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              Native Deployment of ICN in LTE, 4G Mobile Networks
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Abstract

   LTE, 4G mobile networks use IP-based transport for the control plane
   to establish the data session at the user plane for the actual data
   delivery. In the existing architecture, IP transport used in the
   user plane is not optimized for data transport, which leads to
   inefficient data delivery. For instance, IP unicast routing from
   server to clients is used for the delivery of multimedia content to
   User Equipment (UE), with each user receiving a separate stream.
   From a bandwidth and routing perspective, this approach is
   inefficient. Multicast and broadcast technologies have recently
   emerged for mobile networks, but their deployments are very limited
   or at an experimental stage. ICN is a rapidly emerging technology,
   although much of the work is focused on fixed networks. The focus of
   this draft is on native deployment of ICN in cellular mobile networks
   by using ICN in a 3GPP protocol stack. ICN has inherent capabilities
   for multicast, anchorless mobility, and security, while being
   optimized for data delivery using local caching at the edge. The
   proposed approaches in this draft allow ICN to be enabled natively
   over the current LTE stack comprising PDCP/RLC/MAC/PHY, or in a dual
   stack mode (alongside IP). This document is a product of the
   Information-Centric Networking Research Group (ICNRG).

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1. Introduction

   LTE mobile technology is built as an all-IP network. It uses IP
   routing protocols (OSPF, ISIS, BGP, etc.) to establish network routes
   over which route data traffic. Stickiness of an IP address to a
   device is the key to get connected to a mobile network. The same IP
   address is maintained through the session until the device gets
   detached or moves to another network.

   Key protocols used in 4G and LTE networks are GPRS Tunneling protocol
   (GTP), DIAMETER, and other protocols that are built on top of IP.
   One of the biggest challenges with IP-based routing in LTE is that it
   is not optimized for data transport. As an alternative to IP
   routing, this draft presents instead the native implementation of
   Information Centric Networking (ICN) in 3GPP, offering an opportunity
   to leverage inherent ICN capabilities such as in-network caching,
   multicast, anchorless mobility management, and authentication. This
   draft proposes options for deploying ICN in mobile networks, and how
   those options affect mobile providers and end users.

   This document represents the consensus of the Information-Centric
   Networking Research Group (ICNRG). It has been reviewed extensively
   by the Research Group (RG) members active in the specific areas of
   work covered by the document.

2. 3GPP Terminology and Concepts

   1. Access Point Name

       The Access Point Name (APN) is a Fully Qualified Domain Name
       (FQDN) and resolves to a set of gateways in an operator's
       network. APN identifies the packet data network (PDN) with
       which a mobile data user wants to communicate. In addition to
       identifying a PDN, an APN may also be used to define the type of
       service, QoS, and other logical entities inside GGSN, PGW.

   2. Control Plane

       The control plane carries signaling traffic and is responsible
       for routing between eNodeB and MME, MME and HSS, MME and SGW,
       SGW and PGW, etc. Control plane signaling is required to
       authenticate and authorize UE and establish a mobility session
       with mobile gateways (SGW/PGW). Control plane functions also
       include system configuration and management.

3.   Dual Address PDN/PDP Type

     The dual address Packet Data Network/Packet Data Protocol (PDN/
     PDP) Type (IPv4v6) is used in 3GPP context, in many cases as a
     synonym for dual stack; i.e., a connection type capable of
     serving IPv4 and IPv6 simultaneously.

4.   eNodeB

     The eNodeB is a base station entity that supports the Long-Term
     Evolution (LTE) air interface.

5.   Evolved Packet Core

     The Evolved Packet Core (EPC) is an evolution of the 3GPP GPRS
     system characterized by a higher-data-rate, lower-latency,
     packet-optimized system. The EPC comprises some sub components
     of the EPS core such as Mobility Management Entity (MME),
     Serving Gateway (SGW), Packet Data Network Gateway (PDN-GW), and
     Home Subscriber Server (HSS).

6.   Evolved Packet System

     The Evolved Packet System (EPS) is an evolution of the 3GPP GPRS
     system characterized by a higher-data-rate, lower-latency,
     packet-optimized system that supports multiple Radio Access
     Technologies (RATs). The EPS comprises the EPC together with
     the Evolved Universal Terrestrial Radio Access (E-UTRA) and the
     Evolved Universal Terrestrial Radio Access Network (E-UTRAN).

7.   Evolved UTRAN

     The E-UTRAN is a communications network sometimes referred to as
     4G, and consists of eNodeB (4G base stations). The E-UTRAN
     allows connectivity between the User Equipment and the core
     network.

8.   GPRS Tunneling Protocol

     The GPRS Tunneling Protocol (GTP) [TS29.060] [TS29.274]
     [TS29.281] is a tunneling protocol defined by 3GPP. It is a
     network-based mobility protocol, working similar to Proxy Mobile
     IPv6 (PMIPv6). However, GTP also provides functionality beyond
     mobility, such as in-band signaling related to QoS and charging,
     among others.

9.   Gateway GPRS Support Node

The Gateway GPRS Support Node (GGSN) is a gateway function in
the GPRS and 3G network that provides connectivity to the
Internet or other PDNs. The host attaches to a GGSN identified
by an APN assigned to it by an operator. The GGSN also serves
as the topological anchor for addresses/prefixes assigned to the
User Equipment.

10. General Packet Radio Service

The General Packet Radio Service (GPRS) is a packet-oriented
mobile data service available to users of the 2G and 3G cellular
communication systems--the GSM--specified by 3GPP.

11. Home Subscriber Server

The Home Subscriber Server (HSS) is a database for a given
subscriber and was introduced in 3GPP Release-5. It is the
entity containing subscription-related information to support
the network entities that handle calls/sessions.

12. Mobility Management Entity

The Mobility Management Entity (MME) is a network element
responsible for control plane functionalities, including
authentication, authorization, bearer management, layer-2
mobility, and so on. The MME is essentially the control plane
part of the SGSN in the GPRS. The user plane traffic bypasses
the MME.

13. Public Land Mobile Network

The Public Land Mobile Network (PLMN) is a network operated by a
single administration. A PLMN (and, therefore, also an
operator) is identified by the Mobile Country Code (MCC) and the
Mobile Network Code (MNC). Each (telecommunications) operator
providing mobile services has its own PLMN.

14. Policy and Charging Control

The Policy and Charging Control (PCC) framework is used for QoS
policy and charging control. It has two main functions: flow-
based charging (including online credit control), and policy
control (for example, gating control, QoS control, and QoS
signaling). It is optional to 3GPP EPS but needed if dynamic
policy and charging control by means of PCC rules based on user
and services are desired.

15. Packet Data Network

The Packet Data Network (PDN) is a packet-based network that
either belongs to the operator or is an external network such as
the Internet or a corporate intranet. The user eventually
accesses services in one or more PDNs. The operator's packet
core networks are separated from packet data networks either by
GGSNs or PDN Gateways (PGWs).

16. Serving Gateway

The Serving Gateway (SGW) is a gateway function in the EPS,
which terminates the interface towards the E-UTRAN. The SGW is
the Mobility Anchor point for layer-2 mobility (inter-eNodeB
handovers). For each UE connected with the EPS, there is only
one SGW at any given point in time. The SGW is essentially the
user plane part of the GPRS's SGSN.

17. Packet Data Network Gateway

The Packet Data Network Gateway (PGW) is a gateway function in
the Evolved Packet System (EPS), which provides connectivity to
the Internet or other PDNs. The host attaches to a PGW
identified by an APN assigned to it by an operator. The PGW
also serves as the topological anchor for addresses/prefixes
assigned to the User Equipment.

18. Packet Data Protocol Context

A Packet Data Protocol (PDP) context is the equivalent of a
virtual connection between the User Equipment (UE) and a PDN
using a specific gateway.

19. Packet Data Protocol Type

A Packet Data Protocol Type (PDP Type) identifies the used/
allowed protocols within the PDP context. Examples are IPv4,
IPv6, and IPv4v6 (dual-stack).

20. Serving GPRS Support Node

The Serving GPRS Support Node (SGSN) is a network element
located between the radio access network (RAN) and the gateway
(GGSN). A per-UE point-to-point (p2p) tunnel between the GGSN
and SGSN transports the packets between the UE and the gateway.

21. Terminal Equipment

The Terminal Equipment (TE) is any device/host connected to the
Mobile Terminal (MT) offering services to the user. A TE may

        communicate to an MT, for example, over the Point-to-Point
        Protocol (PPP).

    22. UE, MS, MN, and Mobile

        The terms User Equipment (UE), Mobile Station (MS), Mobile Node
        (MN), and mobile refer to the devices that are hosts with the
        ability to obtain Internet connectivity via a 3GPP network. An
        MS comprises the Terminal Equipment (TE) and a Mobile Terminal
        (MT). The terms UE, MS, MN, and mobile are used interchangeably
        within this document.

    23. User Plane

        The user plane refers to data traffic and the required bearers
        for the data traffic. In practice, IP is the only data traffic
        protocol used in the user plane.

