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Enabling ICN in 3GPP's 5G NextGen Core Architecture
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Abstract

   The proposed 3GPP's 5G core nextgen architecture (5GC) offers
   flexibility to introduce new user and control plane function,
   considering the support for network slicing functions, that allows
   greater flexibility to handle heterogeneous devices and applications.
   In this draft, we provide a short description of the proposed 5GC
   architecture, followed by extensions to 5GC's control and user plane
   to support Packet Data Unit (PDU) sessions from Information-Centric
   Networks (ICN). The value of enabling ICN in 5GC is discussed using
   IP-based service scenarios in the context of 5G Local Area Networks
   (5GLAN).

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1. Introduction

The objective of this draft is to propose an architecture to enable
information-centric networking (ICN) in the proposed 5G Next-
generation Core network architecture (5GC) by leveraging its
flexibility to allow new user and associated control plane functions.
The reference architectural discussions in the 5G core network 3GPP
specifications [TS23.501][TS23.502] form the basis of our
discussions. This draft also complements the discussions related to
various ICN deployment opportunities explored in
[I-D.rahman-icnrg-deployment-guidelines], where 5G technology is
considered as one of the promising alternatives.

Though ICN is a general networking technology, it would benefit 5G
particularly from the perspective of mobile edge computing (MEC).
The following ICN features shall benefit MEC deployments in 5G:

o Edge Computing: Multi-access Edge Computing (MEC) is located at
   the edge of the network and aids several latency sensitive
   applications such as augmented and virtual reality (AR/VR), as
   well as the ultra reliable and low latency class (URLLC) of
   applications such as autonomous vehicles. Enabling edge computing
   over an IP converged 5GC comes with the challenge of application
   level reconfiguration required to re-initialize a session whenever
   it is being served by a non-optimal service instance
   topologically. In contrast, named-based networking, as considered
   by ICN, naturally supports service-centric networking, which
   minimizes network related configuration for applications and
   allows fast resolution for named service instances.

o Edge Storage and Caching : A principal design feature of ICN is
   the secured content (or named-data) object, which allows location
   independent data replication at strategic storage points in the
   network, or data dissemination through ICN routers by means of
   opportunistic caching. These features benefit both realtime and
   non-realtime applications whenever there is spatial and temporal
   correlation among content accessed by these users, thereby
   advantageous to both high-bandwidth and low-latency applications
   such as conferencing, AR/VR, and non-real time applications such
   as Video-on-Demand (VOD) and IoT transactions.

o Session Mobility: Existing long-term evolution (LTE) deployments
   handle session mobility using centralized routing using the MME
   function, IP anchor points at Packet Data Network Gateway (PDN-GW)
   and service anchor point called Access Point Name (APN)
   functionality hosted in PDN-GW. LTE uses tunnel between radio
   edge (eNodeB) and PDN-GW for each mobile device attached to
   network. This design fails when service instances are replicated

close to radio access network (RAN) instances, requiring new
techniques to handle session mobility. In contrast, application-
bound identifier and name resolution split principle considered
for the ICN is shown to handle host mobility quite efficiently
[ICNMOB].

In this document, we first discuss 5GC's design principals that
allows the support of new network architectures. Then we summarize
the 5GC proposal, followed by control and user plane extensions
required to support ICN PDU sessions. We then discuss specific
network services enabled using ICN data networks, specifically MEC
use case scenarios and ICN session mobility with aid from the 5GC
control plane.

2. Terminology

Following are terminologies relevant to this draft:

5G-NextGen Core (5GC): Refers to the new 5G core network
architecture being developed by 3GPP, we specifically refer to the
architectural discussions in [TS23.501][TS23.502].

5G-New Radio (5G-NR): This refers to the new radio access
interface developed to support 5G wireless interface [TS38.300].

User Plane Function (UPF): UPF is the generalized logical data
plane function with context of the UE PDU session. UPFs can play
many role, such as, being an flow classifier (UL-CL) (defined
next), a PDU session anchoring point, or a branching point.

Uplink Classifier (UL-CL): This is a functionality supported by an
UPF that aims at diverting traffic (locally) to local data
networks based on traffic matching filters applied to the UE
traffic.

Packet Data Network (PDN or DN): This refers to service networks
that belong to the operator or third party offered as a service to
the UE.

Unified Data Management (UDM): Manages unified data management for
wireless, wireline and any other types of subscribers for M2M, IOT
applications, etc. UDM reports subscriber related vital
information e.g. virtual edge region, list of location visits,
sessions active etc. UDM works as a subscriber anchor point so
that means OSS/BSS systems will have centralized monitoring-of/
access-to of the system to get/set subscriber information.

Authentication Server Function (AUSF): Provides mechanism for
unified authentication for subscribers related to wireless,
wireline and any other types of subscribers such as M2M and IOT
applications. The functions performed by AUSF are similar to HSS
with additional functionalities to related to 5G.

Session Management Function (SMF): Performs session management
functions for attached users equipment (UE) in the 5G Core. SMF
can thus be formed by leveraging the CUPS (discussed in the next
section) feature with control plane session management.

Access Mobility Function (AMF): Perform access mobility management
for attached user equipment (UE) to the 5G core network. The
function includes, network access stratus (NAS) mobility functions
such as authentication and authorization.

Application Function (AF): Helps with influencing the user plane
routing state in 5GC considering service requirements.

Network Slicing: This conceptualizes the grouping for a set of
logical or physical network functions with its own or shared
control, data and service plane to meet specific service
requirements.

3. **5G NextGen Core Design Principles**

The 5GC architecture is based on the following design principles that
allows it to support new service networks like ICN efficiently
compared to LTE networks:

o Control and User plane split (CUPS): This design principle moves
   away from LTE's vertically integrated control/user plane design
   (i.e., Serving Gateway, S-GW, and Packet Data Network Gateway,
   P-GW) to one espousing an NFV framework with network functions
   separated from the hardware for service-centricity, scalability,
   flexibility and programmability. In doing so, network functions
   can be implemented both physically and virtually, while allowing
   each to be customized and scaled based on their individual
   requirements, also allowing the realization of multi-slice co-
   existence. This feature also allows the introduction of new user
   plane functions (UPF) in 5GC. UPFs can play many roles, such as,
   being an uplink flow classifier (UL-CL), a PDU session anchor
   point, a branching point function, or one based on new network
   architectures like ICN with new control functions, or re-using/
   extending the existing ones to manage the new user plane
   realizations.

o Decoupling of RAT and Core Network : Unlike LTE's unified control
   plane for access and the core, 5GC offers control plane separation
   of the RAN from the core network. This allows the introduction of
   new radio access technologies (RAT) along with slices based on new
   network architectures, offering the ability to map heterogeneous
   RAN flows to arbitrary core network slices based on service
   requirements.

o Non-IP PDU Session Support : A PDU session is defined as the
   logical connection between the UE and the data network (DN). 5GC
   offers a scope to support both IP and non-IP PDU (termed as
   "unstructured" payload), and this feature can potentially allow
   the support for ICN PDUs by extending or re-using the existing
   control functions. More discussions on taking advantage of this
   feature in ICN's context is presented in Section 5.2.2.

o Service Centric Design: 5GC's service orchestration and control
   functions, such as naming, addressing, registration/authentication
   and mobility, will utilize API design similar to those used in
   cloud technologies. Doing so enables opening up interfaces for
   authorized service function interaction and creating service level
   extensions to support new network architectures. These APIs
   include the well accepted Get/Response and Pub/Sub approaches,
   while not precluding the use of point-to-point procedural approach
   among 5GC functional units (where necessary).

o Distributed LAN Support: utilizing the aforementioned unstructured
   PDU session support, 5GC offers the capability to expose a Layer 2
   LAN service to cellular user equipment. Such distributed LAN
   targets to complement those in fixed broadband, including local
   WLAN fanouts. Through such LAN capability, services can be
   realized by being virtually embedded into an intranet deployment
   with dedicated Internet-facing packet gateway functionality.
   Examples for such services, among others, are those related to
   Industrial IoT, smart city services and others. Utilizing this
   capability for ICN-based services is presented in Section 6.

4. 5G NextGen Core Architecture

In this section, for brevity purposes, we restrict the discussions to
the control and user plane functions relevant to an ICN deployment
discussion in Section 5. More exhaustive discussions on the various
architecture functions, such as registration, connection and
subscription management, can be found in[TS23.501][TS23.502].

```
                                    +------+
   +-----+ +-------+  +------+      | AF-2 |
   |NSSF | |PCF/UDM|  | AF-1 |      +---+--+
   +--+--+ +--+----+  +--+---+         |
      |       |          |          +---+---+
   +--+-------+--+   +---+-----+ |         |
   |            |N11|         | | SMF-2 |
   |    AMF        +---+  SMF-1 | |         |
   |            |   |         | +---+---+
   +----+----+---+   +----+----+      |
        |    |           |-----------------------+
     +---+   |           |         |N4            |N4
    N1|      |N2         |N4       |  +----------+---------+
      |      |           |    +----+       UPF        | N6 +----+
   +-+-+   +--+--+    +---+---+   | |  |(PDU Session Anchor)+----+ DN |
   |   |   |     |    |       | N9 | |  |                    |    |   |
   |UE |   | RAN | N3 |  UPF  +----+ |  +--------------------+    +----+
   |   +---+     +-----+(UL-CL)|     |
   |   |   |     |    |     |    +----+ +-------------+
   +---+   +-----+    +-------+ N9 |              |
                              |   +----------+---------+
                              +----+       UPF        |    +----+
                              |(PDU Session Anchor)| N6 | DN |
                              |                    +----+    |
                              +--------------------+    +----+
```
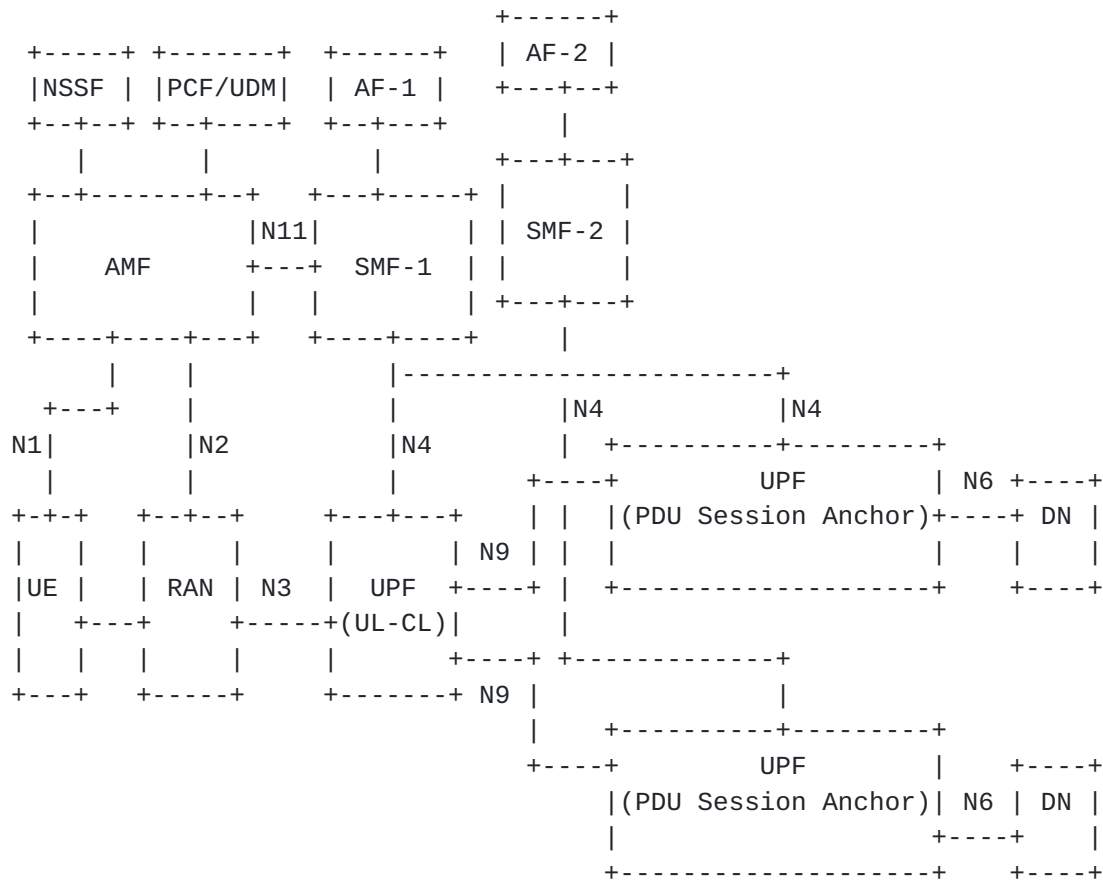
               Figure 1: 5G Next Generation Core Architecture

