ICN Research Group
Internet-Draft
Intended status: Informational
Expires: May 7, 2020

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November 04, 2019

# Native Deployment of ICN in LTE, 4G Mobile Networks
## draft-irtf-icnrg-icn-lte-4g-05

Abstract

LTE, 4G mobile networks use IP-based transport for control plane to establish the data session and user plane for actual data delivery. In existing architecture, IP transport used in the user plane is not optimized for data transport, which leads to an inefficient data delivery. IP unicast routing from server to clients is used for delivery of multimedia content to User Equipment (UE), where each user gets a separate stream. From a bandwidth and routing perspective, this approach is inefficient. Multicast and broadcast technologies have emerged recently for mobile networks, but their deployments are very limited or at an experimental stage due to complex architecture and radio spectrum issues. ICN is a rapidly emerging technology with built-in features for efficient multimedia data delivery. However 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 an inherent capability for multicast, anchorless mobility and security, and it is 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 (along with IP). These approaches can help optimize the mobile networks by leveraging the inherent benefits of ICN.

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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 to route data traffic to the end user's device. 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.

One of the key protocols used in 4G and LTE networks is GPRS Tunneling protocol (GTP). GTP, DIAMETER and other protocols are built on top of IP. One of the biggest challenges with IP-based routing is that it is not optimized for data transport, although it is the most efficient communication protocol. By native implementation of Information Centric Networking (ICN) in 3GPP, we can re-architect a mobile network and optimize its design for efficient data transport by leveraging ICN's caching feature. ICN also offers an opportunity to leverage inherent capabilities of multicast, anchorless mobility management, and authentication. This draft provides insight into options for deploying ICN in mobile networks, and how they affect mobile providers and end users.

### 1.1. Conventions and Terminology

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

### 1.2. 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 and is like 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.

## 2. LTE, 4G Mobile Network

### 2.1. 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 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).

The GTP tunnel is used to carry user traffic between gateways and mobile devices. This forces data to be distributed only by using unicast mechanism. It is also important to understand the overhead of a GTP and IPSec protocols because it has impact on the carried user data traffic. All mobile backhaul traffic is encapsulated using 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), and the encryption and authentication header algorithm used. If we factor Advanced Encryption Standard (AES) encryption with the packet size, the overhead can be significant [OLTEANU], particularly for the smaller payloads.