3. LTE, 4G Mobile Network

3.1. Network Overview

   With the introduction of LTE, mobile networks moved to all-IP
   transport for all elements such as eNodeB, MME, SGW/PGW, HSS, PCRF,
   routing and switching, etc. Although the LTE network is data-
   centric, it has support for legacy Circuit Switch features such as
   voice and SMS through transitional CS fallback and flexible IMS
   deployment [GRAYSON]. For each mobile device attached to the radio
   (eNodeB), there is a separate overlay tunnel (GPRS Tunneling
   Protocol, GTP) between eNodeB and Mobile gateways (i.e., SGW, PGW).

   When any UE is powered up, it attaches to a mobile network based on
   its configuration and subscription. After a successful attachment
   procedure, the UE registers with the mobile core network, and an IPv4
   and/or IPv6 address is assigned. A default bearer is created for
   each UE, and it is assigned to default Access Point Name (APN).

   The GTP tunnel is used to carry user traffic between gateways and
   mobile devices, therefore mandating unicast delivery for any data
   transfer. It is also important to understand the overhead of GTP and
   IPSec protocols. All mobile backhaul traffic is encapsulated using a
   GTP tunnel, which has overhead of 8 bytes on top of IP and UDP
   [NGMN]. Additionally, if IPSec is used for security (which is often
   required if the Service Provider is using a shared backhaul), it adds
   overhead based on the IPSec tunneling model (tunnel or transport) as
   well as the encryption and authentication header algorithm used. If
   we consider as an example an Advanced Encryption Standard (AES)

encryption, the overhead can be significant [OLTEANU], particularly
for smaller payloads.

```
                                   +-------+  Diameter  +-------+
                                   |  HSS  |------------|  SPR  |
                                   +-------+            +-------+
                                       |                    |
          +------+   +------+    S4     |                +-------+
          |  3G  |---| SGSN |-----------------|------+  +------| PCRF  |
      ^   |NodeB |   |      |      |---------+  +---+    |  |   +-------+
   +-+ |  +------+   +------+  S3     |  |  S6a    |  |Gxc    |
   | | |                     +-------+  |  |       |  |       |Gx
   +-+ |       +-----------------|  MME  |------+  |  |       |
   UE  v       |     S1MME       +-------+  S11 |  |  |       |
       +----+-+                         +-------+    +-------+
       |4G/LTE|-----------------------------|  SGW  |-----|  PGW  |
       |eNodeB|            S1U               +-------+  +--|       |
       +------+                                  |  +-------+
                         +--------------------+    |  |
    S1U GTP Tunnel traffic         |         +-------+     |  |
    S2a GRE Tunnel traffic       |S2A        | ePDG  |-------+  |
    S2b GRE Tunnel traffic       |           +-------+  S2B     |SGi
    SGi IP traffic               |               |             |
                       +---------+   +---------+       +-----+
                       | Trusted |   |Untrusted|       | CDN |
                       |non-3GPP |   |non-3GPP |       +-----+
                       +---------+   +---------+
                            |             |
                           +-+           +-+
                           | |           | |
                           +-+           +-+
                           UE            UE
```
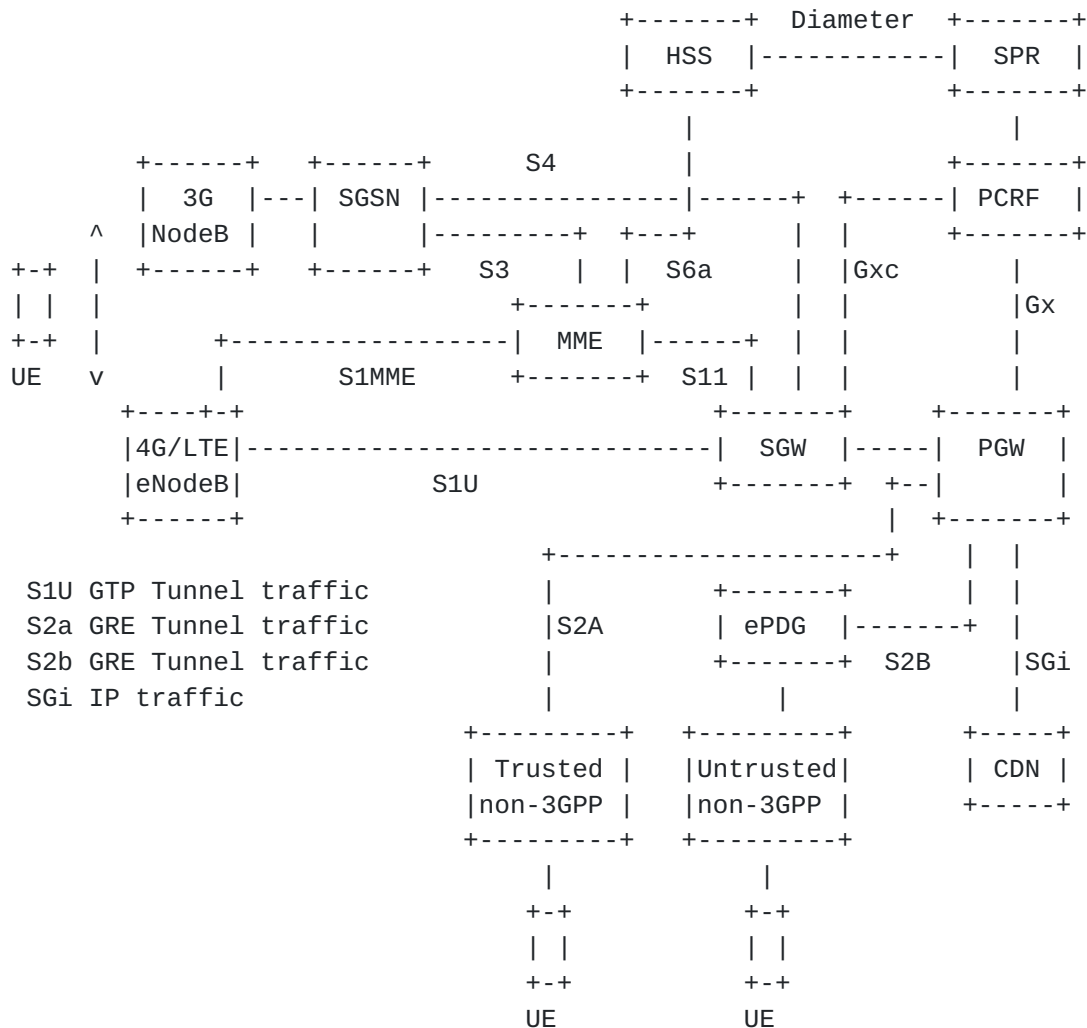
Figure 1: LTE, 4G Mobile Network Overview

If we consider the combined impact of GTP, IPSec and unicast traffic,
the data delivery is not efficient. The IETF has developed various
header compression algorithms to reduce the overhead associated with
IP packets. Some techniques are robust header compression (ROHC) and
enhanced compression of the real-time transport protocol (ECRTP) so
that the impact of overhead created by GTP, IPsec, etc., is reduced
to some extent [BROWER]. For commercial mobile networks, 3GPP has
adopted different mechanisms for header compression to achieve
efficiency in data delivery [TS25.323]; those solutions can be
adapted to other data protocols, such as ICN, too [ICNLOWPAN]
[TLVCOMP].

3.2. QoS Challenges

   During the attachment procedure, a default bearer is created for each
   UE and it is assigned to the default Access Point Name (APN). The
   QoS values assigned during the initial attach are best-effort, with
   no guarantees. Additional dedicated bearer(s) with enhanced QoS
   parameters are established, depending on specific application needs.

   While all traffic within a certain bearer receives the same
   treatment, QoS parameters supporting these requirements can be very
   granular in different bearers. These values vary for the control,
   management and user traffic, and can be very different depending on
   application key parameters such as latency, jitter (important for
   voice and other real-time applications), packet loss, and queuing
   mechanism (strict priority, low-latency, fair, and so on).

   Implementation of QoS for mobile networks is done at two stages: at
   content prioritization/marking and transport marking, and congestion
   management. From the transport perspective, QoS is defined at layer
   2 as class of service (CoS) and at layer 3 either as DiffServ code
   point (DSCP) or type of service (ToS). The mapping of DSCP to CoS
   takes place at layer 2/3 switching and routing elements. 3GPP has a
   specified a QoS Class Identifier (QCI), which represents different
   types of content and equivalent mappings to the DSCP at transport
   layer [TS23.401]. However, this requires manual configuration at
   different elements and is therefore prone to possible
   misconfigurations.

   In summary, QoS configuration in mobile networks for user plane
   traffic requires synchronization of parameters among different
   platforms. Normally, QoS in IP is implemented using DiffServ, which
   uses hop-by-hop QoS configuration at each router. Any inconsistency
   in IP QoS configuration at routers in the forwarding path can result
   in a poor subscriber experience (e.g., packet classified as high
   priority can go to a lower priority queue). By deploying ICN, we
   intend to enhance the subscriber experience using policy-based
   configuration, which can be associated with the named contents
   [ICNQoS] at the ICN forwarder. Further investigation is needed to
   understand how QoS in ICN can be implemented to meet the IP QoS
   requirements [RFC4594].