   In Figure 1, we show one variant of a 5GC architecture from
   [TS23.501], for which the functions of UPF's branching point and PDU
   session anchoring are used to support inter-connection between a UE
   and the related service or packet data networks (or PDNs) managed by
   the signaling interactions with control plane functions. In 5GC,
   control plane functions can be categorized as follows:

   o Common control plane functions that are common to all slices and
      which include the Network Slice Selection Function (NSSF), Policy
      Control Function (PCF), and Unified Data Management (UDM) among
      others.

   o Shared or slice specific control functions, which include the
      Access and Mobility Function (AMF), Session and Management
      Function (SMF) and the Application Function (AF).

   AMF serves multiple purposes: (i) device authentication and
   authorization; (ii) security and integrity protection to non-access
   stratum (NAS) signaling; (iii) tracking UE registration in the

   operator's network and mobility management functions as the UE moves
   among different RANs, each of which might be using different radio
   access technologies (RAT).

   NSSF handles the selection of a particular slice for the PDU session
   request from the user entity (UE) using the Network Slice Selection
   Assistance Information (NSSAI) parameters provided by the UE and the
   configured user subscription policies in PCF and UDM functions.
   Compared to LTE's evolved packet core (EPC), where PDU session states
   in RAN and core are synchronized with respect to management, 5GC
   decouples this using NSSF by allowing PDU sessions to be defined
   prior to a PDU session request by a UE (for other differences see
   [lteversus5g]). This decoupling allows policy based inter-
   connection of RAN flows with slices provisioned in the core network.
   This functionality is useful particularly towards new use cases
   related to M2M and IOT devices requiring pre-provisioned network
   resources to ensure appropriate SLAs.

   SMF is used to handle IP anchor point selection and addressing
   functionality, management of the user plane state in the UPFs (such
   as in uplink classifier (UL-CL), IP anchor point and branching point
   functions) during PDU session establishment, modification and
   termination, and interaction with RAN to allow PDU session forwarding
   in uplink/downlink (UL/DL) to the respective DNs. SMF decisions are
   also influenced by AF to serve application requirements, for e.g.,
   actions related to introducing edge computing functions.

   In the data plane, UE's PDUs are tunneled to the RAN using the 5G RAN
   protocol[TS38.300]. From the RAN, the PDU's five tuple header
   information (IP source/destination, port, protocol etc.) is used to
   map the flow to an appropriate tunnel from RAN to UPF. Though the
   current 5GC proposal[TS23.501] follows LTE on using GPRS tunneling
   protocol (GTP) tunnel from NR to the UPF to carry data PDUs and
   another one for the control messages to serve the control plane
   functions; there are ongoing discussions to arrive upon efficient
   alternatives to GTP.

5. 5GC Architecture with ICN Support

   In this section, we focus on control and user plane enhancements
   required to enable ICN within 5GC, and identify the interfaces that
   require extensions to support ICN PDU sessions. Explicit support for
   ICN PDU sessions within access and 5GC networks will enable
   applications to leverage the core ICN features while offering it as a
   service to 5G users.

```
                        +------------+
                        |    5G      |
                        | Services   |
                        |   (NEF)    |          +----------------+
                        +-------+----+          |      ICN       |
                                |   +--------+  |    Service     |
                                |   |        |  |  Orchestrator  |
                                |   |        |  +-------+--------+
   +----+ +-------+  Npcf++/Nudm++  +-+---+-+         |
   |NSSF| |PCF/UDM+----------------+ ICN-AF|         |
   +-+--+ +-+-----+                +---+---+    +------+--------+
     |      |                          |       |      ICN       |
     |      |                          |   +---+Service/Network|
   +-+-----+-+     +-------+     +---+---+   |   |  Controller   |
   |       |N11++ |       |Naf++ |       +---+   +-----------+---+
   | AMF++  +------+ SMF++ +------+ICN-SMF|                     |
   |       |      |       |      |       |                     |
   +----+--+--+   +---+---+   +---+---+                        |
        | |           |         |NIcn                          |
        | +-------+   +-------+  +----------+                   |
        |         |         |         |     |                   |
        |         |         |     +---+--+   +--+---+           |
        |         |         |     |      |   |      |           |
     |N1++     |N2       |N4     |      |   |      |+ICN-DN|
        |         |         |  +----+ICN-GW+------+ICN-DN|
        |         |  +----+----+  | N9 | +UPF |  N6 |      |
   +----+-+  +-----+----+  |      |  | +------+     +------+
   |      |  |RAN +----+|  | UL-CL/  +---+
   |ICN-UE+--+   |UPF ||  |Branching|
   |      |  |   +----++---+ Point   |
   |      |  |   +------+| N3|       +---+     +------+
   +------+  |   |ICN-GW||  +---------+  | N9 | Local|
            |   +------+|             +----+ICN-DN|
            +----------+             +------+
```
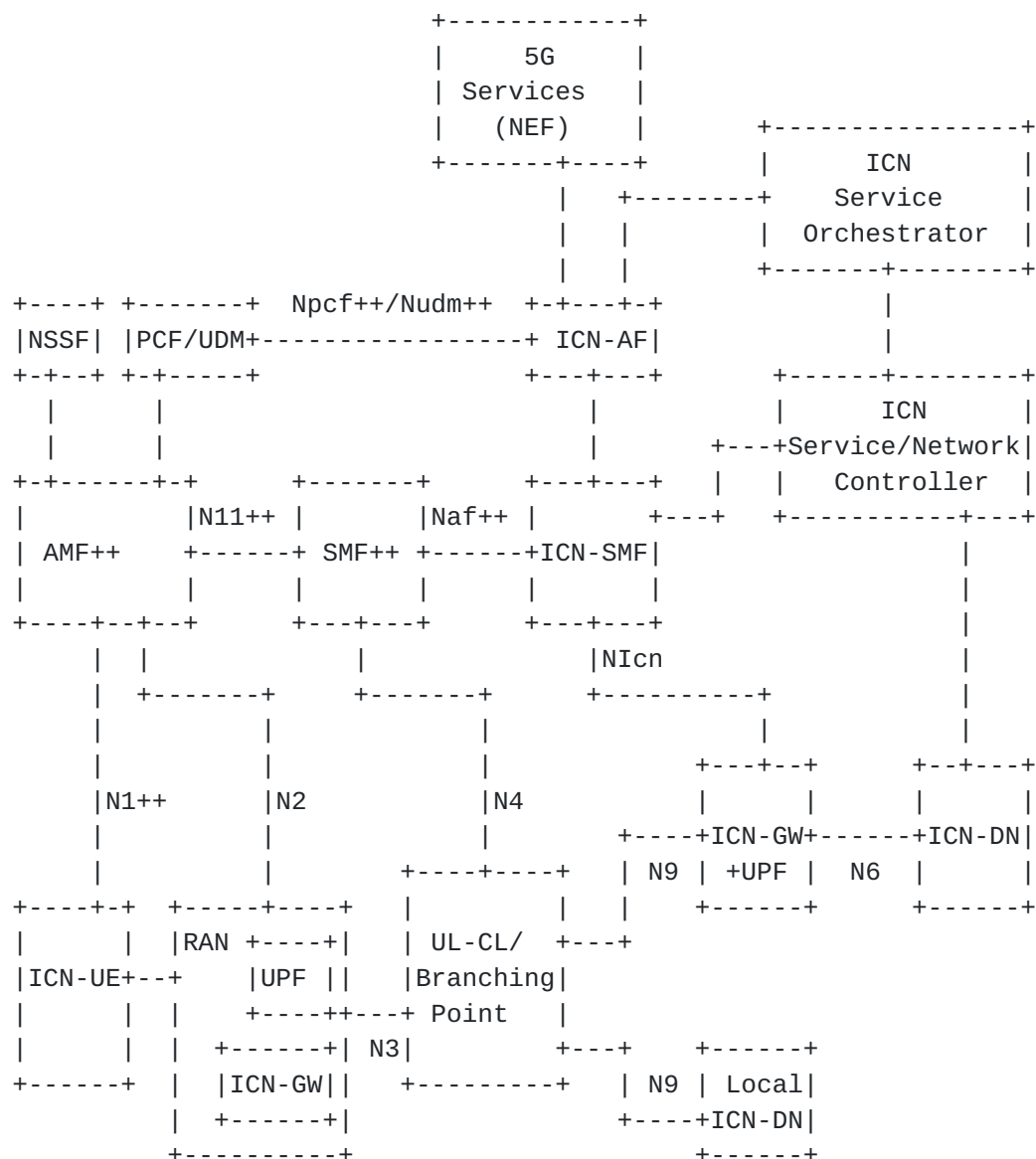
                Figure 2: 5G Next Generation Core Architecture with ICN support

   For an ICN-enabled 5GC network, the assumption is that the UE may
   have applications that can run over ICN or IP, for instance, UE's
   operating system offering applications to operate over ICN [Jacobson]
   or IP-based networking sockets. There may also be cases where UE is
   exclusively based on ICN. In either case, we identify an ICN enabled
   UE as ICN-UE. Different options exist to implement ICN in UE as
   described in [I-D.suthar-icnrg-icn-lte-4g] which is also applicable
   for 5G UE to enable formal ICN session handling, such as, using a
   Transport Convergence Layer (TCL) above 5G-NR, through IP address
   assignment from 5GC or using 5GC provision of using unstructured PDU
   session mode during the PDU session establishment process, which is

discussed in Section 5.2.2. Such convergence layer would implement
necessary IP over ICN mappings, such as those described in [TROSSEN],
for IP-based applications that are assigned to be transported over an
ICN network. 5G UE can also be non-mobile devices or an IOT device
using radio specification which can operate based on [TS38.300].

