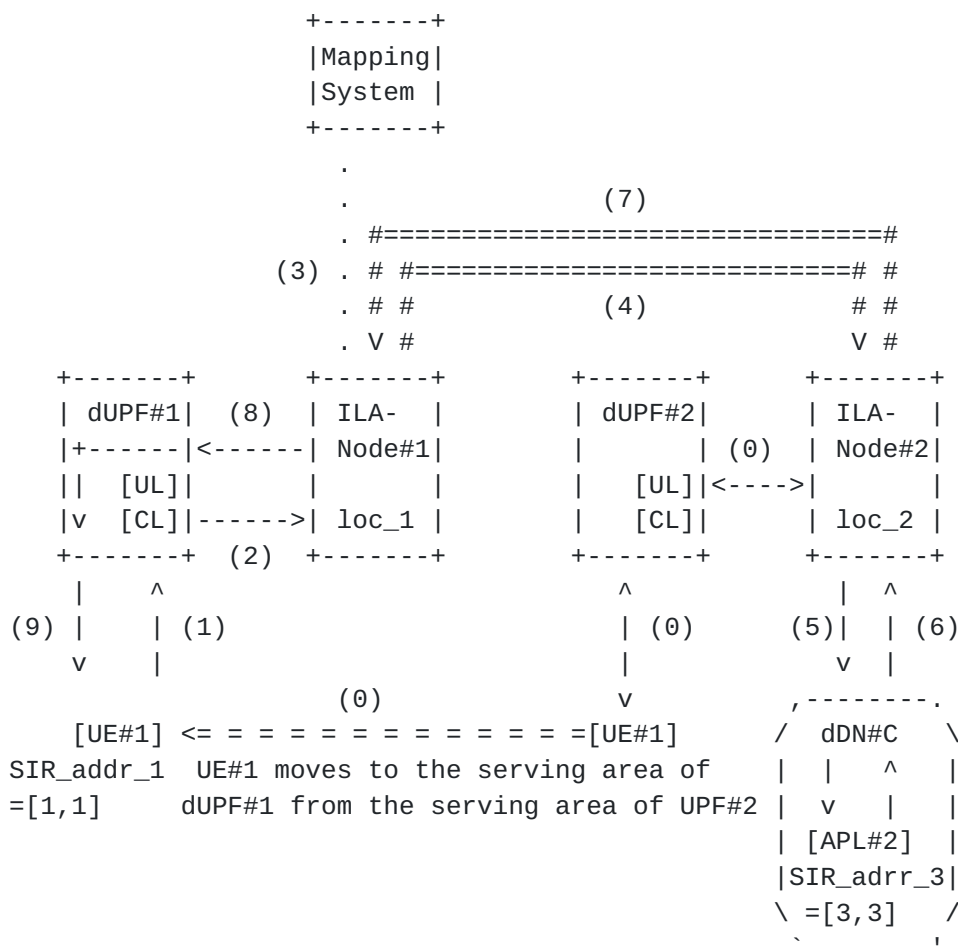   communicating to APL#2.

Uplink Processes

(1) UE#1 sends packets to APL#2 with setting SIR_addr_3 as the
     destination IP address.

(2) dUPF#1 monitors inner packet of received GTP-U packet and
     diverts it to ILA-Node#1 with decapsulation if the prefix of the
     destination address is SIR_prefix_3.

(3) ILA-Node#1 updates own ID-to-LOC mapping table by interaction
     with Mapping System (if needed).

(4) ILA-Node#1 obtains loc_2 as Locator of id_3 from the ID-to-LOC
     mapping table. ILA-Node#1 converts the prefix of the source
     address to loc_1 (Locator of id_1), and the prefix of the
     destination address to loc_2 (Locator of id_3). ILA-Node#1 sends
     the packet to the ILA-Node#2.

