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

The proposed 3GPP's 5G core nextgen architecture (5GC) offers flexibility to introduce new user and control plane function, considering the support for network slicing functions, that allows greater flexibility to handle heterogeneous devices and applications. In this draft, we provide a short description of the proposed 5GC architecture, followed by extensions to 5GC's control and user plane to support packet data unit (PDU) sessions from information-centric networks. The value of enabling ICN in 5GC is discussed using multiple service scenarios in the context of mobile edge computing such as smart mobility and VR use case, and to enable network services such as seamless mobility for ICN sessions.

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1. Introduction

The objective of this draft is to propose an architecture to enable information-centric networking (ICN) in the proposed 5G Next-generation Core network architecture (5GC) by leveraging its flexibility to allow new user and associated control plane functions.

The reference architectural discussions in the 5G core network 3GPP specifications [TS23.501][TS23.502] form the basis of our discussions. This draft also complements the discussions related to various ICN deployment opportunities explored in [I-D.rahman-icnrg-deployment-guidelines], where 5G technology is considered as one of the promising alternatives.

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

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

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

- Session Mobility: Existing long-term evolution (LTE) deployments handle session mobility using centralized routing using the MME function, IP anchor points at Packet Data Network Gateway (PDN-GW) and service anchor point called Access Point Name (APN) functionality hosted in PDN-GW. LTE uses tunnel between radio edge (eNodeB) and PDN-GW for each mobile device attached to network. This design fails when service instances are replicated close to radio access network (RAN) instances, requiring new techniques to handle session mobility. In contrast, application-bound identifier and name resolution split principle considered for the ICN is shown to handle host mobility quite efficiently [ICNMOB].

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

2. Terminology

Following are terminologies relevant to this draft:

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

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

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

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

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

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

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

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

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

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

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

3. 5G NextGen Core Design Principles

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

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

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

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

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

4. 5G NextGen Core Architecture

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

```
                                   +----------+             +---------+
                        +---------+ | PCF/UDM |    +------+ |  AF-2  |
                        | NSSF   | |         |    | AF-1 | +-----+--+
                        +---+----+ +-----+---+    +--+---+       |
                            |            |           |        +--+--------+
                        +---+------------+-+   +-----+------+ |           |
                        |                 |N11|            | |   SMF-2   |
                        |     AMF         +---+   SMF-1    | |           |
                        |                 |   |            | +---------+-+
                        +--------+-+--------+   +----+-------+           |
                                 | |
|------------------------------------+
              +------------------+ |                |                   |
N4              |N4
           N1 |                    |N2              |N4                 |
+--------+-----------+
              |                    |                |                +---------
+        UPF         | N6 +-------+
+-------------+-+       +----------+------+     +---+-----------+    |  |
|(PDU Session Anchor)+----+  DN  |
|               |       |                 |     |               | N9 |  |
|                    |    |      |
|     UE        |       |      RAN        | N3  |    UL-CL      +----+  |
+--------------------+    +-------+
|               +--------+                +-----+               |       |
|               |        |                |     |               +----+
+-----------------+
+---------------+       +------------------+     +----------------+ N9
|                    |

                                                                    |

+----------+---------+
                                                                 +---------
+                    |    +--------+

|        UPF         | N6 |  DN    |

|(PDU Session Anchor)+----+        |

|                    |    +--------+

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

Figure 1: 5G Next Generation Core Architecture

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

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

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

AMF serves multiple purposes: (i) device authentication and authorization; (ii) security and integrity protection to non-access stratum (NAS) signaling; (iii) tracking UE registration in the operator's network and mobility management functions as the UE moves among different RANs, each of which might be using different radio access technologies (RAT).

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

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

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

5. 5GC Architecture with ICN Support

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