5GC will take advantage of network slicing function to instantiate
heterogeneous slices, the same framework can be extended to create
ICN slices as well [Ravindran]. This discussion also borrows ideas
from[TS23.799], which offers a wide range of architectural
discussions and proposals on enabling slices and managing multiple
PDU sessions with local networks (with MEC) and its associated
architectural support (in the service, control and data planes) and
procedures within the context of 5GC.

Figure 2 shows the proposed ICN-enabled 5GC architecture. In the
figure, the new and modified functional components are identified
that interconnects an ICN-DN with 5GC. The interfaces and functions
that require extensions to enable ICN as a service in 5GC can be
identified in the figure with a '++' symbol. We next summarize the
control, user plane and normative interface extensions that help with
the formal ICN support.

5.1. Control Plane Extensions

To support interconnection between ICN UEs and the appropriate ICN DN
instances, we consider the following additional control plane
extensions to orchestrate ICN services in coordination with 5GC's
control components.

o Authentication and Mobility Function (AMF++): ICN applications in
   the UEs have to be authorized to access ICN DNs. For this
   purpose, as in [TS23.501], operator enables ICN as a DN offering
   ICN services. As a network service, ICN-UE should also be
   subscribed to it and this is imposed using the PCF and UDM, which
   may interface with the ICN Application Function (ICN-AF) for
   subscription and session policy management of ICN PDU sessions.
   To enable ICN stack in the UE, AMF++ function has to be enabled
   with the capability of authenticating UE's attach request for ICN
   resources in 5GC. The request can be incorporated in NSSI
   parameter to request either ICN specific slice or using ICN in
   existing IP network slice when the UE is dual stacked. AMF++ can
   potentially be extended to also support ICN specific bootstrapping
   (such as naming and security) and forwarding functions to
   configure UE's ICN layer. These functions can also be handled by
   the ICN-AF and ICN control function in the UE after setting PDU
   session state in 5GC. Here, the recommendation is not about
   redefining the 5G UE attach procedures, but to extend the attach

procedures messages to carry ICN capabilities extensions in
addition to supporting existing IP based services. The extensions
should allow a 5G UE to request authentication to 5GC either in
ICN, IP or dual-stack (IP and ICN) modes. Further research is
required to optimize 5G attach procedures so that an ICN capable
UE can be bootstrapped by minimizing the number of control plane
messages. One possibility is to leverage existing 5G UE attach
procedures as described in 3GPP's [TS23.502], where the UE can
provide ICN identity in the LTE equivalent protocol configuration
option information element (PCO-IE) message during the attach
request as described in [I-D.suthar-icnrg-icn-lte-4g]. In
addition, such requirement can be also be provided by the UE in
NSSI parameters during initial attach procedures. Alternately,
ICN paradigm offers name-based control plane messaging and
security which one can leverage during the 5G UE attach
procedures, however this requires further research.

o Session Management Function (SMF++): Once a UE is authenticated to
   access ICN service in network, SMF manages to connect UE's ICN PDU
   sessions to the ICN DN in the UL/DL. SMF++ should be capable to
   manage both IP, ICN or dual stack UE with IP and ICN capabilities.
   To support ICN sessions, SMF++ creates appropriate PDU session
   policies in the UPF, which include UL-CL and ICN gateway (ICN-GW)
   (discussed in Section 5.2) through the ICN-SMF. For centrally
   delivered services, ICN-GW could also multiplex as an IP anchor
   point for IP applications. If MEC is enabled, these two functions
   would be distributed, as the UL-CL will re-route the flow to a
   local ICN-DN. 3GPP has defined IP based session management
   procedures to handle UE PDU sessions in TS23.502. For ICN UE we
   can either leverage same procedures when ICN is deployed as an
   overlay protocol. Towards this, SMF++ interfaces with AMF++ over
   N11++ to enable ICN specific user plane functions, which include
   tunnel configuration and traffic filter policy to inter-connect UE
   with the appropriate radio and the core slice. Furthermore, AMF++
   sets appropriate state in the RAN and the UE that directs ICN
   flows to the chosen ICN UL-CL in the core network, and towards the
   right UE in the downlink.

o ICN Session Management Function (ICN-SMF): ICN-SMF serves as
   control plane for the ICN state managed in ICN-GW. This function
   can be either incorporated as part of SMF++ or as a stand-alone
   one. This function interacts with SMF++ to obtain and also push
   ICN PDU session management information for the creation,
   modification and deletion of ICN PDU sessions in ICN-GW. For
   instance, when new ICN slices are provisioned by the ICN service
   orchestrator, ICN-SMF requests a new PDU session to the SMF that
   extends to the RAN. While SMF++ manages the tunnels to
   interconnect ICN-GW to UL-CL, ICN-SMF creates the appropriate

forwarding state in ICN-GW (using the forwarding information base
or FIB) to enable ICN flows over appropriate tunnel interfaces
managed by the SMF++. In addition, it also signals resource
management rules to share compute, bandwidth, storage/cache
resources among multiple slice instances co-located in the ICN-GW.

o ICN Application Function (ICN-AF): ICN-AF represents the
   application controller function that interfaces with ICN-SMF and
   PCF/UDM function in 5GC. In addition to transferring ICN
   forwarding rules to ICN-SMF, ICN-AF also interfaces with PCF/UDM
   to transfer user profile and subscription policies along with
   session management requirement to UE's ICN PDU session in the 5GC
   network. ICN-AF is an extension of the ICN service orchestration
   function, which can influence both ICN-SMF and in-directly SMF++
   to steer traffic based on ICN service requirements. ICN-AF can
   also interact with the northbound 5G operator's service functions,
   such as network exposure function(NEF) that exposes network
   capabilities, for e.g. location based services, that can be used
   by ICN-AF for proactive ICN PDU session and slice management and
   offer additional capabilities to the ICN slices.

5.1.1. Normative Interface Extensions

o N1++/N11++: This extension enables ICN specific control functions
   to support ICN authentication, configuration and programmability
   of an ICN-UE via AMF++ and SMF++, and also impose QoS
   requirements, handle mobility management of an ICN PDU session in
   5GC based on service requirements.

o N4: Though this signaling is service agnostic, as discussed in
   Section 5.2, future extensions may include signaling to enable ICN
   user plane features in these network functions. The extension of
   N4 to RAN is to handle the case when UPF function collocates with
   the RAN instance to enable localized ICN DNs.

o NIcn: This extension shall support two functions: (i) control
   plane programmability to enable ICN PDU sessions applicable to 5GC
   to map to name based forwarding rules in ICN-GW; (ii)control plane
   extensions to enable ICN mobility anchoring at ICN-GW, in which
   case it also acts as POA for ICN flows. Features such as ICN
   mobility as a service can be supported with this extension
   [ICNMOB].

o Naf++: This extension supports 5GC control functions such as
   naming, addressing, mobility, and tunnel management for ICN PDU
   sessions to interact with SMF++ and AMF++.

o Npcf++/Nudm++: This extension creates an interface to push ICN
   service and PDU session requirements to PCF and UDM functions that
   interact with the ICN-AF function for ICN slice specific
   configuration. These requirements are enforced at various steps,
   for instance, during ICN application registration, authentication,
   slice mapping, and provisioning of resources for these PDU
   sessions in the UPF.

5.2. User Plane Extensions

The interconnection of a UE to an ICN-DN comprises of two segments,
one from RAN to UL-CL and the other from UL-CL to ICN-GW. These
segments use IP tunneling constructs, where the service semantic
check at UL-CL is performed using IP's five tuples to determine both
UL and DL tunnel mappings. We summarize the relevant UPFs and the
interfaces for handling ICN PDU sessions as follows.

o ICN Gateway (ICN-GW): ICN-GW is where the 5GC PDU sessions
   terminate and ICN service network begins. Compared to the
   traditional anchor points as in PGW, the ICN-GW is also a service
   gateway as it can host services or cache content enabled through
   the ICN architecture. The ICN-GW also includes the UPF functions
   to manage multiple tunnel interfaces enabling the relay of ICN PDU
   flows to appropriate UL-CL instances in the DL. Note that there
   may be multiple ICN-GWs serving different ICN services or slices.
   ICN-GW also manages other ICN functions such as enforcing the
   dynamic name based forwarding state, mobility state, in-network
   service function management, resource management with respect to
   sharing caching, storage, and compute resources among multiple
   services[Ravindran].

o ICN Packet Data Network (ICN-(P)DN): ICN-DN represents a set of
   ICN nodes used for ICN networking and with heterogeneous service
   resources such as storage and computing points. An ICN network
   enables both network and application services, with network
   services including caching, mobility, multicast, multi-path
   routing (and possibly network layer computing), and application
   services including network resources (such as cache, storage,
   network state resources) dedicated to the application.

   * Considering multiple ICN architecture proposals and multiple
      ICN deployment models discussed in
      [I-D.rahman-icnrg-deployment-guidelines], an alternate backward
      compatible (IP-over-)ICN solution is proposed in [TROSSEN].
      Such an ICN-(P)DN can simply consist of SDN forwarding nodes
      and a logically centralized path computation entity (PCE),
      where the PCE is used to determine suitable forwarding
      identifiers being used for the path-based forwarding in the

SDN-based transport network. In addition, the PCE is
responsible for maintaining the appropriate forwarding rules in
the SDN switches. For interconnection to IP-based peering
networks, a packet gateway is being utilized that mirrors the
convergence layer functionality to map incoming ICN traffic
back in to outgoing IP traffic and vice versa. This form of
deployment would require minimal changes to the 5GC's user and
control plane procedures, as the applications on these IP end
points are not exposed (or minimally exposed) to any ICN state
or configuration.

o Uplink Classifier (UL-CL): UL-CL enables classification of flows
   based on source or destination IP address and steers the traffic
   to an appropriate network or service function anchor point. If
   the ICN-GW is identified based on service IP address associated
   with the ICN-UE's flows, UL-CL checks the source or destination
   address to direct traffic to an appropriate ICN-GW. For native
   ICN UE, ICN shall be deployed over 5G-NR; here, there may not be
   any IP association. For such packet flows new classification
   schema shall be required, such as, using 5G-NR protocol extensions
   to determine the tunnel interface to forward the ICN payload on,
   towards the next ICN-GW.

5.2.1. Normative Interface Extensions

o N3: Though the current architecture supports heterogeneous service
   PDU handling, future extensions can include user plane interface
   extensions to offer explicit support to ICN PDU session traffic,
   for instance, an incremental caching and computing function in RAN
   or UL-CL to aid with content distribution.

o N9: Extensions to this interface can consider UPFs to enable
   richer service functions, for instance to aid context processing.
   In addition extensions to enable ICN specific encapsulation to
   piggyback ICN specific attributes such as traffic or mobility data
   between the UPF branching point and the ICN-GW.

o N6: This interface is established between the ICN-GW and the ICN-
   DN, whose networking elements in this segment can be deployed as
   an overlay or as a native Layer-3 network.

