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Experimental Scenarios of ICN Integration in 4G Mobile Networks
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Abstract

4G mobile network uses 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-based unicast is used for the delivery of multimedia content to a mobile terminal, where each user is receiving a separate stream from the server. From a bandwidth and routing perspective, this approach is inefficient. Evolved multimedia broadcast and multicast service (eMBMS) provides capabilities for delivering contents to multiple users simultaneously, but its deployment is very limited or at an experimental stage due to numerous challenges. The focus of this draft is to list the options for use of Information centric technology (ICN) in 4G mobile networks and elaborate the experimental setups for its further evaluation. The experimental setups discussed provide for using ICN either natively or with existing mobility protocol stack. With further investigations based on the listed experiments, ICN with its inherent capabilities such as, network-layer multicast, anchorless mobility, security, and optimized data delivery using local caching at the edge may provide a viable alternative to IP transport in 4G mobile networks.

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1. Introduction

4G mobile technology is built as an all-IP network using routing protocols (OSPF, ISIS, BGP, etc.) to establish network routes. 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 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 4G is that it is not optimized for data transport. As an alternative to IP routing, this draft presents and list the possible options for integration of Information Centric Networking (ICN) in 3GPP 4G mobile network, offering an opportunity to leverage inherent ICN capabilities such as in-network caching, multicast, anchorless mobility management, and authentication. This draft also discuss how those options affect mobile providers and end users.

The goal of the proposed experiments is to present possibilities to create simulated environments for evaluation of the benefits of ICN protocol deployment in a 4G mobile network in different scenarios that have been analyzed in this document. The consensus of the Information-Centric Networking Research Group (ICNRG) is to publish this document in order to facilitate experiments to show deployment options and qualitative and quantitative benefits of ICN protocol deployment in 4G mobile networks.

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 the mobile terminal 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 mobile terminal 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 mobile terminal (MT) 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-MT point-to-point (p2p) tunnel between the GGSN

and SGSN transports the packets between the mobile terminal and the gateway.

21. Mobile Terminal/User Equipment

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 MT, MS, MN, and mobile are used interchangeably within this document.

22. 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. 4G Mobile Network Architecture

This section provide a high-level overview of typical 4G mobile network architecture and their key functions related to a possibility of using of ICN technology.

3.1. Network Overview

4G mobile networks are designed to use IP transport for communication among different elements such as eNodeB, MME, SGW/PGW, HSS, PCRF, etc [GRAYSON]. For backward compatibility with 3G, it has support for legacy Circuit Switch features such as voice and SMS through transitional CS fallback and flexible IMS deployment. 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 mobile terminal is powered up, it attaches to a mobile network based on its configuration and subscription. After a successful attachment procedure, the mobile terminal registers with the mobile core network using IPv4 and/or IPv6 address based on request and capabilities offered by mobile gateways.

The GTP tunnel is used to carry user traffic between gateways and mobile terminal, therefore using the 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.