```
                                                               +------------+
                                                               |     5G     |
                                                               | Services   |
                                                               |   (NEF)
|         +-----------------+
                                                               +-------+----
+         |      ICN        |
                                                                        |
+----------+    Service     |
                                                                        |
|          |  Orchestrator  |
                                                                        |
|          +-----------+----++
               +-------+  +---------+           Npcf++/Nudm++        ++------
+                    |
               | NSSF  |  | PCF/UDM +---------------------------------+ ICN-
AF|                  |
               +----+--+  |         |                                 |
|               +---+--------------+
                    |     +--+------+                                 +---+---
+               |       ICN        |
                    |        |
|            +-------+  Service/Network |
                  +-+--------+--+          +---------------+      +------
+-------+    |      |    Controller    |
                  |             |   N11++   |               |Naf++
|              +-----+      +------------+-----+
                  |   AMF++    +------------+  SMF++        +-------+    ICN-
SMF   |                        |
                  |             |           |               |
|              |                        |
                  +------+-+-----+          +----+-----+----+
+------------+-+                        |
                         | |                          |
| NIcn                     |
       +----------------+ |                          |
+----------+               |
       |                   |
|                                    |               |
       |                   +------+                N4
|                                    |               |
  N1++ |                            |
|                                    |               |
       |                            | N2               |
+------------+-+       +----+-----+
       |                            |                    |          +----------
+              |        |          |
       |                            |                    |          |   N9
```

```
|   ICN-GW     +---------+  ICN-DN  |
       |                           |              +-----+-----+     |
|   + UPF      |   N6   |          |
+------+--+             +---------+--+           |           |     |
+---+----------+        +-----------+
|         |             |RAN +-----+ |           |   UL-CL/  +-----+
| ICN-UE  +-------------+    |UPF  | |           | Branching |
|         |             |    +-----+ +-----------+   Point   |
|         |             |  +--------+ |    N3     |           +-----+
+------------+
+---------+             |  | ICN-GW| |           +-----------+     |
|  Local     |
                        |  +--------+ |                             |    N9
|  ICN-DN    |
                        +------------+                             +-----------
+            |

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

Figure 2: 5G Next Generation Core Architecture with ICN support

For an ICN-enabled 5GC network, the assumption is that the UE may have applications that can run over ICN or IP, for instance, UE's operating system offering applications to operate over ICN [Jacobson] or IP-based networking sockets. There may also be cases where UE is exclusively based on ICN. In either case, we identify an ICN enabled UE as ICN-UE. Different options exist to implement ICN in UE as described in [I-D.suthar-icnrg-icn-lte-4g] which is also applicable for 5G UE to enable formal ICN session handling, such as, using a transport convergence layer above 5G-NR, through IP address assignment from 5GC or using 5GC provision of using unstructured PDU session mode during the PDU session establishment process, which is discussed in Section 5.2.2. Such convergence layer would implement necessary IP over ICN mappings, such as those described in [TROSSEN], for IP-based applications that are assigned to be transported over an ICN network. 5G UE can also be non-mobile devices or an IOT device using radio specification which can operate based on [TS-5GNR].

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

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

5.1. Control Plane Extensions

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

o Authentication and Mobility Function (AMF++): ICN applications in the UEs have to be authorized to access ICN DNs. For this purpose, as in [TS23.501], operator enables ICN as a DN offering ICN services. As a network service, ICN-UE should also be subscribed to it and this is imposed using the PCF and UDM, which may interface with the ICN Application Function (ICN-AF) for subscription and session policy management of ICN PDU sessions. To enable ICN stack in the UE, AMF++ function has to be enabled with the capability of authenticating UE's attach request for ICN resources in 5GC. The request can be incorporated in NSSI parameter to request either ICN specific slice or using ICN in existing IP network slice when the UE is dual stacked. AMF++ can potentially be extended to also support ICN specific bootstrapping

(such as naming and security) and forwarding functions to configure UE's ICN layer. These functions can also be handled by the ICN-AF and ICN control function in the UE after setting PDU session state in 5GC. Here, the recommendation is not about redefining the 5G UE attach procedures, but to extend the attach procedures messages to carry ICN capabilities extensions in addition to supporting existing IP based services. The extensions should allow a 5G UE to request authentication to 5GC either in ICN, IP or dual-stack (IP and ICN) modes. Further research is required to optimize 5G attach procedures so that an ICN capable UE can be bootstrapped by minimizing the number of control plane messages. One possibility is to leverage existing 5G UE attach procedures as described in 3GPP's [TS23.502], where the UE can provide ICN identity in the LTE equivalent protocol configuration option information element (PCO-IE) message during the attach request as described in [I-D.suthar-icnrg-icn-lte-4g]. In addition, such requirement can be also be provided by the UE in NSSI parameters during initial attach procedures. Alternately, ICN paradigm offers name-based control plane messaging and security which one can leverage during the 5G UE attach procedures, however this requires further research.