5.2.2. ICN over non-IP PDU

5GC accommodates non-IP PDU support which is defined for Ethernet or
any unstructured data[TS23.501]. This feature allows native support
of ICN over 5G RAN, with the potential enablement of ICN-GW in the BS
itself as shown in Figure 2. Formalizing this feature to recognize
ICN PDUs has many considerations:

o Attach Procedures for UE with Non-IP PDN: Assuming a 5GC can
   support both IP and non-IP PDN, this requires control plane
   support, as discussed in Section 5. In a typical scenario, when
   UE sends an attach message to 5GC, the type of PDU connection is
   indicated in the PCO-IE field, for e.g. in this case as being non-
   IP PDN to invoke related control plane session management tasks.
   ICN over non-IP PDU session will allow the UE to attach to 5GC
   without any IP configuration. 5GC attach procedures specified
   [TS23.501] can be used to support authentication of UE with PDN
   type set to non-IP, using existing AUSF/UDM functions in
   coordination with the ICN-AF function discussed earlier if
   required.

o User Plane for UE with Non-IP PDN: Without any IP tunnel
   configuration and ICN's default consumer agnostic mode of
   operation requires ways to identify the ICN-UE in the user plane,
   this can be enabled by introducing network identifier in the lower
   layers such as in the PDCP or MAC layer, that can assist for
   functions such as policy and charging at the BS and related
   session management tasks. These identifiers can also be used to
   demultiplex the DL traffic from the ICN-GW in the BS to the
   respective ICN-UEs. Also, ICN extensions can be incorporated in
   control plane signaling to identify an ICN-UE device and these
   parameters can be used by SMF to conduct non-IP routing. The
   policing and charging functions can be enforced by the UPF
   function in the BS which obtains the traffic filtering rules from
   the SMF. To enable flat ICN network from the BS requires
   distributed policy, charging and legal intercept which requires
   further research. Further ICN slice multiplexing can be realized
   by also piggybacking slice-ID (NSSI) along with device ID to
   differentiate handover to multiple ICN slices at the base station.
   Inter-working function (IWF) is required if services based on non-
   IP UE has to transact or communicate with transport, applications
   functions or other UE based on IP services. This also has
   implications on how mobility is managed for such PDU sessions.

o Mobility Handling: Considering mobility can be support by ICN, it
   is inefficient to traverse other intermediate IP networks between
   the BS and the next ICN hop. This requires ICN PDU to be handled
   by an ICN instance in the BS itself, in association with UL-CL
   function local to the BS as shown in Figure 2. Control plane
   extensions discussed in Section 5 can be used in tandem with
   distributed mobility protocols to handle ICN mobility, one such
   solution for producer mobility is proposed in [ICNMOB]

o Routing Considerations: Flat ICN network realizations also offers
   the advantage of optimal routing, compared to anchor point based
   realization in LTE. This also leads to optimal realization of the

data plane considering the absence of overhead due to tunneling
while forwarding ICN traffic. However, developing a routing
control plane in to handle the ICN PDU sessions either leveraging
SMF functions or a distributed realization requires more
investigation. In the centralized approach the SMF could interact
with ICN-SMF to set the forwarding rules in the ICN-GW in the BS
and other ICN-UPFs, however this may also lead to scalability
issues if a flat ICN network is to be realized. This also has
implications to route the non-IP PDU sessions efficiently to the
closest ICN-MEC instance of the service.

o IP over ICN: Native support of ICN in the RAN raises the
   possibility of leveraging the mobility functions in ICN protocols
   as a replacement for GTP tunneling in the 5GC, as described in
   [I-D.white-icnrg-ipoc].

o Mobile Edge Computing: Another significant advantage is with
   respect to service-centric edge computing at the ICN-GW or other
   ICN points, either through explicit hosting of service
   functions[VSER] in ICN or in-network computing based on NFN
   proposal[NFN]. A certain level of orchestration, as discussed in
   Section 5, is required to ensure service interconnection and its
   placement with appropriate compute resources and inter-connected
   with bandwidth resources so that the desired SLA is offered.

5.2.3. Dual Stack ICN Deployment

5.2.3.1. 5G User Plane Protocol Stack

It is important to understand that a User Equipment (UE) can be
either consumer (receiving content) or publisher (pushing content for
other clients). The protocol stack inside mobile device (UE) is
complex as it has to support multiple radio connectivity access to
gNB(s).

```
 +--------+                                          +--------+
 |  App   |                                          |  APP   |
 +--------+                              +---------+  +--------+
 |   IP   |......................................|   IP  |.|.|   IP   |
 +--------+ | +----+------+ | +------+-----+ | +------+--+ | +--------+
 |  PDCP  |.|.|PDCP|GTP-U |.|.|GTP-U | GTP-U|.|.|GTP-U |  | | |        |
 +--------+ | +-----------+ | +------------+ | +------+  | | |        |
 |  RLC   |.|.|RLC |UDP/IP|.|.|UDP/IP|UDP/IP|.|.|UDP/IP|L2|.|.|   L2   |
 +--------+ | +-----------+ | +------------+ | +------+  | | |        |
 |  MAC   |.|.| MAC|  L2  |.|.|  L2  |  L2  |.|.|  L2  |  | | |        |
 +--------+ | +-----------+ | +------------+ | +---------+ | +--------+
 |  L1    |.|.| L1 |  L1  |.|.| L1   |  L1  |.|.|  L1  |L1|.|.|   L1   |
 +--------+ | +----+------+ | +------+-----+ | +------+--+ | +--------+
    UE      |    gNB/RAN    |      UPF       |      UPF     |    DN
            |               |   (UL-CL)      | (PDU Anchor)|
         Uu               N3              N9             N6
```
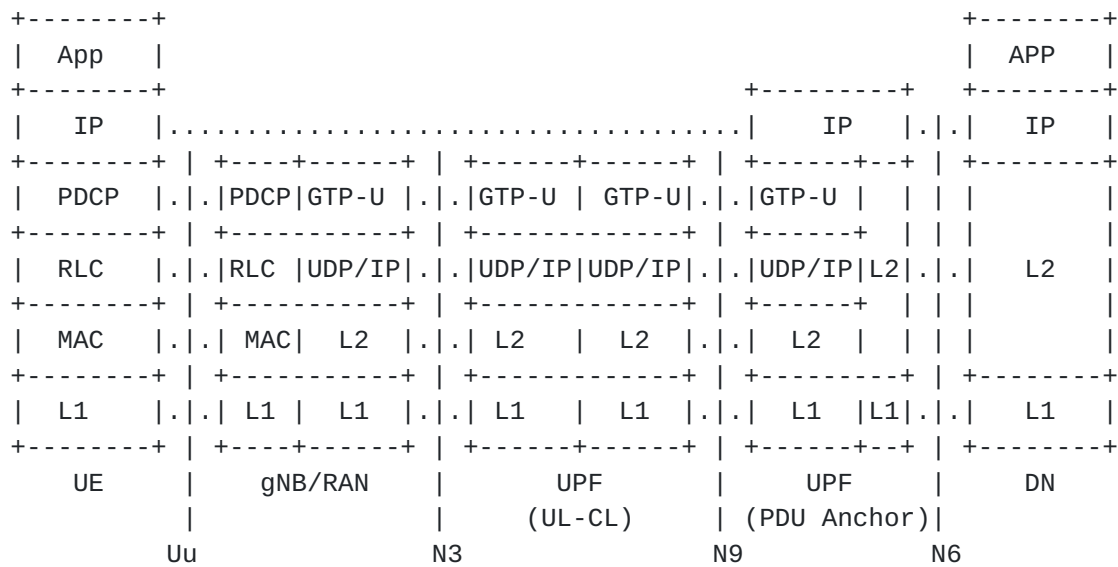
                  Figure 3: 5G User Plane Protocol Stack

   Figure 3 provides high level description of a 5G user plane protocol
   stack, where: 1) the lower 4 layers (i.e. L1, MAC, RLC, PDCP) at UE
   is for radio access and air interface to gNB; 2) the IP layer (i.e.
   PDU layer) at UE is used for providing IP transport infrastructure to
   support PDU session between UE and UPF (PDU Anchor); 3) GUP-U
   provides tunneling between gNB and UPF, or between two UPFs.
   Although UDP/IP exists under GTP-U, IP mainly refers to "IP" between
   UE and UPF (PDU Anchor) for the rest of this document, unless
   explicitly clarified; 4) UL-CL is only for uplink traffic and UPF
   (UL-CL) shall not be needed for downlink traffic towards UE.

5.2.3.2. **Protocol Stack for ICN Deployment in 5G**

```
+--------+                                                 +--------+
|  App   |                                                 |  APP   |
+--------+                                      +---------+ +--------+
|  TCL   |......................................|  TCL    |.|.|  TCL   |
+--------+                                      +---------+ | +--------+
| ICN&IP |......................................| ICN&IP  |.|.| ICN&IP |
|        |                                      |         | | |        |
+--------+ | +----+------+ | +------+------+ | +------+--+ | +--------+
|  PDCP  |.|.|PDCP|GTP-U |.|.|GTP-U | GTP-U|.|.|GTP-U |  | | |        |
+--------+ | +-----------+ | +-------------+ | +------+  | | |        |
|  RLC   |.|.|RLC |UDP/IP|.|.|UDP/IP|UDP/IP|.|.|UDP/IP|L2|.|.|   L2   |
+--------+ | +-----------+ | +-------------+ | +------+  | | |        |
|  MAC   |.|.| MAC| L2   |.|.| L2   | L2   |.|.| L2   |  | | |        |
+--------+ | +-----------+ | +-------------+ | +---------+ | +--------+
|  L1    |.|.| L1 |  L1  |.|.| L1   | L1   |.|.| L1   |L1|.|.|   L1   |
+--------+ | +----+------+ | +------+------+ | +------+--+ | +--------+
    UE     |   gNB/RAN     |     UPF        |     UPF     |    DN
           |               |   (UL-CL)      | (PDU Anchor)|
         Uu              N3              N9              N6
```