(5) ILA-Node#2 converts the prefix of the source address to
     SIR_prefix_1, and the prefix of the destination address to
     SIR_prefix_3, and then sends packets to dDN#C depending on its
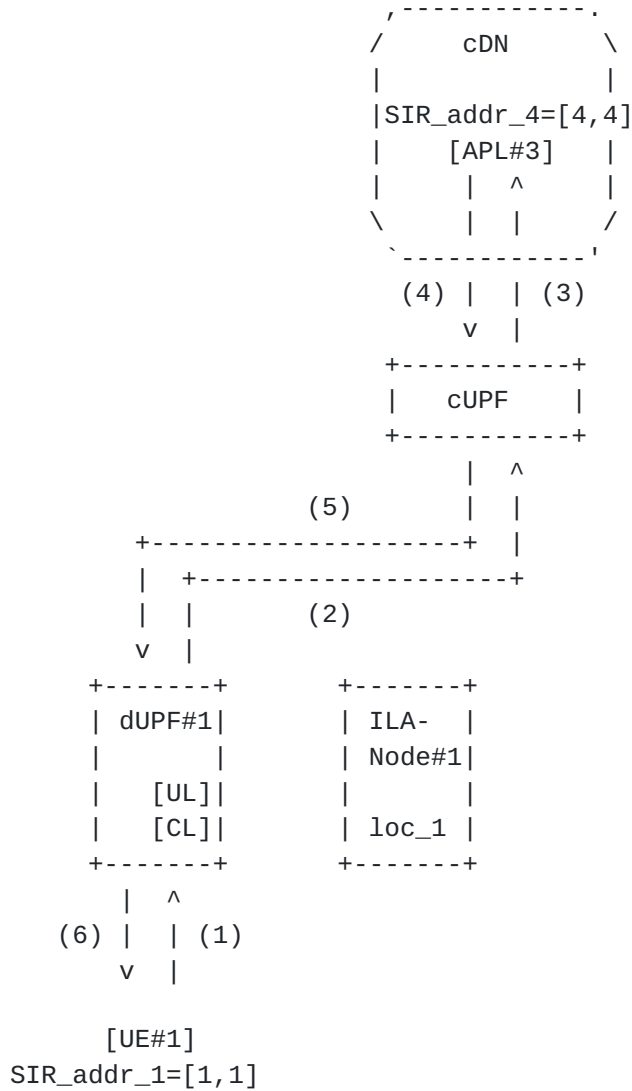   forwarding table.

   Downlink Processes

(6) APL#2 sends packets to UE#1 with setting SIR_address_1 as the
     destination IP address.

(7) ILA-Node#2 obtains loc_1 as Locator of id_1 from the ID-to-LOC
     mapping table. ILA-Node#2 converts the prefix of the source
     address to loc_2 (Locator of id_3), and the prefix of the
     destination address to loc_1 (Locator of id_1). ILA-Node#1 sends
     the packet to the ILA-Node#1.

(8) ILA-Node#1 converts the prefix of the source address to
     SIR_prefix_3, and the prefix of the destination address to
     SIR_prefix_1, and then sends packets to d#UPF1 depending on its
     forwarding table.

(9) dUPF#1 encapsulates the packets with GTP-U and sends packets to
     UE#1.

B.3. UE-to-cDN/Internet Communication

   UE-to-cDN/Internet communication are basically achieved by GTP-U
   mechanism originally equipped in 3GPP 5GS architecture. ILA causes
   some limitation on IP addressing to UEs (e.g., all UEs in an ILA
   domain have the same SIR prefix), and thus some IP translation node
   such as NAT (Network Address Translation) may be required to enable
   UEs to access to external network. In this section, we describe
   processes of UE-to-cDN/Internet communication in the proposal
   architecture. In Internet communication, from aspect of privacy or
   routing with external network, SIR addresses assigned to UEs are

translated by NAT function deployed between dUPF and connection
point.