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

o ICN Session Management Function (ICN-SMF): ICN-SMF serves as control plane for the ICN state managed in ICN-GW. This function can be either incorporated as part of SMF++ or as a stand-alone one. This function interacts with SMF++ to obtain and also push ICN PDU session management information for the creation,

modification and deletion of ICN PDU sessions in ICN-GW. For instance, when new ICN slices are provisioned by the ICN service orchestrator, ICN-SMF requests a new PDU session to the SMF that extends to the RAN. While SMF++ manages the tunnels to interconnect ICN-GW to UL-CL, ICN-SMF creates the appropriate forwarding state in ICN-GW (using the forwarding information base or FIB) to enable ICN flows over appropriate tunnel interfaces managed by the SMF++. In addition, it also signals resource management rules to share compute, bandwidth, storage/cache resources among multiple slice instances co-located in the ICN-GW.

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

5.1.1. Normative Interface Extensions

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

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

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

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

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

5.2. User Plane Extensions

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

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

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

  * Considering multiple ICN architecture proposals and multiple ICN deployment models discussed in [I-D.rahman-icnrg-deployment-guidelines], an alternate backward compatible (IP-over-)ICN solution is proposed in [TROSSEN].

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

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

5.2.1. Normative Interface Extensions

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

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

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

5.2.2. ICN over non-IP PDU

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

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

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

- Mobility Handling: Considering mobility can be support by ICN, it is inefficient to traverse other intermediate IP networks between the BS and the next ICN hop. This requires ICN PDU to be handled by an ICN instance in the BS itself, in association with UL-CL

function local to the BS as shown in Figure 2. Control plane extensions discussed in Section 5 can be used in tandem with distributed mobility protocols to handle ICN mobility, one such solution for producer mobility is proposed in [ICNMOB]

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

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

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

6. 5G/ICN Deployment Scenarios

Here we discuss two relevant network services enabled using ICN in 5G.

6.1. Smart Mobility

We consider here a radio edge service requiring low latency, high capacity and strict quality of service. For the discussion in this draft, we analyze connected vehicle scenario, where the car's navigation system (CNS) uses data from the edge traffic monitoring (TM-E) service instance to offer rich and critical insights on the road conditions (such as real-time congestion assisted with media feeds). This is aided using traffic sensing (TS) information collected through vehicle-to-vehicle (V2V) communication over

dedicated short-range communications (DSRC) radio by the TS-E, or using road-side sensor units (RSU) from which this information can be obtained. The TS-E instances then push this information to a central traffic sensing instance (TS-C). This information is used by the central traffic monitoring service (TM-C) to generate useable navigation information, which can then be periodically pushed to or pulled by the edge traffic monitoring service (TM-E) to respond to requests from vehicle's CNS. For this scenario, our objective is to compare advantages of offering this service over an IP based MEC versus one based on ICN. We can generalize the following discussion to other MEC applications as well.

6.1.1. IP-MEC Scenario

Considering the above scenario, when a vehicle's networking system comes online, it first undergoes an attachment process with the 5G-RAN, which includes authentication, IP address assignment and DNS discovery. The attachment process is followed by PDU session establishment, which is managed by SMF signaling to UL-CL and the UPF instance. When the CNS application initializes, it assumes this IP address as its own ID and tries to discover the closest service instance. Local DNS then resolves the service name to a local MEC service instance. Accordingly, CNS learns the IP service point address and uses that to coordinate between traffic sensing and monitoring applications.

CNS is a mission critical application requiring instant actions which is accurate and reliable all the time. Delay of microsecond or non-response could result in fatalities. Following are main challenges with the IP-MEC design:

- o At the CNS level, non-standardization of the naming schema results in introducing an application level gateway to adapt the sensing data obtained from DSRC system to IP networks, which becomes mandatory if the applications are from different vendors.

- o As the mobility results in handover between RAN instances, service-level or 5GC networking-level mechanisms need to be initiated to discover a better TM-E instance, which may affect the service continuity and result in session reestablishment that introduces additional control/user plane overheads.

- o Data confidentiality among multiple CNS attached 5G RAN, authentication and privacy control are offered through an SSL/TLS mechanism over the transport channel, which has to be re-established whenever the network layer attributes are reset.