   Research papers published so far explore the possibility of
   classifications based on name prefixes (thus addressing the problem
   of IP QoS not being information aware), or on popularity or placement
   (looking at a distance of a content from a requester). However,
   focus of these research efforts is on faster routing of Interest
   requests towards the content rather than content delivery.

3.3. **Data Transport Using IP**

   The data delivered to mobile devices is sent in unicast semantic
   inside the GTP tunnel from an eNodeB to a PDN gateway (PGW), as
   described in 3GPP specifications [TS23.401]. While the technology
   exists to address the issue of possible multicast delivery, there are
   many difficulties related to multicast protocol implementations on
   the RAN side of the network. Transport networks in the backhaul and
   core addressed the multicast delivery a long time ago and have
   implemented it in most cases in their multi-purpose integrated
   transport. But the RAN part of the network is still lagging behind
   due to complexities related to client mobility, handovers, and the
   fact that the potential gain to Service Providers may not justify the
   investment, which explains the prevalence of unicast delivery in
   mobile networks. Techniques to handle multicast (such as LTE-B or
   eMBMS) have been designed to handle pre-planned content delivery,
   such as live content, which contrasts user behavior today, largely
   based on content (or video) on demand model.

   To ease the burden on the bandwidth of the SGi interface, caching is
   introduced in a similar manner as with many Enterprises. In mobile
   networks, whenever possible, cached data is delivered. Caching
   servers are placed at a centralized location, typically in the
   Service Provider's Data Center, or in some cases lightly distributed
   in Packet Core locations with the PGW nodes close to the Internet and
   IP services access (SGi interface). This is a very inefficient
   concept because traffic must traverse the entire backhaul path for
   the data to be delivered to the end user. Other issues, such as out-
   of-order delivery, contribute to this complexity and inefficiency,
   which needs to be addressed at the application level.

3.4. **Virtualizing Mobile Networks**

   The Mobile packet core deployed in a major Service Provider network
   is either based on dedicated hardware or, in some cases, large
   capacity x86 platforms. With the adoption of Mobile Virtual Network
   Operators (MVNO), public safety networks, and enterprise mobility
   networks, elastic mobile core architecture are needed. By deploying
   the mobile packet core on a commercially off-the-shelf (COTS)
   platform, using a virtualized infrastructure (NFVI) framework and
   end-to-end orchestration, new deployments can be simplified to
   provide optimized TCO.

   While virtualization is growing, and many mobile providers use a
   hybrid architecture that consists of dedicated and virtualized
   infrastructures, the control and data planes are still the same.
   There is also work under way to separate the control and user plane
   for the network to scale better. Virtualized mobile networks and

network slicing with control and user plane separation provide a
mechanism to evolve the GTP-based architecture towards an Openflow
SDN-based signaling for LTE and proposed 5G core. Some early
architecture work for 5G mobile technologies provides a mechanism for
control and user plane separation and simplifies the mobility call
flow by introducing Openflow-based signaling [ICN5G]. This has been
considered by 3GPP [EPCCUPS] and is also described in [SDN5G].

4. Data Transport Using ICN

For mobile devices, the edge connectivity is between mobile terminal
and a router or mobile edge computing (MEC) [MECSPEC] element. Edge
computing has the capability of processing client requests and
segregating control and user traffic at the edge of radio, rather
than sending all requests to the mobile gateway.

```
        +----------+
        | Content  +-----------------------------------------+
        | Publisher|                                         |
        +---+---+--+                                         |
            |   |    +--+              +--+            +--+   |
            |   +--->|R1|------------->|R2|----------->|R4|   |
            |        +--+              +--+            +--+   |
            |                           |    Cached          |
            |                           v    content         |
            |                          +--+   at R3          |
            |                  +=======|R3|---+              |
            |                  #       +--+   |              |
            |                  #              |              |
            |                  v              v              |
            |                 +-+            +-+             |
        +---------------| |-------------| |-------------+
                         +-+            +-+
                      Consumer-1     Consumer-2
                          UE             UE


              ===> Content flow from cache
              ---> Content flow from publisher
```
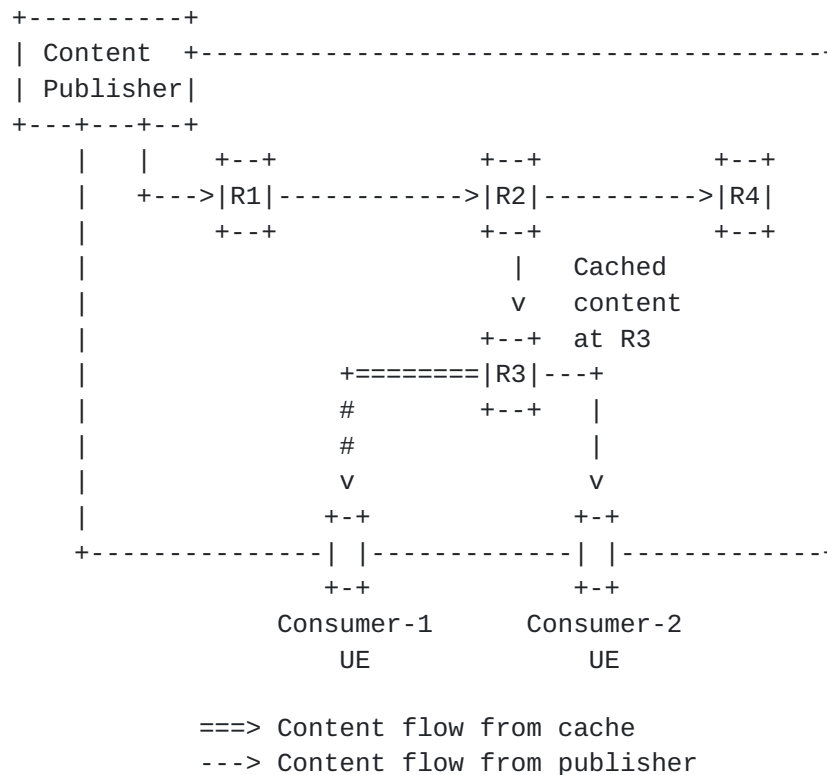
                    Figure 2: ICN Architecture

Edge computing transforms radio access network into an intelligent
service edge capable of delivering services directly from the edge of
the network, while providing the best possible performance to the
client. Edge computing can be an ideal candidate for implementing
ICN forwarders in addition to its usual function of managing mobile

termination. In addition to edge computing, other transport
elements, such as routers, can work as ICN forwarders.

Data transport using ICN is different to IP-based transport by
introducing uniquely named-data as a core design principle.
Communication in ICN takes place between the content provider
(producer) and the end user (consumer), as described in Figure 2.

Every node in a physical path between a client and a content provider
is called the ICN forwarder or router. It can route the request
intelligently and cache content so it can be delivered locally for
subsequent requests from any other client. For mobile networks,
transport between a client and a content provider consists of radio
network + mobile backhaul and IP core transport + Mobile Gateways +
Internet + content data network (CDN).

To understand the suitability of ICN for mobile networks, we will
discuss the ICN framework by describing its protocols architecture
and different types of messages to then consider how we can use this
in mobile networks for delivering content more efficiently. ICN uses
two types of packets called "interest packet" and "data packet" as
described in Figure 3.

```
                  +-----------------------------------+
      Interest | +------+     +------+     +------+ |          +-----+
 +-+       ---->|  CS  |---->| PIT  |---->| FIB  |--------->| CDN |
 | |           | +------+     +------+     +------+ |          +-----+
 +-+           |     |       Add  |       Drop |      | Forward
 UE            <--------+      Intf v       Nack v      |
       Data  |                                          |
                  +-----------------------------------+


                  +-----------------------------------+
 +-+              | Forward                  +------+ |          +-----+
 | | <-----------------------------------| PIT  |<---------| CDN |
 +-+              |                  | Cache  +--+---+ | Data   +-----+
 UE              |              +--v---+       |      |
                 |              | CS  |       v      |
                 |              +------+     Discard |
                  +-----------------------------------+
```
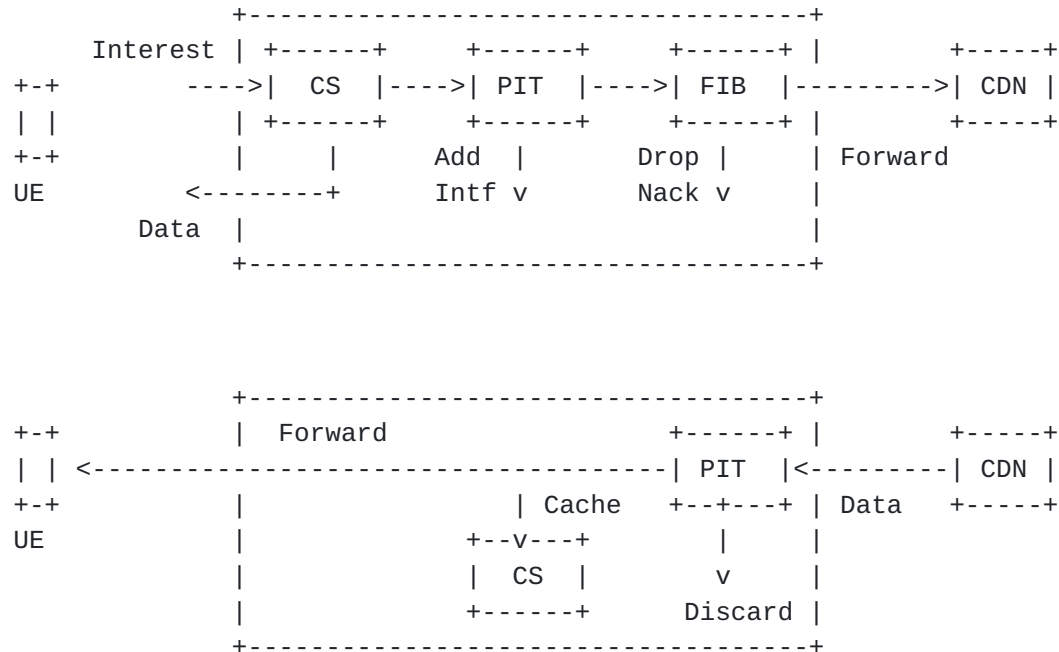
Figure 3: ICN Interest, Data Packet and Forwarder