                    Figure 4: Dual Stack ICN Deployment

   ICN can be deployed in dual stack model for 5G user plane as
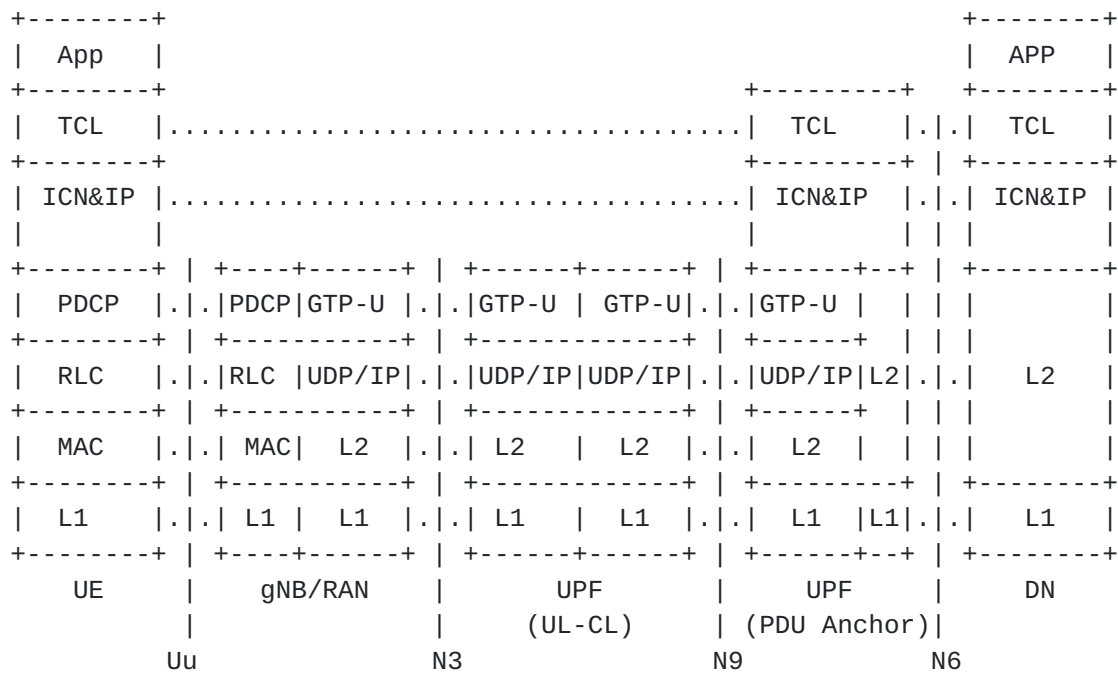   illustrated in Figure 4, where: 1) both ICN and IP (i.e. dual stack)
   can reside between TCL and PDCP to provide transport infrastructure
   from UE to UPF (PDU Anchor); 2) in order to support the dual ICN&IP
   transport layer, PDCP needs some enhancements; 3) a new Transport
   Convergence Layer (TCL) is introduced to coordinate between
   applications and ICN&IP transport layer; 4) Applications on top of
   TCL could be ICN applications or IP applications.

   With this dual stack model, four different cases are possible for the
   deployment of ICN natively and/or with IP dependent on which types of
   applications (ICN or IP) uses which types of underline transport (ICN
   or IP), from the perspective of the applications either on UE (or
   content provider).

   Case 1. IP over IP (IPoIP)

   In this scenario UE uses applications tightly integrated with the
   existing IP transport infrastructure. In this option, the TCL has no
   additional function since the packets are directly forwarded using IP
   protocol stack, which in turn sends the packets over the IP
   transport.

   Case 2. ICN over ICN (ICNoICN)

Similar to case 1 above, ICN applications tightly integrate with the
ICN transport infrastructure. The TCL has no additional
responsibility since the packets are directly forwarded using ICN
protocol stack, which in turn sends the packets over the ICN
transport.

Case 3. ICN over IP (ICNoIP)

In ICN over IP scenario, the underlying IP transport infrastructure
is not impacted (i.e. ICN is implemented as an overlay over IP,
between UE and content provider). IP routing is used from Radio
Access Network (gNB) to mobile backhaul, IP core and UPF. UE
attaches to UPF (PDU Anchor) using IP address. Content provider in
DN is capable of serving content either using IP or ICN, based on UE
request.

An alternative approach to implement ICN over IP is provided in
Hybrid ICN [I-D.muscariello-intarea-hicn], which implements ICN over
IP by mapping of ICN names to the IPv4/IPv6 addresses.

Case 4. IP over ICN (IPoICN)

In IP over ICN scenario, IP application utilize an ICN-based routing
while preserving the overall IP protocol semantics, as shown, e.g.,
in H2020 project [H2020]. Implementing IP services over ICN provides
an opportunity leveraging benefit of ICN in the transport
infrastructure.

Note that the IP over ICN case could be supported for pure IP (over
IP) UEs through introducing a Network Attachment Point (NAP) to
interface to an ICN network. Here, the UPF (PDU Anchor) interfaces
to said NAP in the northbound; alternatively, the NAP can be
integrated as a part of UPF (PDU Anchor). For this scheme, the NAP
provides a standard IP network interface towards the IP-enabled UE
via UPF (PDU Anchor), encapsulates any received IP service (e.g.
HTTP) request into an appropriate ICN packet which is then published
as an appropriately formed named information item. Conversely, the
NAP subscribes to any appropriately formed named information items,
where the information identifier represents any IP-exposed service
that is exposed at any IP-level UE locally connected to the NAP. Any
received ICN packet is then forwarded to the appropriate local IP-
enabled UE after being appropriately decapsulated, recovering the
original IP service (e.g. HTTP) request.

In a dual-stack UE that supports the above cases, the TCL helps
determine what type of transport (e.g. ICN or IP), as well as type
of radio interface (e.g. 5G or WiFi or both), is used to send and
receive the traffic based on preference e.g. content location,

content type, content publisher, congestion, cost, quality of service
etc. It helps to configure and decide the type of connection as well
as the overlay mode (ICNoIP or IPoICN, explained above) between
application and the protocol stack (IP or ICN) to be used.

TCL can use a number of mechanisms for the selection of transport
(i.e. ICN or IP). It can use a per application configuration
through a management interface, possibly even a user-facing setting
realized through a user interface, similar to those used today that
select cellular over WiFi being used for selected applications. In
another option, it might use a software API, which an adapted IP
application could use to specify e.g. an ICN transport for obtaining
its benefits.

Another potential application of TCL is in implementation of network
slicing, where it can have a slice management capability locally or
it can interface to an external slice manager through an API
[I-D.galis-anima-autonomic-slice-networking]. This solution can
enable network slicing for IP and ICN transport selection from the UE
itself. The TCL could apply slice settings to direct certain traffic
(or applications) over one slice and others over another slice,
determined by some form of 'slicing policy'. Slicing policy can be
obtained externally from slice manager or configured locally on UE.

5.2.3.3. Protocol Interactions and Impacts

```
              +----------------+ +----------------+
              | ICN App (New)  | |IP App (Existing)|
              +---------+------+ +-------+---------+
                        |                |
              +---------+----------------+---------+
              |              TCL (New)            |
              +------+--------------------+-------+
                     |                    |
              +------+------+        +------+-------+
              |ICN Function |        | IP Function  |
              |   (New)     |        | (Existing)   |
              +------+------+        +------+-------+
                     |                    |
              +------+--------------------+-------+
              | PDCP (Updated to Support ICN)     |
              +----------------+-----------------+
                               |
              +----------------+-----------------+
              |            RLC (Existing)         |
              +----------------+-----------------+
                               |
              +----------------+-----------------+
              |          MAC Layer (Existing)     |
              +----------------+-----------------+
                               |
              +----------------+-----------------+
              |        Physical L1 (Existing)     |
              +----------------------------------+
```
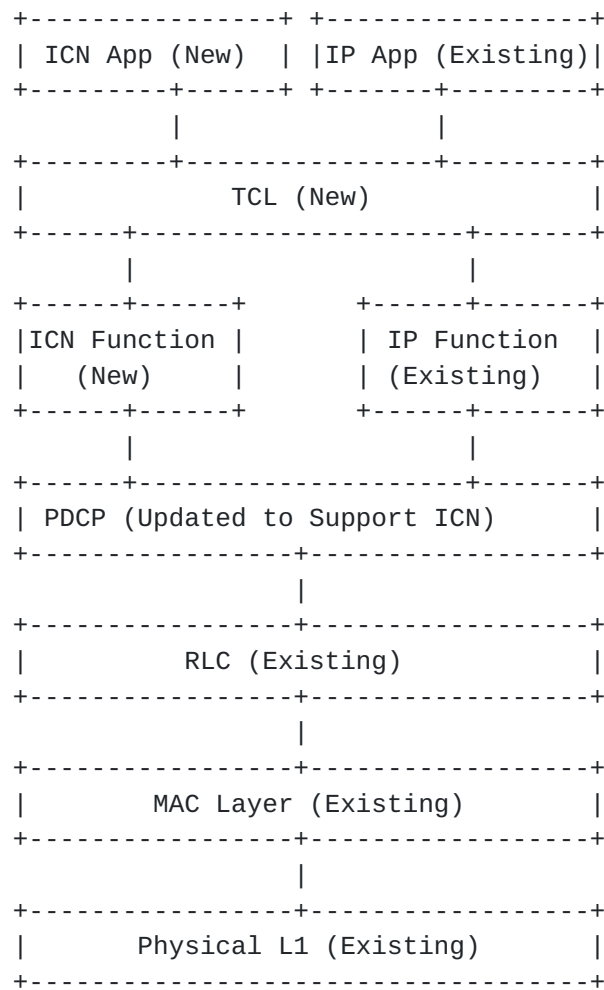
            Figure 5: Dual Stack ICN Protocol Interactions at UE

   The protocol interactions and impact of supporting tunneling of ICN
   packet into IP or to support ICN natively are described in Figure 5.

   o Existing application layer can be modified to provide options for
      new ICN based application and existing IP based applications. UE
      can continue to support existing IP based applications or host new
      applications developed either to support native ICN as transport,
      ICNoIP or IPoICN based transport. Application layer has the
      option of selecting either ICN or IP transport layer as well as
      radio interface to send and receive data traffic. Our proposal is
      to provide a common Application Programming Interface (API) to the
      application developers such that there is no impact on the
      application development when they choose either ICN or IP
      transport for exchanging the traffic with the network. TCL
      function handles the interaction of application with the multiple
      transport options.

o The TCL helps determine what type of transport (e.g. ICN or IP)
   as well as type of radio interface (e.g. 5G NR or WiFi or both),
   is used to send and receive the traffic. Application layer can
   make the decision to select a specific transport based on
   preference e.g. content location, content type, content publisher,
   congestion, cost, quality of service etc. There can be an
   Application Programming Interface (API) to exchange parameters
   required for transport selection. The southbound interactions of
   TCL will be either to IP or ICN at the network layer. When
   selecting the IPoICN [TROSSEN] mode, the TCL is responsible for
   receiving an incoming IP or HTTP packet and publishing the packet
   under a suitable ICN name (i.e. the hash over the destination IP
   address for an IP packet or the hash over the FQDN of the HTTP
   request for an HTTP packet) to the ICN network. In the HTTP case,
   the TCL maintains a pending request mapping table to map returning
   responses to the originating HTTP request. The common API will
   provide a common 'connection' abstraction for this HTTP mode of
   operation, returning the response over said connection
   abstraction, akin to the TCP socket interface, while implementing
   a reliable transport connection semantic over the ICN from the UE
   to the receiving UE or the PGW. If the HTTP protocol stack
   remains unchanged, therefore utilizing the TCP protocol for
   transfer, the TCL operates in local TCP termination mode,
   retrieving the HTTP packet through said local termination. The
   southbound interactions of the Transport Convergence Layer (TCL)
   will be either to IP or ICN at the network layer.

o ICN function (forwarder) is introduced in parallel to the existing
   IP layer. ICN forwarder contains functional capabilities to
   forward ICN packets, e.g. Interest packet to gNB or response
   "data packet" from gNB to the application.

o For dual stack scenario, when UE is not supporting ICN at network
   layer, we use IP underlay to transport ICN packets. ICN function
   will use IP interface to send Interest and Data packets for
   fetching or sending data using ICN protocol function. This
   interface will use ICN overlay over IP using any overlay tunneling
   mechanism.

o To support ICN at network layer in UE, PDCP layer has to be aware
   of ICN capabilities and parameters. PDCP is located in the Radio
   Protocol Stack in the 5G Air interface, between IP (Network layer)
   and Radio Link Control Layer (RLC). PDCP performs following
   functions [TS36.323]:

   * Data transport by listening to upper layer, formatting and
      pushing down to Radio Link Layer (RLC).