6.1.2. ICN-MEC Scenario

If the CNS application is developed over ICN either natively or as an overlay over IP, ICN shall allows the same named data logic to operate over heterogeneous interfaces (such as DSRC radio, and IP transport-over-5G, unlicensed radio over WiFi etc. link), thereby avoiding the need for application layer adaptations.

We can list the advantages of using ICN-based MEC as follows:

o Compared to IP, ICN is unique in supporting both infrastructure and ad hoc communication. This makes it suitable to support communication in vehicular ad hoc networks (VANETS) [Guilio], along with communication to the infrastructure components like the road side units to serve the needs of several smart mobility applications. ICN's name based APIs enables it to operate over multiple heterogeneous radio interfaces simultaneously in broadcast, unicast or anycast modes of communication that can be taken advantage of in a given context.

o As vehicles within a single road segment are likely to seek the same data, ICN-based MEC allows to leverage opportunistic caching and storage enabled at ICN-GW, thereby avoiding service level unicast transmissions.

o Processed and stored traffic data can be easily contextualized to different user requirements.

o Appropriate mobility handling functions can be used depending on mobility type (as consumer or producer), specifically, when an ICN-UE moves from one RAN instance to another, the next IP hop, which identifies the ICN-GW function, has to be re-discovered. Unlike the IP-MEC scenario, this association is not exposed to the applications. As discussed earlier, control plane extensions to AMF and SMF can enable re-programmability of the ICN layer in the vehicle to direct it towards a new ICN-GW, or to remain with the same ICN-GW, based on optimization requirements.

o As ICN offers content-based security, produced content can be consumed while authenticating it at the same time (i.e., allowing any data produced to diffuse to its point of use through named data networking).

6.1.3. IP-over-ICN MEC Scenario

The above application can also be realized in the context of an IP-over-ICN deployment scenario discussed in Section 5.2. In this case, we assume the operation of the IP-based MEC application over the ICN

bearer. The ICN-based methods being used for service registration ensure that routing of CNS service requests reach the 'nearest' service instance (near in topological distance), while utilizing path updates at the CNS endpoint to handle mobility of the vehicle. If assuming HTTP-level (or similar CoAP-level) access to the sensing data, the same TM-E instance can return a single Layer 2 level multicast (assuming a SDN-based L2 sub-system) response to all CNS of passing car that have been requesting the sensing data within a configurable time interval. The ICN-based registration of the TM-E service also allows for secure content delegation being implemented where secured content is being diffused to in-network caching points while the original HTTP/CoAP-level sensing request is directed to the secure content server rather than the origin server, avoiding inefficient triangular routing when doing so.

6.2. Multi-viewer Virtual Reality

VR services are nowadays implemented as HTTP-based file chunk retrieval systems where the file chunk is determined by the viewing angle of the VR headset. Hence, within the same content scenario, consumers exhibiting the same viewing angle relative to the content will exhibit the same access patterns towards the content storage. Nonetheless, IP-based delivery of the VR service will result in separate HTTP unicast sessions being established to each VR headset. When running instead the headset in IP-over-ICN mode (with a dual-stack realization or a single stack UE with the convergence layer as outlined in [I-D.suthar-icnrg-icn-lte-4g], we can now utilize the multicast capabilities of the underlying ICN system to deliver any access to the same file chunk as a multicast message from the content storage to the individual headset UEs using L2 multicast. When viewing angles diverge among headsets, the degree of overlap will do the same and the multicast efficiency will change accordingly albeit in an ad-hoc, instantaneous manner, i.e., not requiring any reconfiguration of underlying transport resources (such as multicast groups). Such multi-viewer VR capability can be utilized in a number of use cases, such as for events at specific site, e.g., stadiums, in an MEC-like deployment. Other use cases could foresee utilizing such capability for remote education scenarios from a single VR server, e.g., provisioned by a school, towards a class of students located at 5G-connected homes or premises This capability of improving on existing HTTP-based VR services via such convergence layer based IP-over-ICN mechanisms has been successfully demonstrated at trade-shows in 2017.