In an LTE network, when a mobile device wants to receive certain
content, it will send an Interest message to the closest eNodeB.

Interest packets follow the TLV format [RFC8609] and contain
mandatory fields, such as name of the content and content matching
restrictions (KeyIdRestr and ContentObjectHashRestr), expressed as a
tuple [RFC8569]. The content matching tuple uniquely identifies the
matching data packet for the given Interest packet. Another
attribute called HopLimit is used to detect looping Interest
messages.

An ICN router will receive an Interest packet and lookup if a request
for such content has arrived earlier from another client. If so, it
may be served from the local cache; otherwise, the request is
forwarded to the next-hop ICN router. Each ICN router maintains
three data structures: Pending Interest Table (PIT), Forwarding
Information Base (FIB), and Content Store (CS). The Interest packet
travels hop-by-hop towards the content provider. Once the Interest
packet reaches the content provider; it will return a Data packet
containing information such as content name, signature, and the
actual data.

The data packet travels in reverse direction following the same path
taken by the Interest packet, maintaining routing symmetry. Details
about algorithms used in PIT, FIB, CS, and security trust models are
described in various resources [CCN]; here, we have explained the
concept and its applicability to the LTE network.

5. ICN Deployment in 4G and LTE Networks

5.1. General ICN Deployment Considerations

In LTE/4G mobile networks, both user and control plane traffic have
to be transported from the edge to the mobile packet core via IP
transport. The evolution of the existing mobile packet core using
Control and User Plane Separation (CUPS) [TS23.714] enables flexible
network deployment and operation by distributed deployment and the
independent scaling of control plane and user plane functions - while
not affecting the functionality of existing nodes subject to this
split.

In the CUPS architecture, there is an opportunity to shorten the path
for user plane traffic by deploying offload nodes closer to the edge
[OFFLOAD]. With this major architecture change, a User Plane
Function (UPF) node is placed close to the edge so traffic no longer
needs to traverse the entire backhaul path to reach the EPC. In many
cases, where feasible, the UPF can be collocated with the eNodeB,
which is also a business decision based on user demand. Placing a
Publisher close to the offload site, or at the offload site, provides
for a significant improvement in user experience, especially with
latency-sensitive applications. This capability allows for the

introduction of ICN and amplifies its advantages. This section
analyzes the potential impact of ICN on control and user plane
traffic for centralized and disaggregate CUPS-based mobile network
architecture.

5.2. ICN Deployment Scenarios

The deployment of ICN provides an opportunity to further optimize the
existing data transport in LTE/4G mobile networks. The various
deployment options that ICN and IP provide are somewhat analogous to
the deployment scenarios when IPv6 was introduced to interoperate
with IPv4 except, with ICN, the whole IP stack is being replaced. We
have reviewed [RFC6459] and analyzed the impact of ICN on control
plane signaling and user plane data delivery. In general, ICN can be
deployed by natively replacing IP transport (IPv4 and IPv6) or as an
overlay protocol. Figure 4 describes a modified protocol stack to
support ICN deployment scenarios.

```
           +----------------+ +-----------------+
           | ICN App (new)  | |IP App (existing)|
           +---------+------+ +-------+---------+
                     |                |
           +---------+----------------+---------+
           | Transport Convergence Layer (new)  |
           +------+--------------------+-------+
                  |                    |
           +------+------+      +------+-------+
           |ICN function |      | IP function  |
           |   (New)     |      | (Existing)   |
           +------+------+      +------+-------+
                  |                    |
               (```).               (```).
              (   ICN  '`.          (   IP    '`.
              ( Cloud   )           ( Cloud    )
               ` __..'+'             ` __..'+'
```
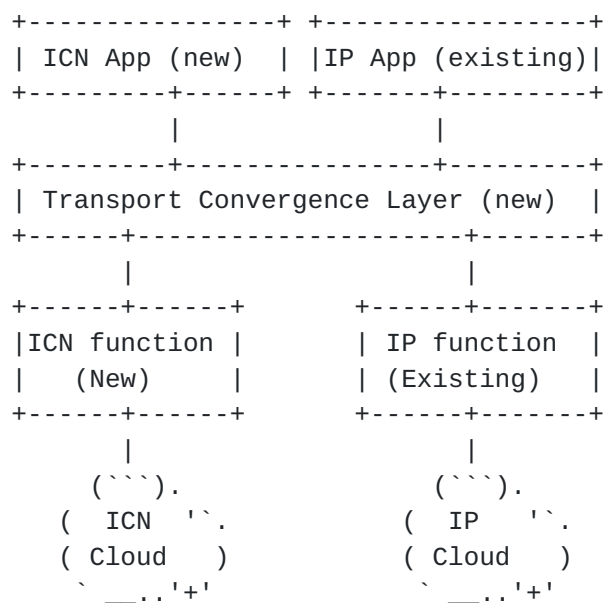
Figure 4: IP/ICN Convergence and Deployment Scenarios

As shown in Figure 4, for applications running either in the UE or in
the content provider system to use the new transport option, we
propose a new transport convergence layer (TCL). This transport
convergence layer helps determine the type of transport (such as ICN
or IP), as well as the type of radio interface (LTE or WiFi or both)
used to send and receive traffic based on preference (e.g., content
location, content type, content publisher, congestion, cost, QoS).
It helps configure and determine the type of connection as well as

the overlay mode (ICNoIP or IPoICN) between application and the
protocol stack (IP or ICN) to be used.

Combined with the existing IP function, the ICN function provides
support for either native ICN and/or the dual stack (ICN/IP)
transport functionality. See Section 5.4.1 for elaborate
descriptions of these functional layers.

The TCL can use several mechanisms for transport selection. It can
use a per-application configuration through a management interface,
possibly even a user-facing setting realized through a user
interface, like 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
(such as an ICN transport) for obtaining its benefits.

Another potential application of TCL is in implementation of network
slicing, with a slice management capability locally or through an
interface to an external slice manager via an API [GALIS]. 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 the slice manager or
configured locally on UE.

From the perspective of applications either on the UE or at a content
provider, the following options are possible for ICN deployment
natively and/or with IP.

1. IP over IP

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

2. ICN over ICN

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

3. ICN over IP (ICNoIP)

    In this scenario, the underlying IP transport infrastructure is
    not impacted (that is, ICN is implemented as an IP overlay

between user equipment (UE) and content provider). IP routing is
used from Radio Access Network (eNodeB) to the mobile backhaul,
the IP core, and the Mobile Gateway (SGW/PGW). The UE attaches
to the Mobile Gateway (SGW/PGW) using an IP address. Also, the
data transport between Mobile Gateway (SGW/PGW) and content
publisher uses IP. The content provider can serve content either
using IP or ICN, based on the UE request.

An approach to implement ICN in mobile backhaul networks is
described in [MBICN]. It implements a GTP-U extension header
option to encapsulate ICN payload in a GTP tunnel. However, as
this design runs ICN as an IP overlay, the mobile backhaul can be
deployed using native IP. The proposal describes a mechanism
where the GTP-U tunnel can be terminated by hair pinning the
packet before it reaches SGW, if an ICN-enabled node is deployed
in the mobile backhaul (that is, between eNodeB and SGW). This
could be useful when an ICN data packet is stored in the ICN node
(such as repositories, caches) in the tunnel path so that the ICN
node can reply without going all the way through the mobile core.
While a GTP-U extension header is used to carry UE specific ICN
payload, they are not visible to the transport, including SGW.
On the other hand, the PGW can use the UE-specific ICN header
extension and ICN payload to set up an uplink transport towards a
content provider in the Internet. In addition, the design
assumes a proxy function at the edge, to perform ICN data
retrieval on behalf of a non-ICN end device.