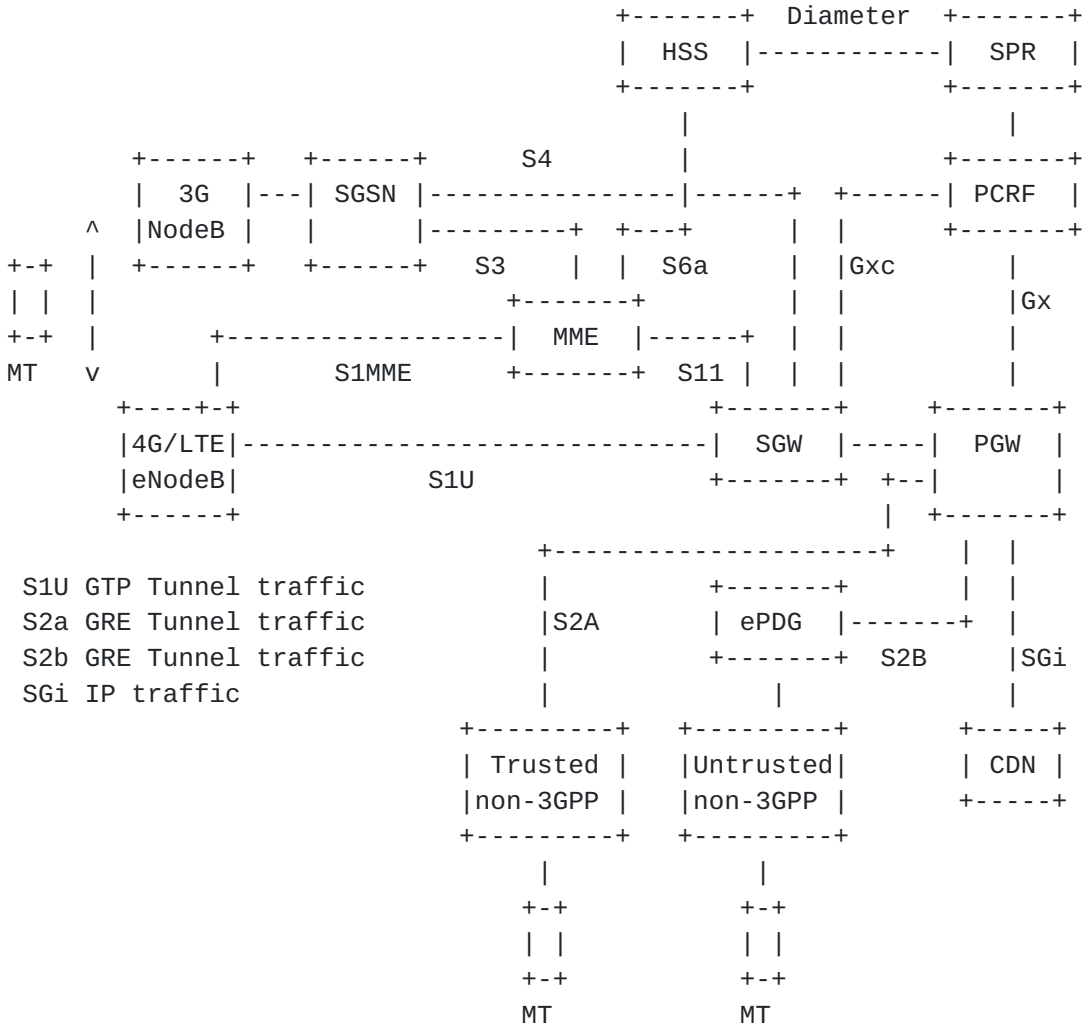


Figure 1: 4G Mobile Network Overview

If we consider the combined impact of GTP, IPSec and unicast traffic, the data delivery is not efficient because of overhead. 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. Mobile Network Quality of Service

During the mobile terminal attachment procedure, a default bearer is created for each mobile terminal and it is assigned to the default Access Point Name (APN), which provides the default transport. For any QoS-aware application, one or more new dedicated bearers are established between eNodeB and Mobile Gateway. Dedicated bearer can be requested either by mobile terminal or mobile gateway based on direction of first data flow. There are many bearers (logical paths) established between eNodeB and mobile gateway for each mobile terminal catering to different data flow simultaneously.

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 as Differentiated Services (DS). 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 underway to understand how QoS in ICN [I-D.anilj-icnrg-dnc-qos-icn] can be implemented with reference to the ICN QoS guidelines [I-D.oran-icnrg-qosarch] to meet the QoS requirements [RFC4594].

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. By using eMBMS [EMBMS], multicast routing can be enabled in mobile backhaul between eNodeB and Mobile Gateways (SGW) however for radio interface it requires broadcast which implies that we need dedicated radio channel. Implementation of eMBMS in RAN 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. Virtualized Mobile Networks

The Mobile gateways deployed in a major Service Provider network are either based on dedicated hardware or, commercially off the shelf (COTS) based x86 technology. 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 COTS platform, using a virtualized infrastructure (NFVI) framework and end-to-end orchestration, new deployments can be simplified to provide optimized total cost of ownership (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 4G 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.