   * Header compression and decompression using Robust Header
      Compression (ROHC).

   * Security protections such as ciphering, deciphering and
      integrity protection.

   * Radio layer messages associated with sequencing, packet drop
      detection and re-transmission etc.

   o No changes are required for lower layer such as RLC, MAC and
      Physical (L1) because they are not IP aware.

6. 5GC Architecture with 5GLAN Support

   In this section, we focus on the implemention of ICN over 5GLAN
   architecture [SA2-5GLAN]

6.1. Background: LAN-based End-to-End Packet Forwarding in 5G

```
  +------+  +------+  +-----+   +-----+   +-----+   +-----+
  | NSSF |  | NEF  |  | NRF |   | PCF |   | UDM |   | AF  |
  +--o---+  +--o---+  +--o--+   +--o--+   +--o--+   +--o--+
 Nnssf|    Nnef|    Nnrf|    Npcf|     Nudm|      Naf|
 -----+-------+-+--------+--+------+-------+-+--------+---------
        Nausf|         Namf|           Nsmf|
         +--o--+       +--o--+         +--o--+
         | AUSF|       | AMF |         | SMF |
         +-----+       +-+-+-+         +--+--+
                        / |               |
              +--------+  |               |
           N1 /           |N2         N4|   +-N9/Nx-+
       +------+            |             | |       |
      /                    |             | |       V
   +-+--+               +----+----+  N3  +-+--+-------+--+  N6  +----+
   | UE +---------------+  (R)AN  +------+      UPF      +----->+ DN |
   +----+               +---------+      +--------------+       +----+
```
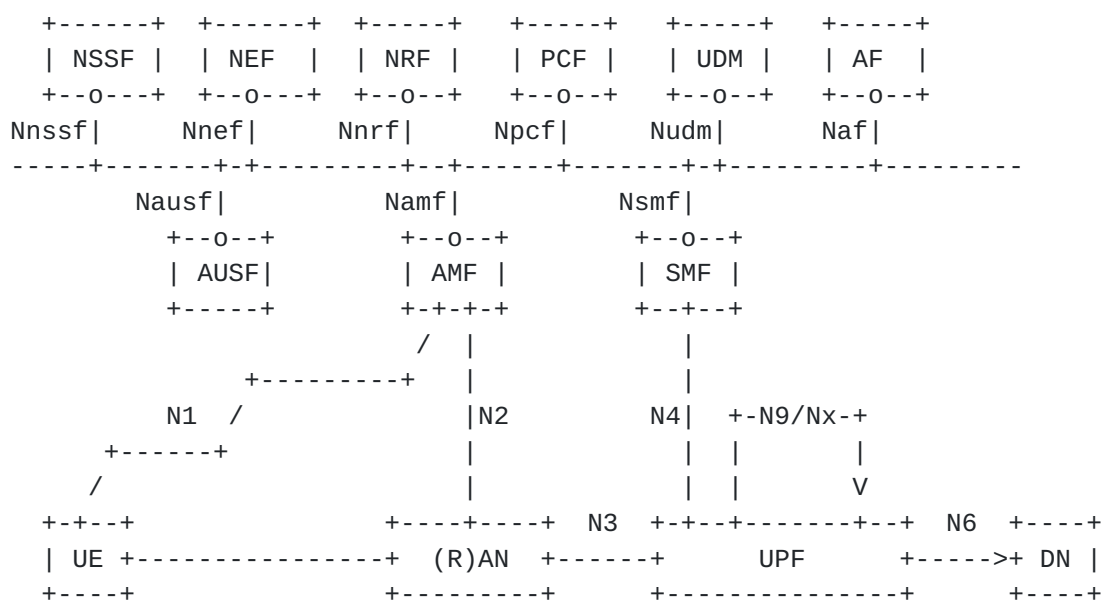
       Figure 6: 5G Core Network with Vertical_LAN (5GLAN) Extensions

   Figure 6 shows the current 5G Core Network Architecture being
   discussed within the scope of the normative work addressing 5GLAN
   Type services in the 3GPP System Architecture Working Group 2 (3GPP
   SA2), referred formally as "5GS Enhanced support of Vertical and LAN
   Services" [SA2-5GLAN]. The goal of this work item is to provide
   distributed LAN-based connectivity between two or more terminals or
   User Equipment entities (UEs) connected to the 5G network. The SMF

(session management function) provides a registration and discovery
protocol that allows UEs wanting to communicate via a relevant 5GLAN
group towards one or more UEs also members of this 5GLAN group, to
determine the suitable forwarding information after each UE
previously registered suitable identifier information with the SMF
responsible to manage the paths across UEs in a 5GLAN group. UEs
register and discover (obtain) suitable identifiers during the
establishment of a Protocol Data Unit (PDU) Session or PDU Session
Modification procedure. Suitable identifier information, according
to [SA2-5GLAN], are Ethernet MAC addresses as well as IP addresses
(the latter is usually assigned during the session setup through the
SMF, i.e., the session management function).

The SMF that manages the path across UEs in a 5GLAN group, then
establishes the suitable procedures to ensure the forwarding between
the required UPFs (user plane functions) to ensure the LAN
connectivity between the UEs (user equipments) provided in the
original request to the SMF. When using the N9 interface to the UPF,
this forwarding will rely on a tunnel-based approach between the UPFs
along the path, while the Nx interface uses path-based forwarding
between UPFs, while LAN-based forwarding is utilized between the
final UPF and the UE (utilizing the N3 interface towards the
destination UE).

In the following, path-based forwarding is assumed, i.e., the usage
of the Nx interface and the utilization of a path identifier for the
end-to-end LAN communication. Here, the path between the source and
destination UPFs is encoded through a bitfield, provided in the
packet header. Each bitposition in said bitfield represents a unique
link in the network. Upon receiving an incoming packet, each UPF
inspects said bitfield for the presence of any local link that is
being served by one of its output ports. Such presence check is
implemented via a simple binary AND and CMP operation. If no link is
being found, the packet is dropped. Such bitfield-based path
representation also allows for creating multicast relations in an ad-
hoc manner by combining two or more path identifiers through a binary
OR operation. Note that due to the assignment of a bitposition to a
link, path identifiers are bidirectional and can therefore be used
for request/response communication without incurring any need for
path computation on the return path.

For sending a packet from one Layer 2 device (UE) connected to one
UPF (via a RAN) to a device connected to another UPF, we provide the
MAC address of the destination and perform a header re-write by
providing the destination MAC address of the ingress UPF when sending
from source device to ingress and placing the end destination MAC
address in the payload. Upon arrival at the egress UPF, after having
applied the path-based forwarding between ingress and egress UPF, the

end destination address is restored while the end source MAC is
placed in the payload with the egress L2 forwarder one being used as
the L2 source MAC for the link-local transfer. At the flat device
(or proxy device), the end source MAC address is restored as the
source MAC, creating the perception of a link-local L2 communication
between the end source and destination devices.


```
+---------+---------+----------+-----------+-----------+
| Src MAC | Dst MAC |  pathID  |  NAME_ID  |  Payload  |
+---------+---------+--------------------+-----------+
```


Figure 7: General Packet Structure

For this end-to-end transfer, the general packet structure of
Figure 7 is used. The Name_ID field is being used for the ICN
operations, while the payload contains the information related to the
transaction-based flow management described in Section 6.2.6 and the
PATH_ID is the bitfield-based path identifier for the path-based
forwarding.

6.1.1. Realization in Existing Transport Networks

An emerging technology for Layer 2 forwarding that suits the 5GLAN
architecture in Figure 6 is that of Software-defined networking (SDN)
[SDNDef], which allows for programmatically forwarding packets at
Layer 2. Switch-based rules are being executed with such rules being
populated by the SDN controller. Rules can act upon so-called
matching fields, as defined by the OpenFlow protocol specification
[OpenFlowSwitch]. Those fields include Ethernet MAC addresses,
IPv4/6 source and destination addresses and other well-known Layer 3
and even 4 transport fields.

As shown in [Reed], efficient path-based forwarding can be realized
in SDN networks by placing the aforementioned path identifiers into
the IPv6 source/destination fields of a forwarded packet . Utilizing
the IPv6 source/destination fields allows for natively supporting 256
links in a transport network. Larger topologies can be supported by
extension schemes but are left out of this paper for brevity of the
presentation. During network bootstrapping, the Name Resolver (NR)
assigns to each link at each switch a unique bitnumber in the
bitfield. In order to forward based on such bitfield path
information, the NR instructs the SDN controller to insert a suitable
wildcard matching rule into the SDN switch. This wildcard at a given
switch is defined by the bitnumber that has been assigned to a
particular link at that switch during bootstrapping. Wildcard
matching as a generalization of longest prefix matching is natively

supported by SDN-based switches since the OpenFlow v1.3
specification, efficiently implemented through TCAM based operations.
With that, SDN forwarding actions only depend on the switch-local
number of output ports, while being able to transport any number of
higher-layer flows over the same transport network without specific
flow rules being necessary. This results in a constant forwarding
table size while no controller-switch interaction is necessary for
any flow setup; only changes in forwarding topology (resulting in a
change of port to bitnumber assignment) will require suitable changes
of forwarding rules in switches.

Although we focus the methods in this draft on Layer 2 forwarding
approaches, path-based transport networks can also be established as
an overlay over otherwise Layer 2 networks. For instance, the BIER
(Bit Indexed Explicit Replication) [RFC8279] efforts within the
Internet Engineer Task Force (IETF) establish such path-based
forwarding transport as an overlay over existing, e.g., MPLS
networks. The path-based forwarding identification is similar to the
aforementioned SDN realization although the bitfield represents
ingress/egress information rather than links along the path.

Yet another transport network example is presented in [Khalili],
utilizing flow aggregation over SDN networks. The flow aggregation
again results in a path representation that is independent from the
specific flows traversing the network.