4. IP over ICN (IPoICN)

[IPoICN] provides an architectural framework for deployment of IP
as an overlay over ICN protocol. Implementing IP services over
ICN provides an opportunity to leverage the benefits of ICN in
the transport infrastructure while there is no impact on end
devices (UE and access network) as they continue to use IP.
IPoICN however, will require an inter-working function (IWF/
Border Gateway) to translate various transport primitives. The
IWF function will provide a mechanism for protocol translation
between IPoICN and native IP deployment for mobile network.
After reviewing [IPoICN], we understand and interpret that ICN is
implemented in the transport natively; however, IP is implemented
in UE, eNodeB, and Mobile gateway (SGW/PGW), which is also called
as a network attach point (NAP).

For this, said NAP receives an incoming IP or HTTP packet (the
latter through TCP connection termination) and publishes 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 NAP maintains a pending request mapping table
to map returning responses to the terminated TCP connection.

5. Hybrid ICN (hICN)

An alternative approach to implement ICN over IP is provided in
Hybrid ICN [HICN]. It describes a novel approach to integrate
ICN into IPv6 without creating overlays with a new packet format
as an encapsulation. hICN addresses the content by encoding a
location-independent name in an IPv6 address. It uses two name
components--name prefix and name suffix--that identify the source
of data and the data segment within the scope of the name prefix,
respectively.

At application layer, hICN maps the name into an IPv6 prefix and,
thus, uses IP as transport. As long as the name prefixes, which
are routable IP prefixes, point towards a mobile GW (PGW or local
breakout, such as CUPS), there are potentially no updates
required to any of the mobile core gateways (for example, SGW/
PGW). The IPv6 backhaul routes the packets within the mobile
core. hICN can run in the UE, in the eNodeB, in the mobile
backhaul, or in the mobile core. Finally, as hICN itself uses
IPv6, it cannot be considered as an alternative transport layer.

5.3. ICN Deployment in LTE Control Plane

In this section, we analyze signaling messages that are required for
different procedures, such as attach, handover, tracking area update,
and so on. The goal of this analysis is to see if there are any
benefits to replacing IP-based protocols with ICN for LTE signaling
in the current architecture. It is important to understand the
concept of point of attachment (POA). When UE connects to a network,
it has the following POAs:

1. eNodeB managing location or physical POA

2. Authentication and Authorization (MME, HSS) managing identity or
    authentication POA

3. Mobile Gateways (SGW, PGW) managing logical or session management
    POA

In the current architecture, IP transport is used for all messages
associated with the control plane for mobility and session
management. IP is embedded very deeply into these messages utilizing
TLV syntax for carrying additional attributes such as a layer 3
transport. The physical POA in the eNodeB handles both mobility and
session management for any UE attached to 4G, LTE network. The

number of mobility management messages between different nodes in an
LTE network per signaling procedure is shown in Table 1.

Normally, two types of UE devices attach to the LTE network: SIM
based (need 3GPP mobility protocol for authentication) or non-SIM
based (which connect to WiFi network). Both device types require
authentication. For non-SIM based devices, AAA is used for
authentication. We do not propose to change UE authentication or
mobility management messaging for user data transport using ICN. A
separate study would be required to analyze the impact of ICN on
mobility management messages structures and flows. We are merely
analyzing the viability of implementing ICN as a transport for
control plane messages.

It is important to note that, if MME and HSS do not support ICN
transport, they still need to support UE capable of dual stack or
native ICN. When UE initiates an attach request using the identity
as ICN, MME must be able to parse that message and create a session.
MME forwards UE authentication to HSS, so HSS must be able to
authenticate an ICN-capable UE and authorize create session
[TS23.401].

LTE Signaling Procedures	MME	HSS	SGW	PGW	PCRF
Attach	10	2	3	2	1
Additional default bearer	4	0	3	2	1
Dedicated bearer	2	0	2	2	0
Idle-to-connect	3	0	1	0	0
Connect-to-Idle	3	0	1	0	0
X2 handover	2	0	1	0	0
S1 handover	8	0	3	0	0
Tracking area update	2	2	0	0	0
Total	34	2	14	6	3

Table 1: Signaling Messages in LTE Gateways

Anchorless mobility [ALM] provides a fully decentralized, control-
plane agnostic solution to handle producer mobility in ICN. Mobility
management at layer-3 level makes it access agnostic and transparent
to the end device or the application. The solution discusses
handling mobility without having to depend on core network functions
(e.g. MME); however, a location update to the core network may still
be required to support legal compliance requirements such as lawful
intercept and emergency services. These aspects are open for further
study.

One of the advantages of ICN is in the caching and reusing of the content, which does not apply to the transactional signaling exchange. After analyzing LTE signaling call flows [TS23.401] and messages inter-dependencies (see Table 1), our recommendation is that it is not beneficial to deploy ICN for control plane and mobility management functions. Among the features of ICN design, Interest aggregation and content caching are not applicable to control plane signaling messages. Control plane messages are originated and consumed by the applications and they cannot be shared.

5.4. ICN Deployment in LTE User Plane

We will consider Figure 1 to discuss different mechanisms to deploy ICN in mobile networks. In Section 5.2, we discussed generic deployment scenarios of ICN. In this section, we discuss the specific use cases of native ICN deployment in LTE user plane. We consider the following options:

1. Dual stack ICN deployment in UE

2. Native ICN deployments in UE

3. ICN deployment in eNodeB

4. ICN deployment in mobile gateways (SGW/PGW)

5.4.1. Dual stack ICN deployments in UE

The control and user plane communications in LTE, 4G mobile networks are specified in 3GPP documents [TS23.203] and [TS23.401]. It is important to understand that UE can be either consumer (receiving content) or publisher (pushing content for other clients). The protocol stack inside the mobile device (UE) is complex because it must support multiple radio connectivity access to eNodeB(s).

Figure 5 provides a high-level description of a protocol stack, where IP is defined at two layers: (1) user plane communication and (2) UDP encapsulation. User plane communication takes place between Packet Data Convergence Protocol (PDCP) and Application layer, whereas UDP encapsulation is at GTP protocol stack.

The protocol interactions and impact of supporting tunneling of ICN packet into IP or to support ICN natively are described in Figure 5 and Figure 6, respectively.

```
  +--------+                                         +--------+
  |  App   |                                         |  CDN   |
  +--------+                                         +--------+
  |Transp. | |              |              |         |Transp. |
  |Converg.|.|..............|..............|.........|.|Converge|
  +--------+ |              |              | +--------+ | +--------+
  |        |.|..............|..............|.|         |.|.|         |
  | ICN/IP | |              |              | | ICN/IP  | | | ICN/IP|
  |        | |              |              | |         | | |        |
  +--------+ | +----+-----+ | +-----+-----+ | +-----+--+ | +--------+
  |        |.|.|    |     |.|.|     |     |.|.|     |  | | | |        |
  |  PDCP  | | |PDCP|GTP-U| | |GTP-U|GTP-U| | |GTP-U|  | | | |   L2   |
  +--------+ | +----------+ | +-----------+ | +-----+  | | | |        |
  |  RLC   |.|.|RLC | UDP |.|.| UDP | UDP |.|.|UDP   |L2|.|.| |        |
  +--------+ | +----------+ | +-----------+ | +-----+  | | | |        |
  |  MAC   |.|.| MAC|  L2 |.|.| L2  | L2  |.|.| L2  |  | | | |        |
  +--------+ | +----------+ | +-----------+ | +--------+ | +--------+
  |  L1    |.|.| L1 | L1  |.|.| L1  | L1  |.|.| L1 |L1|.|.|   L1   |
  +--------+ | +----+-----+ | +-----+-----+ | +-----+--+ | +--------+
     UE     |  BS(eNodeB)  |     SGW       |     PGW     |
         Uu            S1U            S5/S8           SGi
```
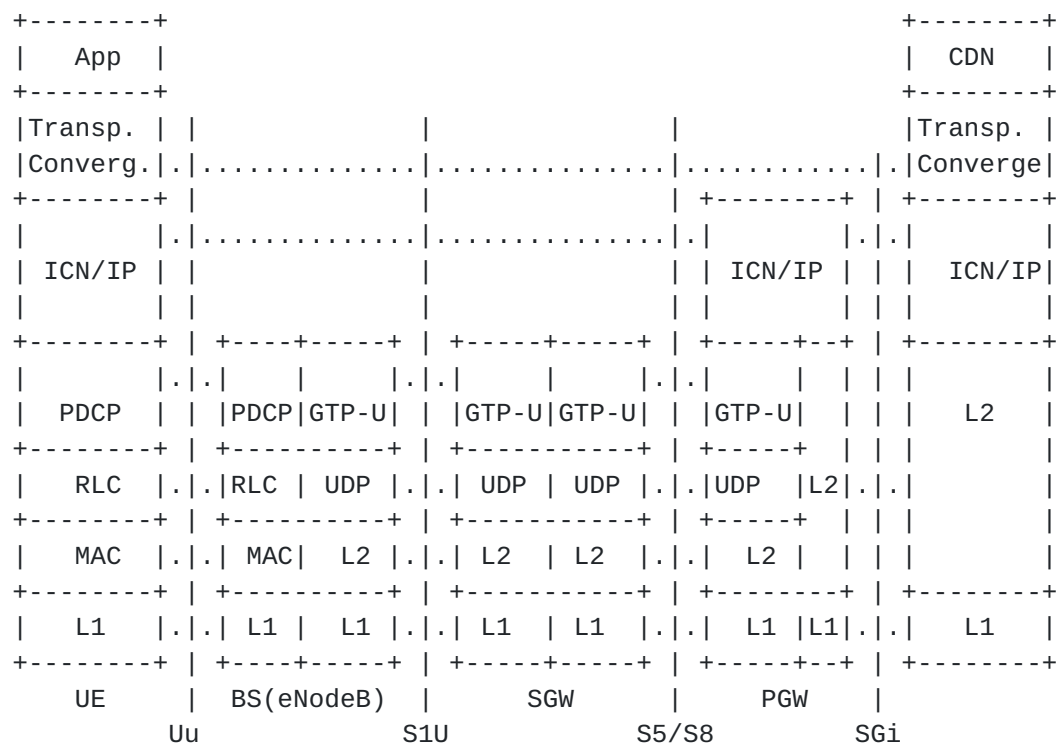
Figure 5: Dual Stack ICN Deployment in UE