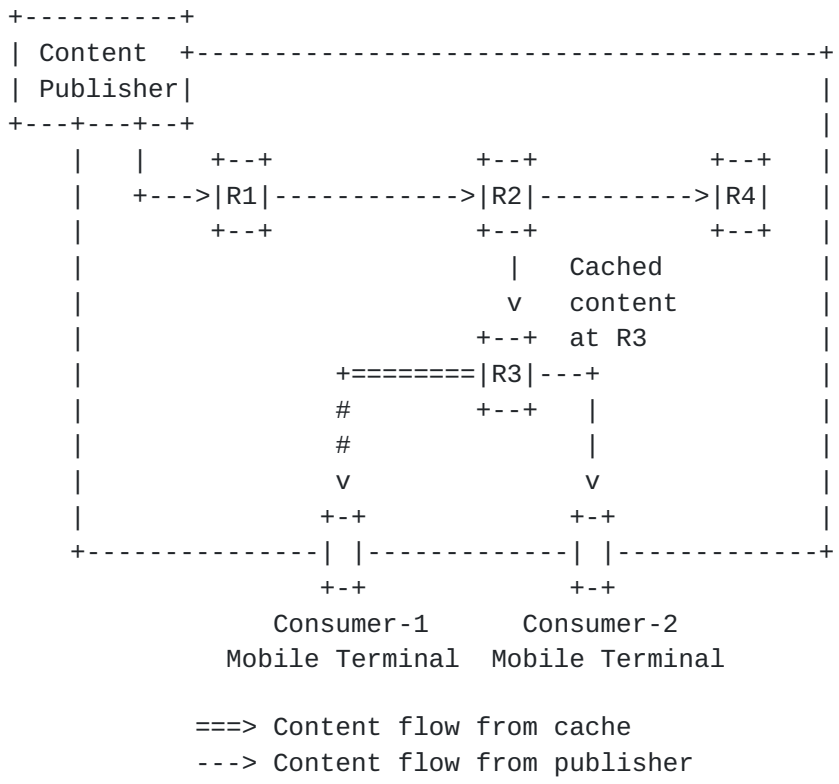


Figure 2: ICN Architecture

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.

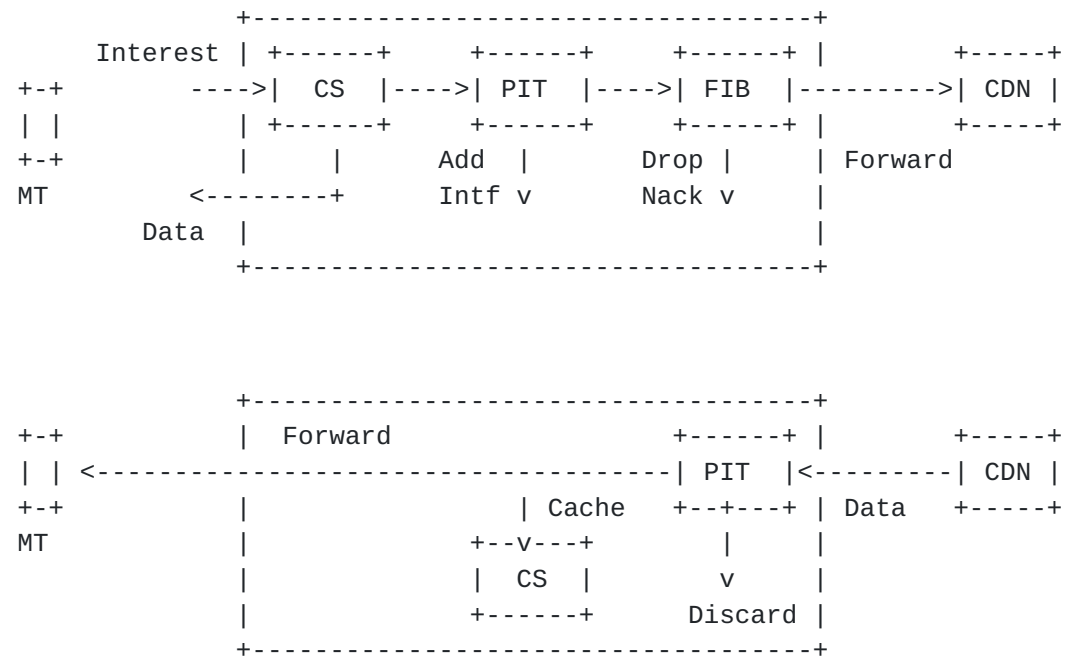


Figure 3: ICN Interest, Data Packet and Forwarder

In an 4G 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 4G network.

5. Experimental Scenarios for ICN Deployment

In 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 and operations 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 this section, we analyze the potential impact of ICN on control and user plane traffic for centralized and disaggregated CUPS-based mobile network architecture. We list various experimental options and opportunities to study the feasibility of the deployment of ICN in 4G networks. The proposed experiments would help the network and OEM designers to understand various issues, optimizations, and advantages of deployment of ICN in 4G networks.

5.1. General Considerations

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.

5.2. Scenarios of ICN Integration

The integration of ICN provides an opportunity to further optimize the existing data transport in 4G mobile networks. The various opportunities from the coexistence of ICN and IP transport in the mobile network are somewhat analogous to the deployment scenarios when IPv6 was introduced to interoperate with IPv4 except, with ICN, the whole IP stack can be 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 used natively by replacing IP transport (IPv4 and IPv6) or as an overlay protocol. Figure 4 describes a proposal to modify the existing transport protocol stack to support ICN in 4G mobile network.