6.2. IP-based Service over ICN over 5GLAN

```
                      +-------------------------------+
                      |      Forwarding Network        |    .... Control
                      |   +-------------------------+  |
                      |   | .         NR          . |  |     **** Data
                      |   +-.---------------------.-+  |
 +--------------+     |     .                   .   |   +--------------+
 |     App      |     |   +-.---------+  +---------.-+ |   |     App      |
 +-----+----+---+     |   | . ******* |  | ******* . | |   +--------------+
 |HTTP*|TCP*|IP.|     |   | . * UPF * |  | * UPF * . | |   |.IP|*TCP|*HTTP|
 +----*+---*+--.+     |   +-.-*-----*-+  +-*------*-.-+ |   +.--+*---+*----+
 |ICN *    *   .|     |     . *     *      *      * .   |   |.    *     * ICN|
 +----*----*---.+  +---+ . *     ******* *   * . +---+  +.---*----*----+
 |L2  *    *   ....|RAN+.. *                 * ..+RAN|....   *     *    |
 |    ********************                      ********************    |
 +--------------+  +---+ . *                   * . +---+  +--------------+
                      |   . *                   * .  |
                      |   +-.-*-----+       +-----*-.+  |
                      +--| . *  RAN|------|RAN  * .|--+
                         +-.-*-----+       +-----*-.+
                            . *                 * .
                            . *******       ******* .
 Legacy   Service        ....... *       * .......   Service
 Device   Proxy             . *       * .           Proxy
 +-----+ +------------------+ . *       * . +------------------+
 |APP *| |    *********     | . *       * . |    *********     |
 +----*+ +----*+      *     | . *       * . |    *      +*----+
 |HTTP*| |HTTP*|*******     | . *       * . |    *******|*HTTP|
 +----*+ +----*-+     *     | . *       * . |    *      +*----+
 |TCP *| |TCP * |******     | . *       * . |    ******| * TCP|
 +----*+ +----*--+  +*------+ . *       * . +-----*+  +---*----+ +-------+
 |IP  *| |IP  *  |***|* ICN .| . *       * . |.ICN *|***|   * IP| | IP     |
 +----*+ +----*--+---+*-----.+ . *       * . +.----*+---+---*----+ |Peering|
 |L2  *| |   *   L2  *    ... *       * ....   *        *    | |Network|
 |    *********    ***********     ***********    ***********   |
 +-----+ +------------------+       +------------------+  +-------+
```
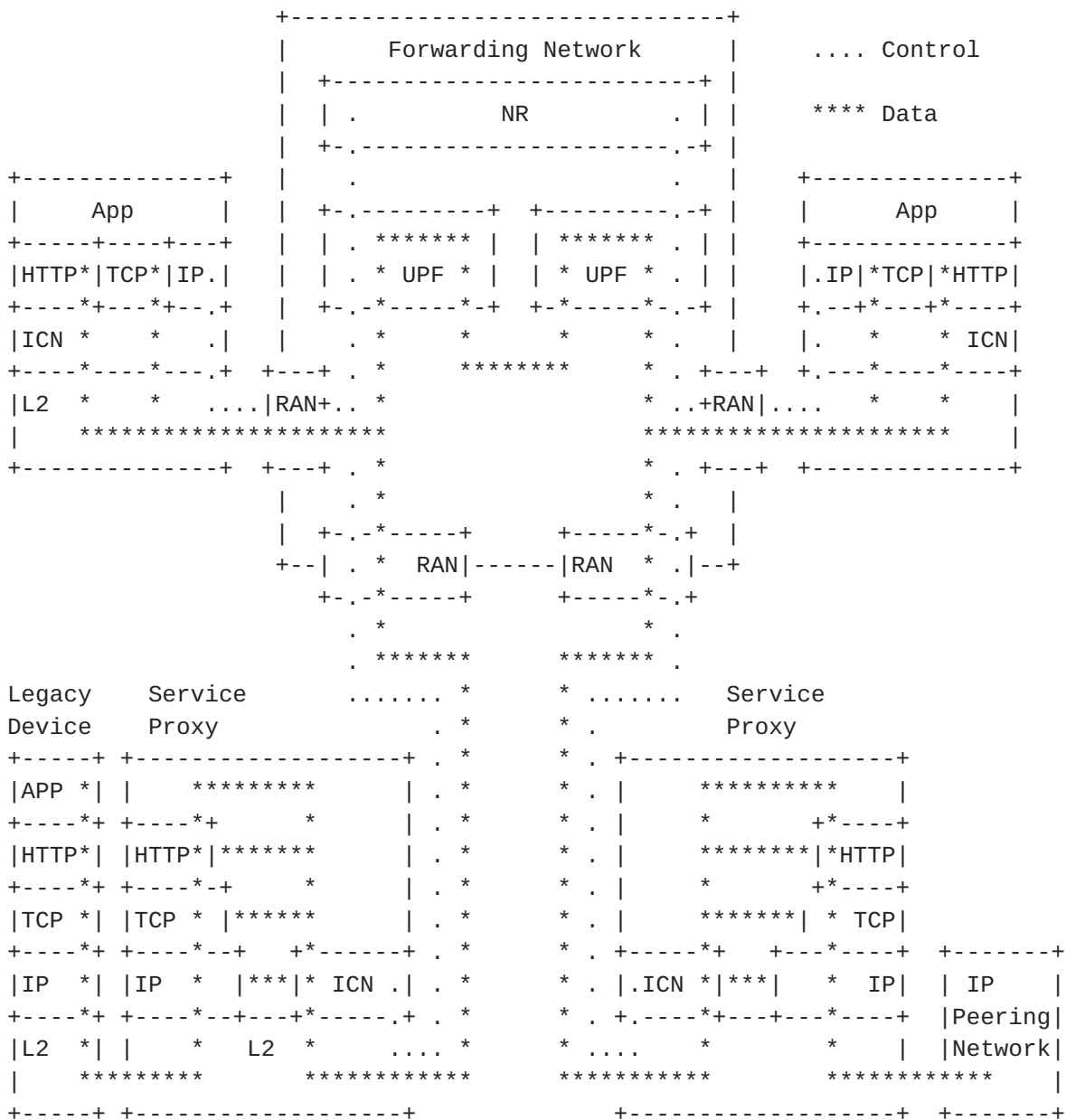
Figure 8: IP-based Services over ICN over 5GLAN

Figure 8 shows the protocol layering for realizing IP-based protocols
over an ICN over 5GLAN transport, assuming an end-to-end LAN
connectivity provided by solutions such as 5GLAN.

Note that such LAN connectivity can also be found in environments
such as localized LAN-based deployments in smart cities, enterprises
and others. Hence, the solutions described in this section also
applies to those deployments.

Key to the approach is that Internet services are being interpreted
as the main unit of transfer in the architecture shown in Figure 8.
For this, any Internet service is treated as a Named Service
Transaction (NST) which is in turn suitably routed over an ICN layer
in one or more other devices. As a result of this name-based
interpretation of any Internet service, the protocol stack in end
devices flattens to four layers with Internet services and ICN, with
ICN acting as a name-based routing layer for all IP protocol
implemented atop, with Layer 1 and 2 realizing the end-to-end packet
forwarding outlined in Section 6.1.

The details of the mapping and the operations of the ICN layer are
presented in Section 6.2.3 for the example of HTTP. As explained in
that section, the ICN layer uses an interaction with the NR to
register and discover HTTP-based services for determining the
suitable end-to-end packet forwarding information.

An important aspect of the architecture is the mapping of the end-to-
end flow semantic established in many Internet services onto the flat
protocol stack. Section 6.2.7 outlines the flow management that
exists between the end devices.

Interfaces to legacy devices and peering networks are preserved
through service proxy devices, which terminate a traditional Internet
protocol stack communication and translate it into a resulting flat
protocol transaction based on the operations defined in
Section 6.2.3. Termination here can be based on well-known port
numbers for specific Internet protocols, ultimately falling back to
the IP datagram service being the minimal service being mapped.

6.2.1. General Operations

The semantics of our name-based routing as that of a publish-
subscribe system over a name. The intention to receive packets with
a certain name is expressed through a subscription while sending
packets to a name is expressed through a publication. The matching
of a sender to a receiver is realized through NR in Figure 8. The
exact nature of the matching is defined through the semantics of the
service and, therefore, through the nature of the name provided. For
instance, HTTP and raw IP services are matched to exactly one
subscriber only, providing an anycast capability, while IP multicast
services are matched against any subscriber (with the IP multicast
address being the name).

Structured names are used with the root specific to the (Internet)
service name, such as URL, and therefore deriving the matching
semantics directly from the name.

The subscription to a name is realized through a registration
protocol between end device and NR. Hence, any end device exposing a
certain Internet service registers the suitable name with the NR,
which in turn stores reachability information that is suitable for
path calculation between the ingress and egress L2 forwarders between
which the communication eventually will take place. In our current
realization, we utilize shortest paths only although other link
weights can be utilized for, e.g., delay-constrained and other
policies.

In our realization, we use network domain unique host identifiers
that are being assigned to end devices during the connectivity setup.
Sending a packet of a given Internet service is realized through a
discovery protocol, which returns a suitable pathID, i.e., the
forwarding information between ingress and egress L2 forwarder, and
the destination MAC address of the hosting end device. It is this
pathID and MAC address that is being used in the general packet
structure of Figure 7 to forward the packet to the destination.

To reduce latency in further communication, the forwarding
information is locally cached at the end device, while the cached
information is being maintained through path updates sent by the NR
in case of hosting end devices having moved or de-registered,
therefore avoiding stale forwarding information.

6.2.2. ICN API to Upper Layers

The pub/sub operations of the ICN layer are exposed through the
following API calls:

o conn = send(name, payload)

o send(conn, payload)

o conn = receive(name, &payload)

o receive(conn, &payload)

The first send() call is used for initiating a send operation to a
name with a connection handle returned, while the second send() is
used for return calls, using a connection parameters that is being
received with the receive() call to an incoming connection or for
subsequence outgoing calls after an initial request to a name has
been made. A return send() is being received at the other (client)
side through the second receive() call where the conn parameter is
obtained by the corresponding send() call for the outgoing call.
With these API functions, we provide means for providing name-based
transactions with return responses association provided natively.

The conn parameter represents the bitfield used for path-based
forwarding in the remote host case or the hash of the local MAC
address in case of link-local connections.

6.2.3. HTTP over ICN

To realize the flat device nature, Internet service layers, such as
the HTTP protocol stack or the TCP protocol stack, will need to be
adapted to run atop this new API, implementing the semantics of the
respective Internet protocol through suitable transactions at the
name level. In the example of HTTP, the standard operations of DNS
resolution for the server to be contacted and opening of a TCP socket
are altogether replaced by a single send(FQDN, HTTP request) call,
while the response will be sent by the server, which received the
request through a receive(FQDN, &payload) call, using the returned
conn parameter to send the response with the second send() API call.
Note that the use of bidirectional pathIDs, no NR lookup is performed
at the HTTP serving endpoint.

6.2.4. Ad-Hoc Multicast for HTTP over ICN

The basis of a named service transaction allows to deliver the same
HTTP responses to several requestees in efficient multicast (see
[I-D.purkayastha-bier-multicast-http-response] for use cases in a
BIER-based transport network environment).

This opportunity is realized by sending the same payload (i.e., an
HTTP response to the same resource across a number of pending
requests) through a combination of several conn parameters received
in the incoming requests via the receive() function.

What is required in the HTTP stack implementation is a logic to
decide that two or more outstanding requests are possible to be
served by one response. For this, upon receiving an incoming
request, the HTTP stack determines any outstanding request to the
same resource. 'Same' here is defined as URI-specific combination of
the request URI and URI-specific header fields, such as browsing
agent or similar, called requestID in the following.