The protocols and software stack used inside LTE capable UE support
both 3G and LTE software interworking and handover. the latest 3GPP
Rel.13 onward specification describes the use of IP and non-IP
protocols to establish logical/session connectivity. We intend to
leverage the non-IP protocol-based mechanism to deploy ICN protocol
stack in UE, as well as in eNodeB and mobile gateways (SGW, PGW).

1. An existing application layer can be modified to provide options
    for a new ICN-based application and existing IP-based
    applications. The UE can continue to support existing IP-based
    applications or host new applications developed to support native
    ICN as transport, ICNoIP, or IPoICN-based transport. The
    application layer has the option of selecting either ICN or IP
    transport, as well as radio interface, to send and receive data
    traffic.

    Our proposal is to provide an Application Programming Interface
    (API) to the application developers so they can choose either ICN
    or IP transport for exchanging the traffic with the network. As
    mentioned in Section 5.2, the transport convergence layer (TCL)
    function handles the interaction of applications with multiple
    transport options.

2.   The transport convergence layer helps determine the type of
     transport (such as ICN, hICN, or IP) and type of radio interface
     (LTE or WiFi, or both) used to send and receive traffic.
     Application layer can make the decision to select a specific
     transport based on preference, such as content location, content
     type, content publisher, congestion, cost, QoS, and so on. There
     can be an Application Programming Interface (API) to exchange
     parameters required for transport selection. Southbound
     interactions of Transport Convergence Layer (TCL) will be either
     to IP or ICN at the network layer.

     When selecting the IPoICN mode, the TCL is responsible for
     receiving an incoming IP or HTTP packet and publishing the packet
     to the ICN network under a suitable ICN name (that is, 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). 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 '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.

```
          +----------------+ +----------------+
          | ICN App (new)  | |IP App (existing)|
          +---------+------+ +-------+---------+
                    |                |
          +---------+----------------+---------+
          | Transport Convergence Layer (new)  |
          +------+--------------------+-------+
                 |                    |
          +------+------+      +------+-------+
          |ICN function |      | IP function  |
          |   (New)     |      | (Existing)   |
          +------+------+      +------+-------+
                 |                    |
          +------+--------------------+-------+
          | PDCP (updated to support ICN)     |
          +----------------+------------------+
                           |
          +----------------+------------------+
          |          RLC (Existing)           |
          +----------------+------------------+
                           |
          +----------------+------------------+
          |         MAC Layer (Existing)      |
          +----------------+------------------+
                           |
          +----------------+------------------+
          |        Physical L1 (Existing)     |
          +-----------------------------------+
```
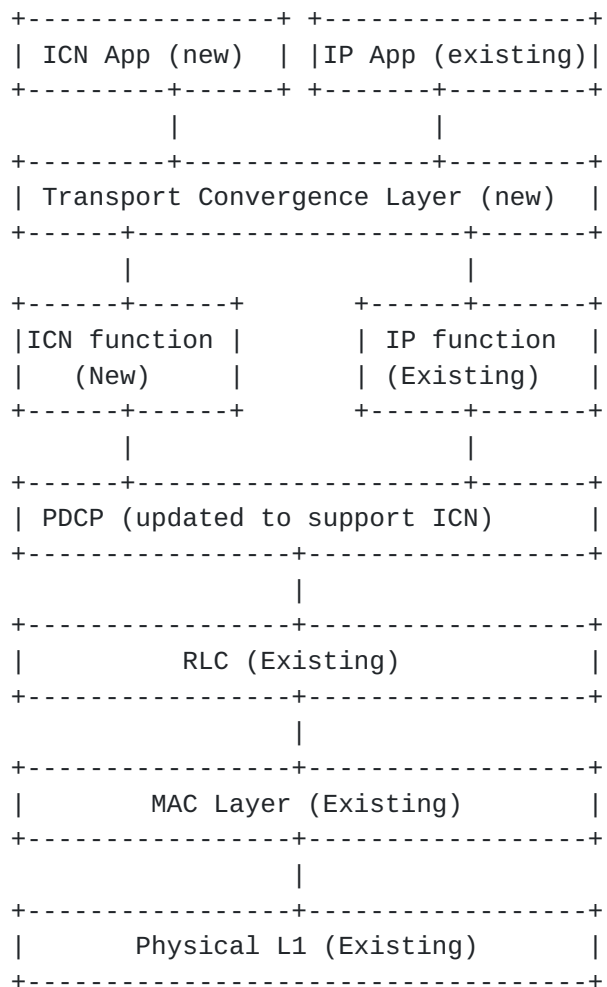
                 Figure 6: Dual Stack ICN Protocol Interactions

   3. The ICN function (forwarder) is introduced in parallel to the
       existing IP layer. The ICN forwarder contains functional
       capabilities to forward ICN packets, such as an Interest packet
       to eNodeB or a response "data packet" from eNodeB to the
       application.

   4. For the dual-stack scenario, when UE is not supporting ICN as
       transport, we use an IP underlay to transport ICN packets. The
       ICN function will use the IP interface to send Interest and Data
       packets for fetching or sending data using ICN protocol function.
       This interface will use the ICN overlay over IP using any overlay
       tunneling mechanism.

   5. To support ICN at network layer in UE, the PDCP layer must be
       aware of ICN capabilities and parameters. PDCP is located in the
       Radio Protocol Stack in the LTE Air interface, between IP

(Network layer) and Radio Link Control Layer (RLC). PDCP
performs the following functions [[TS36.323](TS36.323)]:

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

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

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

4. Radio layer messages associated with sequencing, packet drop
    detection and re-transmission, and so on.

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

One key point to understand in this scenario is that ICN is deployed
as an overlay on top of IP.

[5.4.2](5.4.2). Native ICN Deployments in UE

We propose to implement ICN natively in UE by modifying the PDCP
layer in 3GPP protocols. Figure 7 provides a high-level protocol
stack description where ICN is used at the following different
layers:

1. User plane communication

2. Transport layer

User plane communication takes place between PDCP and application
layer, whereas ICN transport is a substitute of the GTP protocol.
The removal of the GTP protocol stack is a significant change in the
mobile architecture because GTP is used not just for routing but for
mobility management functions, such as billing, mediation, and policy
enforcement.

If we implement ICN natively in the UE, the communication between UE
and eNodeB will change. Also, this will avoid tunneling the user
plane traffic from eNodeB to the mobile packet core (SGW, PGW) using
a GTP tunnel.

For native ICN deployment, an application will be configured to use
ICN forwarder so there is no need for Transport Convergence. Also,
to support ICN at the network layer in UE, we need to modify the
existing PDCP layer to be aware of ICN capabilities and parameters.