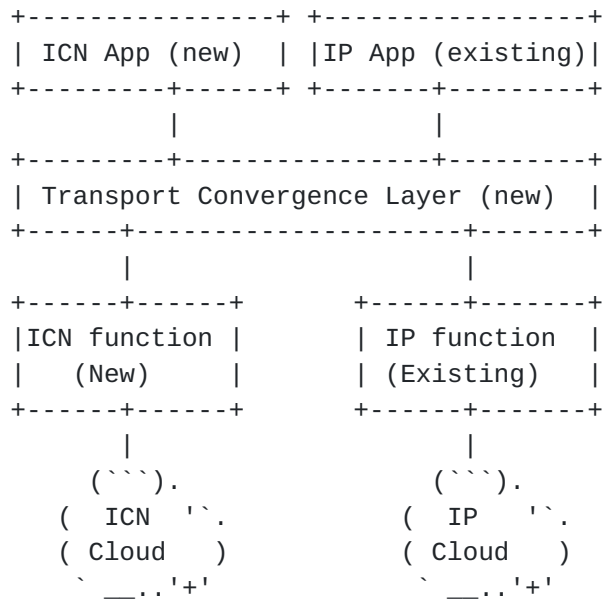


Figure 4: IP/ICN Convergence Scenarios

As shown in Figure 4, for applications - running either in the mobile terminal or in the content provider system - to use the ICN transport option, we propose a new transport convergence layer (TCL). The TCL 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 (native IP or ICN) or the overlay mode (ICNoIP or IPoICN) between application and the protocol stack (IP or ICN).

Combined with the existing IP function, the ICN function provides support for either native ICN and/or the dual transport (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 a user-facing setting realized through a user interface, like those used to select cellular over WiFi. In another option, it might use a software API, which an adapted IP application could use to specify the type of transport option (such as ICN) to take advantage of 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 mobile terminal itself. The TCL could apply slice settings to direct certain applications traffic 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 the mobile terminal.

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

1. IP over IP

   In this scenario, the mobile terminal applications are 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 tightly integrate with the ICN transport infrastructure. The TCL has no additional responsibility because packets are forwarded directly using the

native 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 mobile terminal and content provider). IP routing is used from the Radio Access Network (eNodeB) to the mobile backhaul, the IP core, and the Mobile Gateway (SGW/PGW). The mobile terminal 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 mobile terminal request.

One of the approaches 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 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 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 mobile terminal specific ICN payload, they are not visible to the transport, including SGW. On the other hand, the PGW can use the mobile terminal-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 running 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 (MT 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 the native IP. After reviewing [IPoICN], we understand and interpret that ICN is implemented in the transport

natively; however, IP is implemented in MT, 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 mobile terminal, 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. Integration of ICN in 4G 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 4G signaling in the current architecture. It is important to understand the concept of point of attachment (POA). When mobile terminal 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 mobile terminal attached to 4G network. The number of mobility management messages between different nodes in an 4G network per signaling procedure is shown in Table 1.

Normally, two types of mobile terminals attach to the 4G 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 mobile terminal 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 mobile terminal capable of dual transport or native ICN. When mobile terminal initiates an attach request using the identity as ICN, MME must be able to parse that message and create a session. MME forwards mobile terminal authentication to HSS, so HSS must be able to authenticate an ICN-capable mobile terminal and authorize create session [TS23.401].

4G 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 4G 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 4G signaling call flows [TS23.401] and messages inter-dependencies (see Table 1), our recommendation is that it is not beneficial to use 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. Integration of ICN in 4G User Plane

We will consider Figure 1 to discuss different mechanisms to integrate ICN in mobile networks. In Section 5.2, we discussed generic experimental setups of ICN integration. In this section, we discuss the specific options of possible use of native ICN in 4G user plane. We consider the following options:

1. Dual transport (IP/ICN) mode in Mobile Terminal

2. Using ICN in Mobile Terminal

3. Using ICN in eNodeB

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

5.4.1. Dual Transport (IP/ICN) Mode in Mobile Terminal

The control and user plane communications in 4G mobile networks are specified in 3GPP documents [TS23.203] and [TS23.401]. It is important to understand that mobile terminal can be either consumer (receiving content) or publisher (pushing content for other clients). The protocol stack inside the mobile terminal (MT) 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 used 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.