B.3.1. Case B-5: Internet Communication

```
                         ,------------.
                        /      cDN      \
                        |               |
                        |SIR_addr_4=[4,4]
                        |     [APL#3]   |
                        |      |  ^     |
                        \      |  |    /
                         `------------'
                          (4) |  | (3)
                              v  |
                         +-----------+
                         |   cUPF    |
                         +-----------+
                              |  ^
                   (5)        |  |
            +------------------+  |
            |  +------------------+
            |  |       (2)
            v  |
         +-------+      +-------+
         | dUPF#1|      | ILA-  |
         |       |      | Node#1|
         |   [UL]|      |       |
         |   [CL]|      | loc_1 |
         +-------+      +-------+
            |  ^
        (6) |  | (1)
            v  |

           [UE#1]
      SIR_addr_1=[1,1]
```

              Legend: SIR_addr_x=[(SIR_Prefix), (Identifier)]

                    Figure 14: Procedure in Case B-5

   (0) Within this network, UEs are belonged to the same ILA domain,
        and the same SIR prefix (SIR_prefix_1) are assigned to UEs.
        Applications in cDN are belonged to different ILA domain. and

different SIR prefix (SIR_prefix_4) is assigned to these
applications. SIR_addr_1=[1,1] and SIR_addr_4=[4,4] are assigned
to UE#1 and APL#3. APL#3 is located in cDN.

Uplink Processes

(1) UE#1 sends packets to APL#3 with setting SIR_adrr_4 as the
     destination IP address.

(2) dUPF#1 monitors inner of received GTP-U packets. Since the
     destination IP address (SIR_adder_4) does not hit the filter of
     ULCL, dUPF#1 re-encapsulates the packet to another GTP-U
     connecting to cUPF and forwards to cUPF.

(3) cUPF decapusalates GTP-U packets and forwards them to APL#3 in
     cDN depending on its own forwarding table.

Downlink Processes

(4) APL#3 in cDN sends packets to UE#1 with setting SIR_addr_1 as
     the destination IP address.

(5) cUPF encapsulates the packets received from APL#3 and forwards
     them to dUPF#1 with GTP-U encapsulation depending on its own
     forwarding table.

(6) dUPF re-encapsulates the packets to another GTP-U and forwards
     to UE#1.

B.3.2. **Case B-6: Internet Communication**

```
                            IP_Addr_5
                            [Server#1]
                                |   ^
                            (5) v   | (4)
                              .--.
                             (     )-.
                           .'          '
                          (   Internet  )
                           (           -'
                            '-(       )
                               '---'
                            (5) |   ^ (4)
                                v   |
                           +-----------+
                           |    NAT    | SIR_Addr_1 <-> IP_Addr_10
                           +----+-+----+
                                | |
                            (6) v | (3)
                           +-----------+
                           |   cUPF    |
                           +-----------+
                                |   ^
                   (7)          |   |
              +-------------------+  |
              |   +-------------------+
              |   |      (2)
              v   |
           +-------+        +-------+
           | dUPF#1|        | ILA-  |
           |       |        | Node#1|
           |   [UL]|        |       |
           |   [CL]|        | loc_1 |
           +-------+        +-------+
               |   ^
           (8) |   | (1)
               v   |

             [UE#1]
         SIR_addr_1=[1,1]


              Legend: SIR_addr_x=[(SIR_Prefix), (Identifier)]



                 Figure 15: Procedure in Case B-6
```

(0) Within this network, UEs are belonged to the same ILA domain,
     and the same SIR prefix (SIR_prefix_1) are assigned to UEs.
     SIR_addr_1=[1,1] assigned to UE#1 and server#1 has IP_addr_5.
     UE#1 communicate with server#1 over Internet.

Uplink Processes

(1) UE#1 sends packets to server#1 with setting IP_adrr_5 as the
     destination IP address.

(2) dUPF#1 monitors inner of received GTP-U packets. Since the
     destination IP address (SIR_adder_4) does not hit the filter of
     ULCL, dUPF#1 re-encapsulates the packet to another GTP-U
     connecting to cUPF and forwards to cUPF.

(3) cUPF decapusalates GTP-U packets and forwards them to Internet
     depending on its own forwarding table.

(4) NAT translates SIR_addr_1 of received packets to IP_addr_10 and
     the packets are forwarded to server#1 over Internet.

Downlink Processes

(5) Server#1 sends packets to UE#1 with setting IP_addr_1 as the
     destination IP address.

(6) NAT translates IP_addr_10 of received packets to SIR_addr_1, and
     packets are sent to cUPF.

(7) cUPF encapsulates the packets with GTP-U and sends them to
     dUPF#1 depending on its own forwarding table.

(8) dUPF re-encapsulates the packets to another GTP-U and forwards
     to UE#1.

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