The native implementation will also provide opportunities to develop
new use cases leveraging ICN capabilities, such as seamless mobility,
UE to UE content delivery using radio network without traversing the
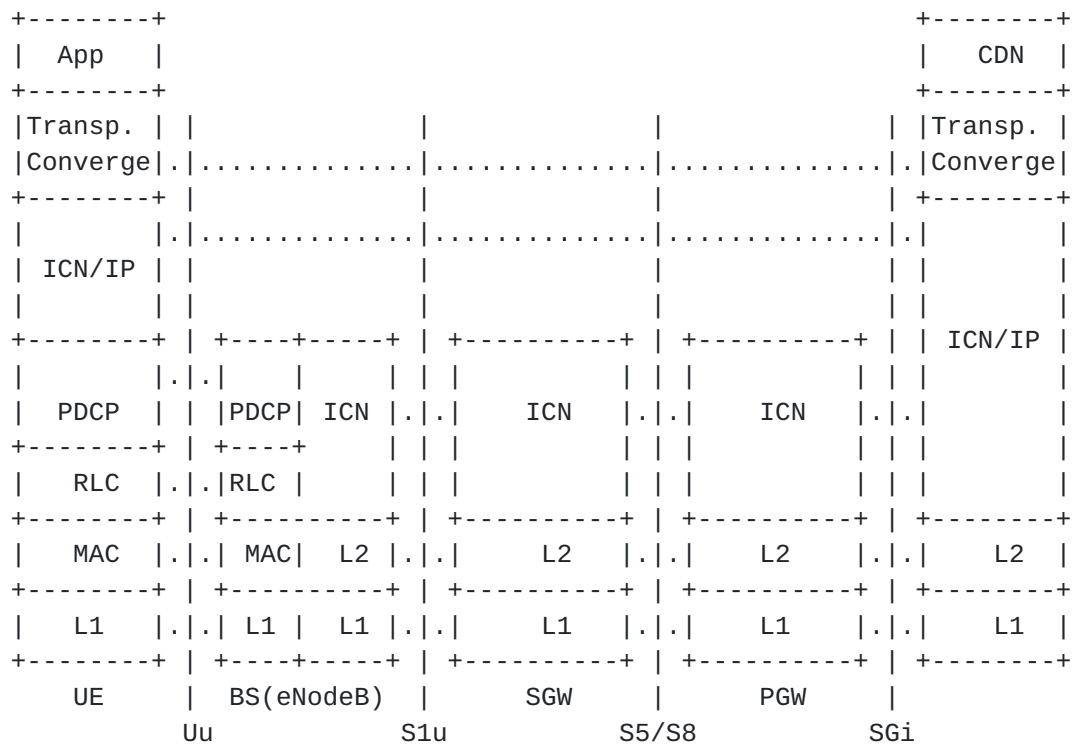mobile gateways, and more.

```
+--------+                                          +--------+
|  App   |                                          |  CDN   |
+--------+                                          +--------+
|Transp. | |                |              |        | |Transp. |
|Converge|.|..............|..............|..............|.|Converge|
+--------+ |                |              |        | +--------+
|        |.|..............|..............|..............|.|        |
| ICN/IP | |                |              |        | |        |
|        | |                |              |        | |        |
+--------+ | +----+-----+ | +----------+ | +----------+ | | ICN/IP |
|        |.|.|    |     | | | |        | | |        | | | |        |
|  PDCP  | | |PDCP| ICN |.|.|    ICN   |.|.|   ICN  |.|.| |        |
+--------+ | +----+     | | | |        | | |        | | | |        |
|  RLC   |.|.|RLC |     | | | |        | | |        | | | |        |
+--------+ | +----------+ | +----------+ | +----------+ | +--------+
|  MAC   |.|.| MAC| L2  |.|.|    L2    |.|.|    L2  |.|.|    L2  |
+--------+ | +----------+ | +----------+ | +----------+ | +--------+
|  L1    |.|.| L1 | L1  |.|.|    L1    |.|.|    L1  |.|.|    L1  |
+--------+ | +----+-----+ | +----------+ | +----------+ | +--------+
    UE      |  BS(eNodeB)  |    SGW      |    PGW      |
          Uu            S1u          S5/S8          SGi
```

Figure 7: Native ICN Deployment in UE

5.5. ICN Deployment in eNodeB

The eNodeB is a physical point of attachment for the UE, where radio
protocols are converted into IP transport protocol for dual stack/
overlay and native ICN, respectively (see Figure 6 and Figure 7).
When a UE performs an attach procedure, it is assigned an identity
either as IP or dual stack (IP and ICN), or ICN. UE can initiate
data traffic using any of the following options:

1. Native IP (IPv4 or IPv6)

2. Native ICN

3. Dual stack IP (IPv4/IPv6) or ICN

The UE encapsulates a user data transport request into PDCP layer and
sends the information on the air interface to eNodeB, which in turn
receives the information and, using PDCP [TS36.323], de-encapsulates

the air-interface messages and converts them to forward to core
mobile gateways (SGW, PGW). As shown in Figure 8, to support ICN
natively in eNodeB, it is proposed to provide transport convergence
layer (TCL) capabilities in eNodeB (similar to as provided in UE),
which provides the following functions:

1. It decides the forwarding strategy for a user data request coming
    from UE. The strategy can decide based on preference indicated
    by the application, such as congestion, cost, QoS, and so on.

2. eNodeB to provide open Application Programming Interface (API) to
    external management systems, to provide capability to eNodeB to
    program the forwarding strategies.

```
                  +---------------+  |
                  | UE request    |  |    ICN          +---------+
            +---> | content using |--+--- transport -->|         |
            |     |ICN protocol   |  |                  |         |
            |     +---------------+  |                  |         |
            |                        |                  |         |
            |     +---------------+  |                  |         |
  +-+       |     | UE request    |  |    IP            |To mobile|
  | |---+---+---> | content using |--+--- transport -->|    GW   |
  +-+       |     | IP protocol   |  |                  |(SGW,PGW)|
   UE       |     +---------------+  |                  |         |
            |                        |                  |         |
            |     +---------------+  |                  |         |
            |     | UE request    |  |    Dual stack    |         |
            +---> | content using |--+--- IP+ICN    -->|         |
                  |IP/ICN protocol|  |    transport    +---------+
                  +---------------+  |
                        eNodeB        S1u
```
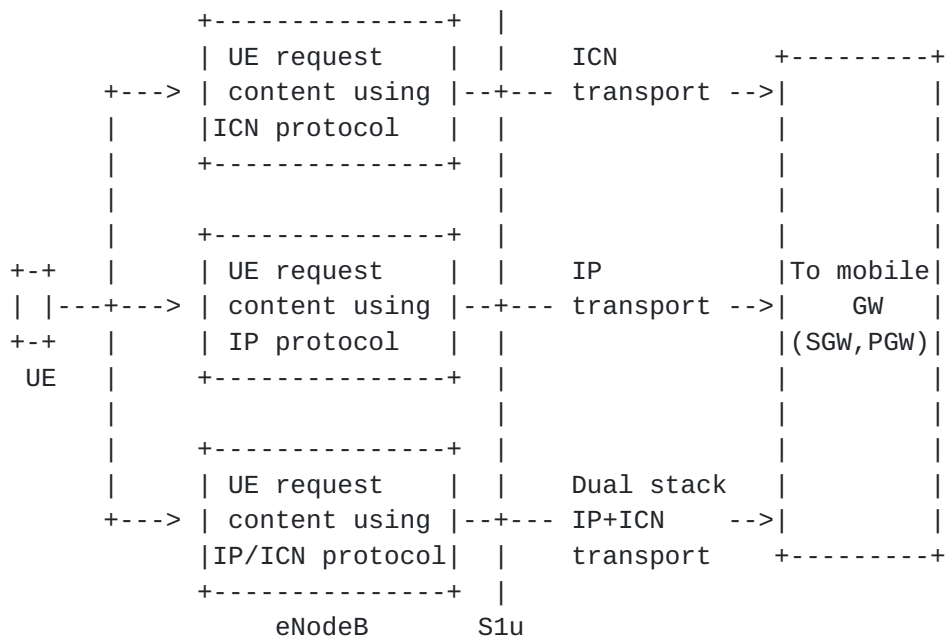
                Figure 8: Native ICN Deployment in eNodeB

3. eNodeB can be upgraded to support three different types of
    transport: IP, ICN, and dual stack IP+ICN towards mobile
    gateways, as depicted in Figure 8. It is also proposed to deploy
    IP and/or ICN forwarding capabilities into eNodeB, for efficient
    transfer of data between eNodeB and mobile gateways. Following
    are choices for forwarding a data request towards mobile
    gateways:

    1. Assuming eNodeB is IP enabled and the UE requests an IP
        transfer, eNodeB forwards data over IP.

> 2. Assuming eNodeB is ICN enabled and the UE requests an ICN
>   transfer, eNodeB forwards data over ICN.
>
> 3. Assuming eNodeB is IP enabled and the UE requests an ICN
>   transfer, eNodeB overlays ICN on IP and forwards user plane
>   traffic over IP.
>
> 4. Assuming eNodeB is ICN enabled and the UE requests an IP
>   transfer, eNodeB overlays IP on ICN and forwards user plane
>   traffic over ICN [IPoICN].

5.6. ICN Deployment in Packet Core (SGW, PGW) Gateways

Mobile gateways---also known as Evolved Packet Core (EPC)--include
SGW, PGW, which perform session management for UE from the initial
attach to disconnection. When UE is powered on, it performs NAS
signaling and attaches to PGW after successful authentication. PGW
is an anchoring point for UE and responsible for service creations,
authorization, maintenance, and so on. The Entire functionality is
managed using IP address(es) for UE.

To implement ICN in EPC, the following functions are proposed:

1. Insert ICN attributes in session management layer as additional
   functionality with IP stack. Session management layer is used
   for performing attach procedures and assigning logical identity
   to user. After successful authentication by HSS, MME sends a
   create session request (CSR) to SGW and SGW to PGW.