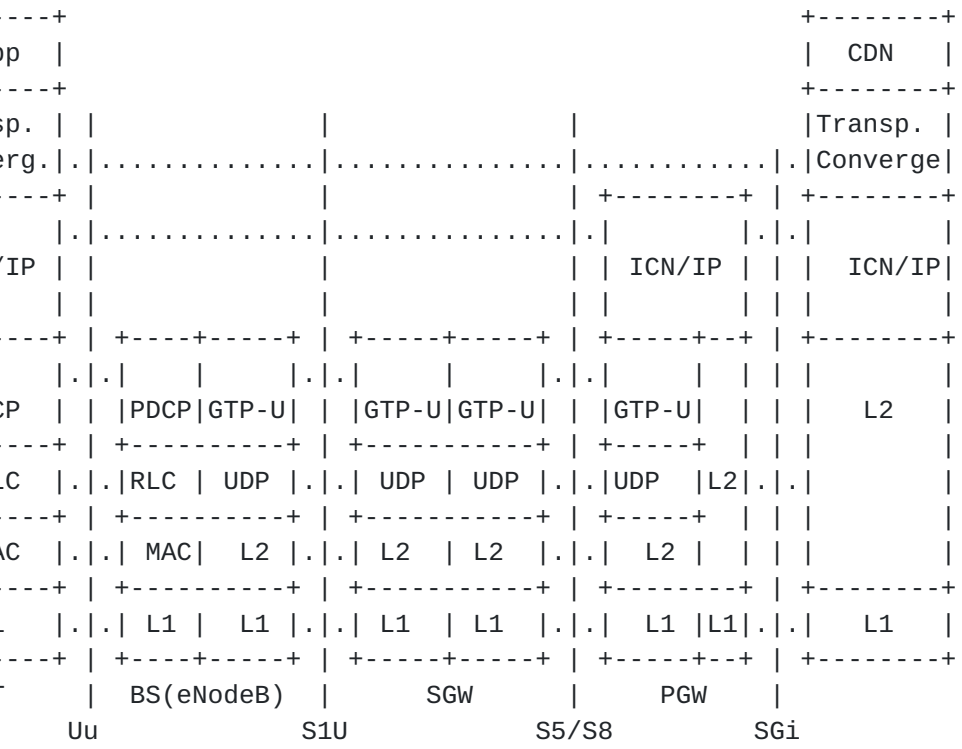


Figure 5: Dual Transport (IP/ICN) mode in Mobile Terminal

The protocols and software stack used inside 4G capable mobile terminal support both 3G and 4G software interworking and handover. 3GPP Rel.13 onward specifications describe the use of IP and non-IP protocols to establish logical/session connectivity. We can leverage the non-IP protocol-based mechanism to deploy ICN protocol stack in the mobile terminal, as well as in eNodeB and mobile gateways (SGW, PGW). The following paragraphs describe per-layer considerations of supporting tunneling of ICN packet into IP or to support ICN natively.

1. An existing application layer can be modified to provide options for a new ICN-based application and existing IP-based applications. The mobile terminal can continue to support existing IP-based applications or can develop new applications to support native ICN, ICNoIP, or IPoICN-based transport. The application layer can be provided with an 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 can maintain 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 mobile terminal to the receiving mobile terminal 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.

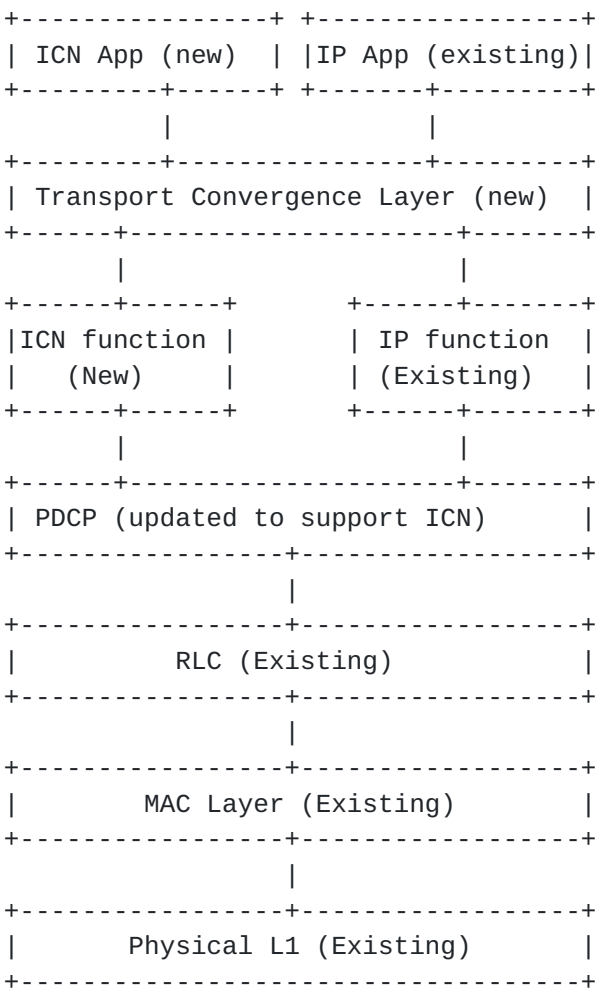


Figure 6: Dual Stack ICN Protocol Interactions

3. The ICN function (forwarder) is proposed to run in parallel to the existing IP layer. The ICN forwarder forwards the ICN packets, such as an Interest packet to eNodeB or a response "data packet" from eNodeB to the application.