When any UE is powered up, it attaches to a mobile network based on its configuration and subscription. After a successful attach procedure, 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).

```
                                          +-------+  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

The data delivered to mobile devices is unicast inside the GTP tunnel. If we consider the combined impact of GTP, IPSec and unicast traffic, the data delivery is not efficient. IETF has developed various header compression algorithms to reduce overhead associated with IP packets. Some techniques are robust header compression (ROHC) and enhanced compression of the real-time transport protocol (ECRTP) so that 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], and can be adapted to ICN, as well [ICNLOWPAN] [TLVCOMP].

## 2.2. QoS Challenges

During the attach procedure, a default bearer is created for each UE and it is assigned to the default Access Point Name (APN). The QoS values that uplink and downlink bandwidth assigned during the initial attach are minimal. Additional dedicated bearer(s) with enhanced QoS parameters are established depending on specific application needs.

While all traffic within a certain bearer gets 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 QoS Class Identifier (QCI), which represents different types of content and equivalent mapping to DSCP at transport layer [TS23.401]. However, this requires manual configuration at different elements and, if there are misconfigurations at any place in the path, it will not work properly.

In summary, QoS configuration for mobile networks for user plane (for user traffic) and transport in an IP-based mobile network is complex 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.

### 2.3. Data Transport Using IP

The data delivered to mobile devices is unicast inside 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 implementation on the RAN side of the network. Transport networks in the backhaul and core addressed the multicast delivery long 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. With that said, the data delivery in the mobility remains greatly unicast. 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 the 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.

Data delivered to mobile devices is unicast inside a GTP tunnel. If we consider the combined impact of GTP, IPSec, and unicast traffic, the end-to-end data delivery is not efficient. By deploying ICN, we intend to either terminate the GTP tunnel at the mobility anchoring point by leveraging control and user-plane separation, or replace it with native ICN protocols.

### 2.4. 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 adoption of Mobile Virtual Network Operators (MVNO), public safety network, and enterprise mobility network, we need elastic mobile core architecture. By deploying

mobile packet core on a commercially off-the-shelf (COTS) platform using virtualized infrastructure (NFVI) framework and end-to-end orchestration, we can simplify new deployments and provide optimized TCO.

While virtualization is growing, and many mobile providers use hybrid architecture consisting of dedicated and virtualized infrastructures, the control and data delivery planes are still the same. There is also work under way to separate the control plane and user plane so the network can scale better. Virtualized mobile networks and network slicing with control and user plane separation provide mechanism to evolve GTP-based architecture to open-flow 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 mobility call flow by introduction of open-flow-based signaling [ICN5G]. This has been considered by 3GPP [EPCCUPS] and is also described in [SDN5G].

## 3. Data Transport Using ICN

For mobile devices, the edge connectivity to the network is between radio and a router or mobile edge computing (MEC) [MECSPEC] element. MEC 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

MEC transforms radio 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.  MEC can be an ideal candidate for ICN forwarder in addition to its usual function of managing mobile termination.  In addition to MEC, other transport elements, such as routers, can work as ICN forwarders.

Data transport using ICN is different compared to IP-based transport. It evolves the Internet infrastructure by introducing uniquely named data as a core Internet 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 to cache the content so it can be delivered locally for subsequent request from any other client.  For mobile network, 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 describing protocols architecture and different types of messages, and then consider how we can use this in a mobile network 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 get certain content, it will send an Interest message to the closest eNodeB.  Interest packet follows the TLV format [RFC8609] and contains mandatory fields such as name of the content and content matching restrictions (KeyIdRestr and ContentObjectHashRestr) forming the 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 perform lookup if a request for such content has come earlier from another client.  If yes, it is 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 reaches the content provider, it will return a Data packet containing information such as content name, signature, and data.

Data packet travels in reverse direction following the same path taken by the Interest packet, which maintains 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.

## 4. ICN Deployment in 4G and LTE Networks

### 4.1. 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 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 between 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, 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 optimization 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.

### 4.2. ICN Deployment Scenarios

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 UE or in 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 4.4.1 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, where it can have a slice management capability locally or it can interface to an external slice manager through 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 UE or a content provider, the following options are possible for ICN deployment natively and/or with IP.

1. IP over IP

   In this scenario, UE uses applications tightly integrated with the existing IP transport infrastructure. In this option, 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 mobile backhaul, IP core, and Mobile Gateway (SGW/PGW). UE attaches to Mobile Gateway (SGW/PGW) using IP address. Also, the data transport between Mobile Gateway (SGW/PGW) and content publisher uses IP. 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 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 GTP-U tunnel can be terminated by hairpinning 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 repos, caches) in the tunnel path; it can reply right away

without going all the way through the mobile core. While 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 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)

H2020 project [H2020] provides an architectural framework for deployment of IP as an overlay over ICN protocol [IPoICN]. Implementing IP services over ICN provides an opportunity leveraging benefit of ICN in the transport infrastructure and 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.

### 4.3. 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 and TLV, carrying additional attributes such as a layer 3 transport. Physical POA in 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 are 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.

### 4.4. ICN Deployment in LTE User Plane

We will consider Figure 1 to discuss different mechanisms to deploy ICN in mobile networks. In Section 4.2, 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)

#### 4.4.1. 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 mobile device (UE) is complex because it has to 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. 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. Existing application layer can be modified to provide options for a new ICN-based application and existing IP-based applications. 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. 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 4.2, 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 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.

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

4. For the dual-stack scenario, when UE is not supporting ICN as transport, 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.

5. 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 LTE Air interface, between IP (Network

layer) and Radio Link Control Layer (RLC). PDCP performs the following functions [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.

### 4.4.2. 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 GTP protocol. Removal of GTP protocol stack is a significant change in 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 UE, 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 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.  PDCP layer must be aware of ICN capabilities and parameters.

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

### 4.5.  ICN Deployment in eNodeB

eNodeB is a physical point of attachment for 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 UE performs attach procedures, it is assigned an identity either as IP, 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

UE encapsulates user data transport request into PDCP layer and sends the information on air interface to eNodeB. eNodeB receives the information and, using PDCP [TS36.323], de-encapsulates 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 recommended 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 UE requests IP transfer, eNodeB forwards data over IP.

2. Assuming eNodeB is ICN enabled and UE requests ICN transfer, eNodeB forwards data over ICN.

3. Assuming eNodeB is IP enabled and UE requests ICN, eNodeB overlays ICN on IP and forwards user plane traffic over IP.

4. Assuming eNodeB is ICN enabled and UE requests IP, eNodeB overlays IP on ICN and forwards user plane traffic over ICN [IPoICN].

### 4.6. 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 needed:

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 has to 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.

## 4.7. Lab Testing

To further test the modifications proposed above in different scenarios, a simple lab can be set up, as shown in Figure 9.