Once such determination is made that two requests are relating to the
same resource, i.e., are having the same request ID, the HTTP stack
maintains a temporary mapping of the request ID to the respective
conn parameters delivered by the receive() call. Upon receiving the
HTTP response from its application-level logic, the HTTP stack will
generate the suitable send(conn, payload) call where the provided
conn parameter is bitwise OR of all previously stored conn parameters
received in the receive() call. The ICN layer will recognize the use
of those ad-hoc created conn parameters and set the destination MAC

address in the general packet structure of Figure 8 to the Ethernet
broadcast MAC address as the destination address, leading to sending
the response to all end devices at the egress L2 forwarders to which
the response will be forwarded based on the combined conn parameter.
Alternatively, one could request IEEE assignment for a specific
Ethernet multicast address for this scheme instead of using the
broadcast address. For the local end device to determine the
relevance of the response received at the broadcast channel, the HTTP
stack of the serving endpoint includes the aforementioned requestID
into the payload of the packet (see Figure 8), while the originating
endpoint maintains an internal table with the requestID of pending
requests and its associated conn handle. If no matching requestID is
found, the packet is not being delivered to the NbR layer of the
incoming device. If a request is found, the ICN layer delivers the
response via the receive() call, using the conn handle stored in the
pending request table. Note that this filtering mechanism can easily
be implemented in hardware upon standardizing the appropriate payload
and header fields.

6.2.5. Service Proxy Operations

The service proxy in Figure 8 serves the integration of legacy
devices, i.e., with regular IP protocol stack, and the
interconnection to IP-based peering networks. It registers suitable
identifiers with the NR to ensure the reception of (ICN-packets)
packet, while providing suitable protocol termination for the various
supported protocols. For instance, for HTTP, the service proxy
towards the peering network will register a wildcard name to the NR
to receive any HTTP request not destined to a network-locally
registered FQDN, operating as an HTTP proxy towards the peering
network.

6.2.6. ICN Flow Management

EDITOR NOTE: left for future draft updates.

6.2.7. NR Operations

The NR in Figure 8 combines the operations of the SMF and the PMF in
5GLAN (see Figure 6), by allowing for registering IP protocol
identifiers for discovery and subsequent path computation by
resolving the destination(s) to a suitable pathID and destination MAC
address for forwarding. This will require extensions to the
operations of the SMF to allow for such higher layer identifiers to
be registered (and discovered), in addition to the already supported
Ethernet and IP addresses.

6.2.8. Mobility Handling

   EDITOR NOTE: left for future draft updates.

6.2.9. Dual Stack Device Support

   [I-D.suthar-icnrg-icn-lte-4g] outlines the possibility of supporting
   dual-stack devices for 4G LTE networks by allowing IP as well as ICN
   protocol stacks to be deployed with the operation of IP and ICN based
   applications. For this, a convergence layer is described that
   selects the appropriate data path for each ICN or IP application,
   e.g., based on configuration per application (similar to selecting
   network interfaces such as WiFi over cellular). An appropriate data
   path, as outlined in [I-D.suthar-icnrg-icn-lte-4g], can be the
   routing over IP or ICN. As a possible datapath selection,
   [I-D.suthar-icnrg-icn-lte-4g] envisions the realization of IP-over-
   ICN (Section 4.2 in [I-D.suthar-icnrg-icn-lte-4g]) in which the
   convergence layer would realize similar mapping functions as
   described in this draft. Hence, we foresee the utilization of such
   dual-stack devices connected to an IP-based services over ICN over
   5GLAN environment. When utilizing the service proxy, IP applications
   that are configured to use the IP data path only could still utilize
   the ICN-based forwarding in the network. In that case, functionality
   such as the opportunistic multicast in Section 6.2.4 would only reach
   up to the service proxy with unicast traffic continuing along the
   datapath towards the user equipment.

6.3. ICN over 5GLAN

   EDITOR NOTE: left for future draft updates.

7. Conclusion

   In this draft, we explore the feasibility of realizing future
   networking architectures like ICN within the proposed 3GPP's 5GC
   architecture. Towards this, we summarized the design principles that
   offer 5GC the flexibility to enable new network architectures. We
   then discuss 5GC architecture along with the user/control plane
   extensions required to handle ICN PDU sessions formally. We then
   apply the proposed architecture to enabling IP-based services over an
   ICN network in the context of 5GLAN.

8. IANA Considerations

   This document requests no IANA actions.

9. Security Considerations

   This draft proposes extensions to support ICN in 5G's next generation
   core architecture. ICN being name based networking opens up new
   security and privacy considerations which have to be studied in the
   context of 5GC. This is in addition to other security considerations
   of 5GC for IP or non-IP based services considered in [TS33.899].

10. Acknowledgments

   ...

11. Informative References

   [Guilio]   Grassi, G., Pesavento, D., Pau, G., Vayyuru, R., Wakikawa,
              Ryuji., Wakikawa, Ryuji., and Lixia. Zhang, "Vehicular
              Inter-Networking via Named Data", ACM Hot Mobile (Poster),
              2013.

   [H2020]   H2020, "The POINT Project", https://www.point-h2020.eu/ .

   [I-D.galis-anima-autonomic-slice-networking]
              Galis, A., Makhijani, K., Yu, D., and B. Liu, "Autonomic
              Slice Networking", draft-galis-anima-autonomic-slice-
              networking-05 (work in progress), September 2018.

   [I-D.muscariello-intarea-hicn]
              Muscariello, L., Carofiglio, G., Auge, J., and M.
              Papalini, "Hybrid Information-Centric Networking", draft-
              muscariello-intarea-hicn-01 (work in progress), December
              2018.

   [I-D.purkayastha-bier-multicast-http-response]
              Purkayastha, D., Rahman, A., Trossen, D., and T. Eckert,
              "Applicability of BIER Multicast Overlay for Adaptive
              Streaming Services", draft-purkayastha-bier-multicast-
              http-response-01 (work in progress), October 2018.

   [I-D.rahman-icnrg-deployment-guidelines]
              Rahman, A., Trossen, D., Kutscher, D., and R. Ravindran,
              "Deployment Considerations for Information-Centric
              Networking (ICN)", draft-rahman-icnrg-deployment-
              guidelines-05 (work in progress), January 2018.

   [I-D.suthar-icnrg-icn-lte-4g]
              suthar, P., Stolic, M., Jangam, A., and D. Trossen,
              "Native Deployment of ICN in LTE, 4G Mobile Networks",
              draft-suthar-icnrg-icn-lte-4g-04 (work in progress),
              November 2017.

   [I-D.white-icnrg-ipoc]
              White, G., Shannigrahi, S., and C. Fan, "Internet Protocol
              Tunneling over Content Centric Mobile Networks", draft-
              white-icnrg-ipoc-01 (work in progress), June 2018.

   [ICNMOB]   Azgin, A., Ravidran, R., Chakraborti, A., and G. Wang,
              "Seamless Producer Mobility as a Service in Information
              Centric Networks.", 5G/ICN Workshop, ACM ICN Sigcomm 2016,
              2016.

   [IEEE_Communications]
              Trossen, D. and G. Parisis, "Designing and Realizing an
              Information-Centric Internet", Information-Centric
              Networking, IEEE Communications Magazine Special Issue,
              2012.

   [Jacobson]
              Jacobson, V. and et al., "Networking Named Content",
              Proceedings of ACM Context, , 2009.

   [Khalili] Khalili, R., Poe, W., Despotovic, Z., and A. Hecker,
              "Reducing State of SDN Switches in Mobile Core Networks by
              Flow Rule Aggregation", IEEE ICCCN 2016, Hawaii, USA,
              August 2016.

   [lteversus5g]
              Kim, J., Kim, D., and S. Choi, "3GPP SA2 architecture and
              functions for 5G mobile communication system.", ICT
              Express 2017, 2017.

   [NFN]   Sifalakis, M., Kohler, B., Christopher, C., and C.
              Tschudin, "An information centric network for computing
              the distribution of computations", ACM, ICN Sigcomm, 2014.

   [OpenFlowSwitch]
              Open Networking Foundation, available at
              https://www.opennetworking.org/wp-content/uploads/2014/10/
              openflow-switch-v1.5.1.pdf, "OpenFlow Switch Specification
              V1.5.1", 2018.

[Ravindran]
          Ravindran, R., Chakraborti, A., Amin, S., Azgin, A., and
          G. Wang, "5G-ICN : Delivering ICN Services over 5G using
          Network Slicing", IEEE Communication Magazine, May, 2016.

[Reed]   Reed, M., AI-Naday, M., Thomos, N., Trossen, D.,
          Petropoulos, G., and S. Spirou, "Stateless Multicast
          Switching in Software Defined Networks", IEEE ICC 2016,
          Kuala Lumpur, Maylaysia, 2016.

[RFC7927] Kutscher, D., Ed., Eum, S., Pentikousis, K., Psaras, I.,
          Corujo, D., Saucez, D., Schmidt, T., and M. Waehlisch,
          "Information-Centric Networking (ICN) Research
          Challenges", RFC 7927, DOI 10.17487/RFC7927, July 2016,
          <https://www.rfc-editor.org/info/rfc7927>.

[RFC8279] Wijnands, IJ., Ed., Rosen, E., Ed., Dolganow, A.,
          Przygienda, T., and S. Aldrin, "Multicast Using Bit Index
          Explicit Replication (BIER)", RFC 8279,
          DOI 10.17487/RFC8279, November 2017,
          <https://www.rfc-editor.org/info/rfc8279>.

[SA2-5GLAN]
          3gpp-5glan, "SP-181129, Work Item Description,
          Vertical_LAN(SA2), 5GS Enhanced Support of Vertical and
          LAN Services", 3GPP ,
          http://www.3gpp.org/ftp/tsg_sa/TSG_SA/TSGS_82/Docs/
          SP-181120.zip.

[SDNDef]   Open Networking Foundation, available at
          https://www.opennetworking.org/sdn-definition/, "Software-
          Defined Networking (SDN) Definition", 2018.

[TROSSEN] Trossen, D., Reed, M., Riihijarvi, J., Georgiades, M., and
          G. Xylomenos, "IP Over ICN - The Better IP ?", EuCNC,
          European Conference on Networks and Communications , July,
          2015.

[TS23.501]
          3gpp-23.501, "Technical Specification Group Services and
          System Aspects; System Architecture for the 5G System;
          Stage 2 (Rel.15)", 3GPP , December 2018.

[TS23.502]
          3gpp-23.502, "Technical Specification Group Services and
          System Aspects; Procedures for the 5G System; Stage 2
          (Rel. 15)", 3GPP , January 2019.

   [TS23.799]
             3gpp-23.799, "Technical Specification Group Services and
             System Aspects; Study on Architecture for Next Generation
             System (Rel. 14)", 3GPP , 2017.

   [TS33.899]
             3gpp-33.899, "Study on the security aspects of the next
             generation system", 3GPP , 2017.

   [TS36.323]
             3gpp-36.323, "Technical Specification Group Radio Access
             Network; Evolved Universal Terrestrial Radio Access
             (E-UTRA); Packet Data Convergence Protocol (PDCP)
             specification (Rel. 15)", 3GPP , January 2019.

   [TS38.300]
             3gpp-38-300, "Technical Specification Group Radio Access
             Network; NR; NR and NG-RAN Overall Description; Stage 2
             (Rel.15)", 3GPP , January 2019.

   [VSER]   Ravindran, R., Liu, X., Chakraborti, A., Zhang, X., and G.
             Wang, "Towards software defined ICN based edge-cloud
             services", CloudNetworking(CloudNet), IEEE Internation
             Conference on, IEEE Internation Conference on
             CloudNetworking(CloudNet), 2013.

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