4. For the dual-transport scenario, when mobile terminal is not supporting ICN as transport, the TCL can use the IP underlay to tunnel the ICN packets. The ICN function can use the IP interface to send Interest and Data packets for fetching or sending data respectively. This interface can use the ICN overlay over IP.

5. To support ICN at network layer in mobile terminal, the PDCP layer should 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) as 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. Using ICN in Mobile Terminal

We can implement ICN natively in mobile terminal by modifying the PDCP layer in 3GPP protocols. Figure 7 provides a high-level protocol stack description where ICN can be used at the following different layers:

1. User plane communication

2. Transport layer

ICN transport would be a substitute of the GTP protocol. The removal of the GTP protocol stack is a significant change in the mobile architecture and requires a through study mainly because it is used not just for routing but for mobility management functions, such as billing, mediation, and policy enforcement.

The implemention of ICN natively in the mobile terminal leads to a changed communication model between mobile terminal and eNodeB. Also, we can avoid tunneling the user plane traffic from eNodeB to the mobile packet core (SGW, PGW) through a GTP tunnel.

For native ICN use, an application can be configured to use ICN forwarder and it does not need the TCL layer. Also, to support ICN at the network layer, the existing PDCP layer may need to be changed to be aware of ICN capabilities and parameters.

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

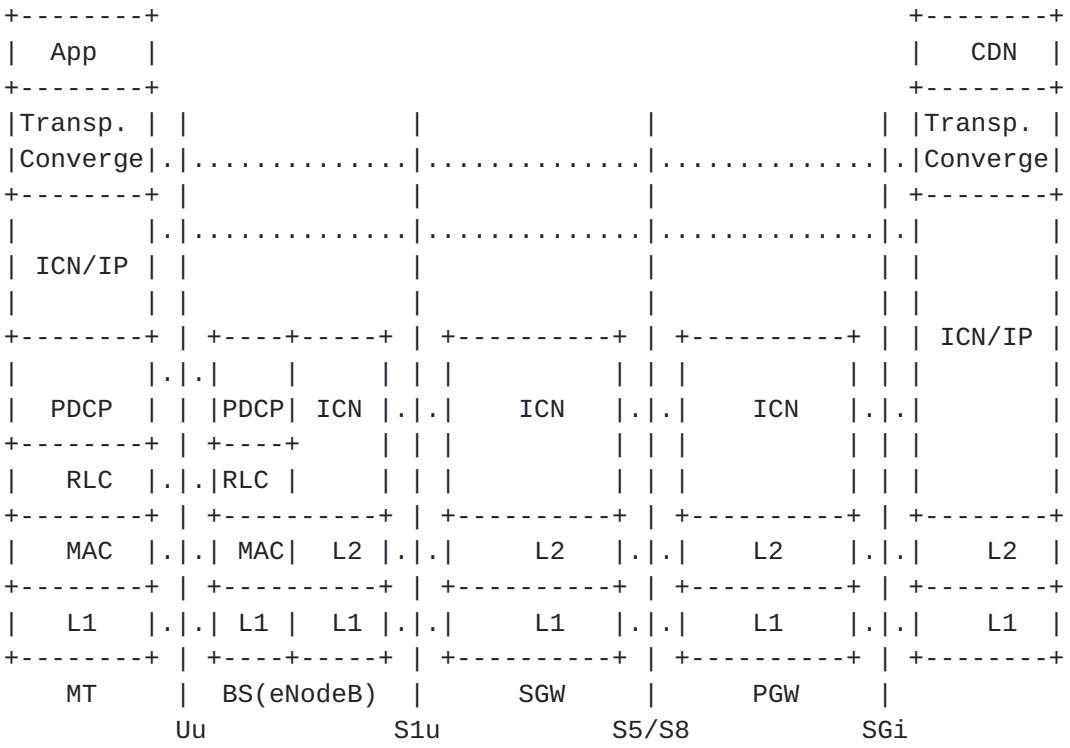


Figure 7: Using Native ICN in Mobile Terminal

5.4.3. Using ICN in eNodeB

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

1. Native IP (IPv4 or IPv6)

2. Native ICN

3. Dual transport IP (IPv4/IPv6) and ICN

The mobile terminal 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 MT), which provides the following functions:

1. It decides the forwarding strategy for a user data request coming from mobile terminal. 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.