```
+------------------------------------------+
| +-----+   +------+   (```).     +------+ |   (````).    +-----+
| | SUB |-->| EMU  |--(x-haul'.-->| EPC  |--->(  PDN ).-->| CDN |
| +-----+   +------+   `__..''    +------+ |   `__...'    +-----+
+------------------------------------------+
```

Figure 9: Native ICN Deployment Lab Setup

The following test scenarios can be set up with VM-based deployment:

1. SUB: ICN simulated client (using ndnSIM), a client application on workstation requesting content.

2. EMU: test unit emulating eNodeB and UE. This will be a test node allowing for UE attachment and routing traffic subsequently from the Subscriber to the Publisher.

3. EPC: Evolved Packet Core in a single instance (such as vPC-SI).

4. CDN: content delivery by a Publisher server.

For the purpose of this testing, ICN emulating code (when available) can be inserted in the test code in EMU to emulate ICN-capable UE and/or eNodeB. An example of the code to be used is NS3 in its LTE model. Effect of such traffic on EPC and CDN can be observed and documented. In a subsequent phase, EPC code supporting ICN can be tested when available.

Another option is to simulate the UE/eNodeB and EPC functions using NS3's LTE [NS3LTE] and EPC [NS3EPC] models respectively. LTE model includes the LTE Radio Protocol stack, which resides entirely within the UE and the eNodeB nodes. This capability provides the simulation of UE and eNodeB deployment use cases. Similarly, EPC model includes core network interfaces, protocols and entities, which reside within the SGW, PGW and MME nodes, and partially within the eNodeB nodes.

Even with its current limitations (such as IPv4 only, lack of integration with ndnSIM, no support for UE idle state), LTE simulation may be a very useful tool. In any case, both control and user plane traffic should be tested independently according to the deployment model discussed in Sections 4.4 through 4.6.

## 5. 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 mobile gateway, services

4. Content positioning 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 technique. When UE is powered up, it performs key exchange between UE's USIM and HSS/Authentication Center using NAS messages, including ciphering and integrity protections between UE and MME. Details of secure UE authentication, key exchange, ciphering, and integrity protections messages are given in the 3GPP call flow [TS23.401].

LTE is an all-IP network and uses IP transport in its mobile backhaul (between eNodeB and core network). In case of provider-owned backhaul, it may not implement security mechanisms; however, they are necessary in case it uses a shared or leased network. 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 [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 mobile backhaul. When ICN forwarding is enabled on mobile transport routers, we need to deploy security practices based on [RFC7476] and [RFC7927].

Some key functions supported by LTE mobile gateway (SGW, PGW) are content based billing, deep packet inspection (DPI), and lawful intercept (LI). For ICN-based user plane traffic, it is required to integrate ICN security for sessions between UE and gateway. However, in the ICN network, some of the services provided by mobile gateways mentioned above may not work because only consumers who have

decryption keys can access the content. Further research in this area is needed.

## 6. 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. In Section 4.7, we provide details of an experimental setup for evaluation of ICN deployment scenarios described in Section 4.2. 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.

Mobile Edge Computing (MEC) [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, MEC, 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 simple and scalable architecture. Authors will continue to explore how ICN forwarding in MEC could be used in 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], 5G network architecture proposes simplification of control plane messages and can be a candidate for use of ICN.

As a starting step towards ICN user plane deployment, it is recommended 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. Authors welcome contributions and suggestions, including those related to further validations of the principles by implementing prototype and/or proof of concept in the lab and in the production environment.

## 7. Acknowledgements

We thank all contributors, reviewers, and the chairs for the valuable time in providing comments and feedback that helped improve this draft.

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