2. When MME sends Create Session Request message (Step 12 in
   [TS23.401]) to SGW or PGW, it includes a Protocol Configuration
   Option Information Element (PCO IE) containing UE capabilities.
   We can use PCO IE to carry ICN-related capabilities information
   from UE to PGW. This information is received from UE during the
   initial attach request in MME. Details of available TLV, which
   can be used for ICN, are given in subsequent sections. UE can
   support either native IP, ICN+IP, or native ICN. IP is referred
   to as both IPv4 and IPv6 protocols.

3. For ICN+IP-capable UE, PGW assigns the UE both an IP address and
   ICN identity. UE selects either of the identities during the
   initial attach procedures and registers with the network for
   session management. For ICN-capable UE, it will provide only ICN
   attachment. For native IP-capable UE, there is no change.

4. To support ICN-capable attach procedures and use ICN for user
   plane traffic, PGW needs to have full ICN protocol stack
   functionalities. Typical ICN capabilities include functions such

as content store (CS), Pending Interest Table (PIT), Forwarding
Information Base (FIB) capabilities, and so on. If UE requests
ICN in PCO IE, then PGW registers UE with ICN names. For ICN
forwarding, PGW caches content locally using CS functionality.

5. PCO IE described in [TS24.008] (see Figure 10.5.136 on page 598)
    and [TS24.008] (see Table 10.5.154 on page 599) provide details
    for different fields.

    1. Octet 3 (configuration protocols define PDN types), which
        contains details about IPv4, IPv6, both or ICN.

    2. Any combination of Octet 4 to Z can be used to provide
        additional information related to ICN capability. It is most
        important that PCO IE parameters are matched between UE and
        mobile gateways (SGW, PGW) so they can be interpreted
        properly and the UE can attach successfully.

6. Deployment of ICN functionalities in SGW and PGW should be
    matched with UE and eNodeB because they will exchange ICN
    protocols and parameters.

7. Mobile gateways SGW, PGW will also need ICN forwarding and
    caching capability. This is especially important if CUPS is
    implemented. User Plane Function (UPF), comprising the SGW and
    PGW user plane, will be located at the edge of the network and
    close to the end user. ICN-enabled gateway means that this UPF
    would serve as a forwarder and should be capable of caching, as
    is the case with any other ICN-enabled node.

8. The transport between PGW and CDN provider can be either IP or
    ICN. When UE is attached to PGW with ICN identity and
    communicates with an ICN-enabled CDN provider, it will use ICN
    primitives to fetch the data. On the other hand, for a UE
    attached with an ICN identity, if PGW must communicate with an IP
    enabled CDN provider, it will have to use an ICN-IP interworking
    gateway to perform conversion between ICN and IP primitives for
    data retrieval. In the case of CUPS implementation with an
    offload close to the edge, this interworking gateway can be
    collocated with the UPF at the offload site to maximize the path
    optimization. Further study is required to understand how this
    ICN-to-IP (and vice versa) interworking gateway would function.

6. Security and Privacy Considerations

This section will cover some security and privacy considerations in
user equipment (UE) and LTE network because of introduction of ICN.

6.1. Security Considerations

   To ensure only authenticated UEs are connected to the network, LTE
   mobile network implements various security mechanisms. From the
   perspective of ICN deployment in the user plane, it needs to take
   care of the following security aspects:

   1. UE authentication and authorization

   2. Radio or air interface security

   3. Denial of service attacks on the mobile gateway, services either
       by the UE or by external entities in the Internet

   4. Content poisoning either in transport or servers

   5. Content cache pollution attacks

   6. Secure naming, routing, and forwarding

   7. Application security

   Security over the LTE air interface is provided through cryptographic
   techniques. When UE is powered up, it performs a key exchange
   between UE's USIM and HSS/Authentication Center using NAS messages,
   including ciphering and integrity protections between UE and MME.
   Details for secure UE authentication, key exchange, ciphering, and
   integrity protections messages are given in the 3GPP call flow
   [TS23.401]. With ICN we are modifying protocol stack for user plane
   and not control plane. The NAS signaling is exchanged between UE and
   mobile gateways e.g. MME, using control plane, therefore there is no
   adverse impact of ICN on UE.

   LTE uses IP transport in its mobile backhaul (between eNodeB and core
   network). In case of provider-owned backhaul, it may not be
   necessary to implement any security mechanisms because the entire IP
   transport is owned by service provider. Deployment of security
   gateways and encryption might be necessary when IP transport is
   provided by other provider as shared media or leased lines. The
   native IP transport continues to leverage security mechanism such as
   Internet key exchange (IKE) and the IP security protocol (IPsec).
   More details of mobile backhaul security are provided in 3GPP network
   security specifications [TS33.310] and [TS33.320]. When mobile
   backhaul is upgraded to support dual stack (IP+ICN) or native ICN, it
   is required to implement security techniques that are deployed in the
   mobile backhaul. When ICN forwarding is enabled on mobile transport
   routers, we need to deploy security practices based on [RFC7476] and
   [RFC7927].

LTE mobile gateways (SGW, PGW) perform some of key functions such as content based online/offline billing and accounting, deep packet inspection (DPI), and lawful interception (LI). When ICN is deployed in user plane , we need to integrate ICN security for sessions between UE and gateway. If we encrypt user plane payload metadata then it might be difficult to perform routing based on contents and it may not work because we need decryption keys at every forwarder to route the content. The content itself can be encrypted between publisher and consumer to ensure privacy. Only the user with right decryption key shall be able to access the content. We need further research for ICN impact on LI, online/offline charging and accounting.

6.2. Privacy Considerations

In any network, caching implies a trade-off between network efficiency and privacy. The activity of users is exposed to the scrutiny of cache owners with whom they may not have any relationship. By monitoring the cache transactions, an attacker could obtain significant information related to the objects accessed, topology and timing of the requests [RFC7945]. Privacy concerns are amplified by the introduction of new network functions such as Information lookup and Network storage, and different forms of communication [FOTIOU]. Privacy risks in ICN can be broadly divided in the following categories [TOURANI]:

1. Timing attack

2. Communication monitoring attack

3. Censorship and anonymity attack

4. Protocol attack

5. Naming-signature privacy

Introduction of TCL effectively enables ICN at the application and/or transport layer, depending on the scenario described in section 5. Enabling ICN in LTE networks is expected to increase efficiency by taking advantage of ICN's inherent characteristics. While this approach would potentially leave some of the above-mentioned privacy concerns open, a mere presence of the TCL does not present increased risk and vulnerability.

1. IPoIP Section 5.2 would not be affected as TCL has no role in it and ICN does not apply

2. ICNoICN scenario Section 5.2 has increased risk of a privacy
    attack, and that risk is applicable to ICN protocol in general
    rather than specifically to the LTE implementation. Since this
    scenario describes communication over ICN transport, every
    forwarder in the path could be a potential risk for privacy
    attack

3. ICNoIP scenario Section 5.2 uses IP for transport, so the only
    additional ICN-related potential privacy risk areas are the
    endpoints (consumer and publisher) where, at the application
    layer, content is being served

4. IPoICN scenario Section 5.2 could have potentially increased risk
    due to possible vulnerability of the forwarders in the path of
    ICN transport

As shown above, introduction of TCL as a vehicle to implement ICN in
LTE does not present additional privacy risk beyond issues already
identified as they apply to ICN in general. Further research in this
area is needed.

7. Summary

In this draft, we have discussed complexities of LTE network and key
dependencies for deploying ICN in user plane data transport.
Different deployment options described cover aspects such as inter-
operability and multi-technology, which is a reality for any Service
Provider. One can use LTE gateway software and ICN simulator and
deploy ICN data transport in user plane as an overlay, dual stack (IP
+ ICN), hICN, or natively (by integrating ICN with CDN, eNodeB, SGW,
PGW and transport network). Notice that, for deployment scenarios
discussed above, additional study is required for lawful
interception, billing/mediation, network slicing, and provisioning
APIs.

Edge Computing [CHENG] provides capabilities to deploy
functionalities such as Content Delivery Network (CDN) caching and
mobile user plane functions (UPF) [TS23.501]. Recent research for
delivering real-time video content [MPVCICN] using ICN has also been
proven to be efficient [NDNRTC] and can be used towards realizing the
benefits of ICN deployment in eNodeB, edge computing, mobile gateways
(SGW, PGW) and CDN. The key aspect for ICN is in its seamless
integration in LTE and 5G networks with tangible benefits so we can
optimize content delivery using a simple and scalable architecture.
The authors will continue to explore how ICN forwarding in edge
computing could be used for efficient data delivery from the mobile
edge.

Based on our study of control plane signaling, it is not beneficial
to deploy ICN with existing protocols unless further changes are
introduced in the control protocol stack itself. As mentioned in
[TS23.501], the 5G network architecture proposes a simplification of
control plane messages and can be a candidate for the use of ICN.

As a starting step towards ICN user plane deployment, it is proposed
to incorporate protocol changes in UE, eNodeB, SGW/PGW for data
transport. ICN has inherent capabilities for mobility and content
caching, which can improve the efficiency of data transport for
unicast and multicast delivery. The authors welcome contributions
and suggestions, including those related to further validations of
the principles by implementing prototype and/or proof of concept in
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