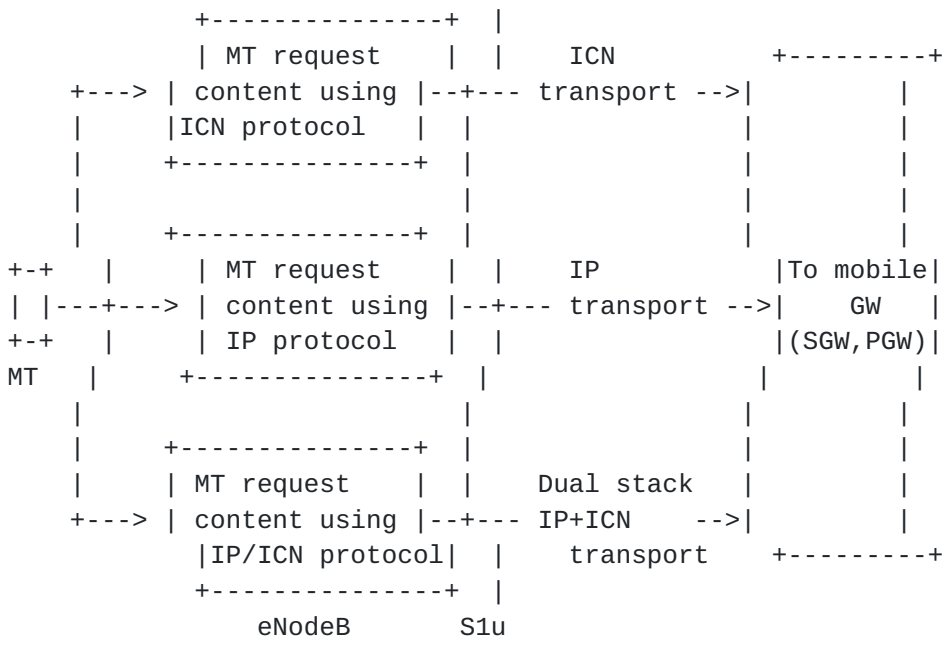


Figure 8: Integration of Native ICN in eNodeB

3. eNodeB can be upgraded to support three different types of transport: IP, ICN, and dual transport 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 MT requests an IP transfer, eNodeB forwards data over IP.

2. Assuming eNodeB is ICN enabled and the MT requests an ICN transfer, eNodeB forwards data over ICN.

3. Assuming eNodeB is IP enabled and the MT requests an ICN transfer, eNodeB overlays ICN on IP and forwards user plane traffic over IP.

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

5.4.4. Using ICN in Packet Core (SGW, PGW) Gateways

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

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 MT capabilities. We can use PCO IE to carry ICN-related capabilities information from MT to PGW. This information is received from MT during the initial attach request in MME. Details of available TLV, which can be used for ICN, are given in subsequent sections. MT 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 MT, PGW assigns the MT both an IP address and ICN identity. MT selects either of the identities during the initial attach procedures and registers with the network for session management. For ICN-capable MT, it will provide only ICN attachment. For native IP-capable MT, 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 MT requests ICN in PCO IE, then PGW registers MT 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 MT and mobile gateways (SGW, PGW) so they can be interpreted properly and the MT can attach successfully.

6. The ICN functionalities in SGW and PGW should be matched with MT 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 MT 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 MT 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. ICN Deployment Goals

This section proposes an experimental lab setup and discusses the open issues and questions that use of ICN protocol is intended to address.

6.1. An Experimental Test Setup

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

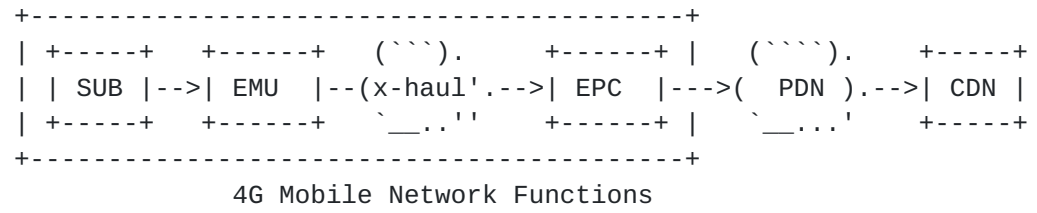


Figure 9: Native ICN Deployment Lab Setup

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. 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 5GOpenCore [Open5GCore]).

4. CDN: content delivery by a Publisher server.

For the purpose of this testing, ICN emulating code can be inserted in the test code in EMU to emulate ICN-capable 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 Section 5.4.

6.2. Open Questions to be Addressed

There are several open questions with ICN implementation scenarios in 4G mobile networks that the proposed experiments intend to address. Some of these issues are.

1. Viability of ICN inclusion in the 3GPP protocol stack. How realistic is it to succeed in modifying the stack, considering the scenarios explained in Section 5.4, and complete the user session without feature degradation?

2. Efficiency gained in terms of the amount of traffic in multicast scenarios.

3. Efficiency gained in terms of latency for cached content, mainly in the CDN use case.

4. Confirm how (in)adequate would be ICN implementation in control plane (which this draft discourages).

7. Security and Privacy Considerations

This section will cover some security and privacy considerations in mobile and 4G network because of introduction of ICN.

7.1. Security Considerations

To ensure only authenticated mobile terminals are connected to the network, 4G mobile network implements various security mechanisms. From the perspective of using ICN in the user plane, it needs to take care of the following security aspects:

1. MT authentication and authorization

2. Radio or air interface security

3. Denial of service attacks on the mobile gateway, services either by the MT 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 MT is powered up, it performs a key exchange between MT's USIM and HSS/Authentication Center using NAS messages, including ciphering and integrity protections between MT and MME. Details for secure MT 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 MT and mobile gateways e.g. MME, using control plane, therefore there is no adverse impact of ICN on MT.

4G uses IP transport in its mobile backhaul (between eNodeB and core network). In case of provider-owned backhaul, service provider may require to implement a security mechanism in the backhaul 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 specifications [TS33.310] and [TS33.320]. When mobile backhaul is upgraded to support dual transport (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].

4G 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 MT 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.

7.2. Privacy Considerations

In 4G networks, two main privacy issues are [MUTHANA]

1. User Identity Privacy Issues. The main privacy issue within the 4G is the exposure of the IMSI. The IMSI can be intercepted by adversaries. Such attacks are commonly referred to as "IMSI catching".

2. Location Privacy Issues. IMSI Catching is closely related to the issue of location privacy. Knowing IMSI of user allows the

attacker to track the user's movements and create profile about the user and thus breaches the user's location privacy.

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 4G networks is expected to increase efficiency by taking advantage of ICN's inherent characteristics. This approach would potentially leave some of the above-mentioned privacy concerns open as a consequence of using ICN transport and ICN inherent privacy vulnerabilities.

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 4G 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

Privacy issues already identified in 4G remain a concern if ICN is introduced in any of the scenarios described earlier and compound to the new, ICN-related privacy issues. Many research papers have been published proposing solutions to the privacy issues listed above. For LTE-specific privacy issues, some of the proposed solutions [MUTHANA] are IMSI encryption by a MT, mutual authentication, concealing the real IMSI within a random bit stream of certain size where only the subscriber and HSS could extract the respective IMSI, IMSI replacement with a changing pseudonym that only the HSS server can map it the UE's IMSI, and others. Similarly, some of the proposed ICN-specific privacy concerns mitigation methods, applicable where ICN transport is introduced as specified earlier in this section, include [FOTIOU]:

Delay for the first, or first k interests on edge routers (timing attack)

Creating a secure tunnel or clients flagging the requests as non-cacheable for privacy (communication monitoring attack)

Encoding interest by mixing content and cover file or using hierarchical DNS-based brokering model (censorship and anonymity attack)

Use of rate-limiting requests for a specific namespace (protocol attack)

Cryptographic content hash-based naming or digital identity in an overlay network (naming-signature privacy)

Further research in this area is needed. Detailed discussion of privacy is beyond the scope of this document.

8. Summary

In this draft, we have discussed the 4G networks and the experimental setups to study the advantages of potential use of ICN for efficient delivery of contents to mobile terminals. We have discussed different options to try and test the ICN and dependencies such as ICN functionalities and changes required in different 4G network elements. In order to further explore potential use of ICN one can devise an experimental set-up consisting of 4G network elements and deploy ICN data transport in user plane. Different options can be either overlay, dual transport (IP + ICN), hICN, or natively (by

integrating ICN with CDN, eNodeB, SGW, PGW and transport network). Note that, for the 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 using ICN in eNodeB, edge computing, mobile gateways (SGW, PGW) and CDN. The key aspect for ICN is in its seamless integration in 4G 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 a starting step towards use of ICN in user plane, it is proposed to incorporate protocol changes in MT, 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 the lab and in the production environment.

9. Acknowledgements

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The IRSG review was provided by Colin Perkins.

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