6.3. ICN Session Mobility

Mobility scenario assumes a general ICN-UE handover from S-RAN to T-RAN, where each of them is served by different UPFs, i.e., UL-CL-1 and UL-CL-2. We also assume that UL-CL-1 and UL-CL-2 use different gateways, referred to as ICN-GW-1 and ICN-GW-2. From an ICN perspective, we discuss here the producer mobility case, which can be handled in multiple ways, one of which is proposed in [ICNMOB].However, the details of the ICN mobility solution are orthogonal to this discussion. Here, ICN-UE refers to an application producer (e.g., video conferencing application, from which ICN consumers request real-time content. Here we also assume the absence of any direct physical interface, Xn, between the two RANs. The current scenario follows the handover procedures discussed in [TS23.502], with focus here on integrating it with an ICN-GW and ICN-DN, where mobility state of the ICN sessions are handled.

The overall signaling overhead to handle seamless mobility also depends on the deployment models discussed in Section 4. Here we consider the case when RAN, UL-CL and ICN-GW are physically disjoint; however in the case where RAN and UL-CL are co-located then a part of the signaling to manage the tunnel state between the RAN and UL-CL is localized, which then improves the overall signaling efficiency. This can be further extended to the case when ICN-GWs are co-located with the RAN and UL-CL, leading to further simplification of the mobility signaling.

Next, we discuss the high-level steps involved during handover.

- Step 1: When the ICN-UE decides to handover from S-RAN to T-RAN, ICN-UE signals the S-RAN with a handover-request indicating the new T-RAN it is willing to connect. This message includes the affected PDU session IDs from the 5GC perspective, along with the ICN names that require mobility support.

- Step 2: S-RAN then signals the AMF serving the ICN-UE about the handover request. The request includes the T-RAN details, along with the affected ICN PDU sessions.

- Step 3: Here, when SMF receives the ICN-UE's and the T-RAN information, it identifies UL-CL-2 as the better candidate to handle the ICN PDU sessions to T-RAN. In addition, it also identifies ICN-GW-2 as the appropriate gateway for the affected ICN PDU sessions.

- Step 4: SMF signals the details of the affected PDU sessions along with the traffic filter rules to switch the UL traffic from UL-CL-2 to ICN-GW-2 and DL flows from UL-CL-2 to T-RAN.

o Step 5: SMF then signals ICN-SMF about the PDU session mobility change along with the information on UL-CL-2 for it to provision the tunnel between ICN-GW-2 and UL-CL-2.

o Step 6: Based on the signaling received on the ICN PDU session, ICN-SMF identifies the affected gateways, i.e., ICN-GW-1 and ICN-GW-2: (i) ICN-SMF signals ICN-GW-2 about the affected PDU session information to update its DL tunnel information to UL-CL-2. Then, based on the ICN mobility solution, appropriate ICN mobility state to switch the future incoming Interests from ICN-GW-1 to UL-CL-2; (ii) ICN-SMF also signals ICN-GW-1 with the new forwarding label[ICNMOB] to forward the incoming Interest traffic to ICN-GW-2. This immediately causes the new Interest payload for the ICN-UE to be send to the new ICN gateway in a proactive manner.

o Step 7: ICN-SMF then acknowledges SMF about the successful mobility update. Upon this, the SMF then acknowledges AMF about the state changes related to mobility request along with the tunnel information that is required to inter-connect T-RAN with UL-CL-2.

o Step 8: AMF then updates the T-RAN PDU session state in order to tunnel ICN-UE's PDU sessions from T-RAN to UL-CL-2. This is followed by initiating the RAN resource management functions to reserve appropriate resources to handle the new PDU session traffic from the ICN-UE.

o Step 9: AMF then signals the handover-ack message to the UE, signaling it to handover to the T-RAN.

o Step 10: UE then issues a handover-confirm message to T-RAN. At this point, all the states along the new path comprising the T-RAN, UL-CL-2 and ICN-GW-2 is set to handle UL-DL traffic between the ICN-UE and the ICN-DN.

o Step 11: T-RAN then signals the AMF on its successful connection to the ICN-UE. AMF then signals S-RAN to remove the allocated resources to the PDU session from the RAN and the tunnel state between S-RAN and UL-CL-1.

o Step 12: AMF then signals SMF about the successful handover, upon which SMF removes the tunnel states from UL-CL-1. SMF then signals the ICN-SMF, which then removes the ICN mobility state related to the PDU session from ICN-GW-1. Also at this point, ICN-SMF can signal the ICN-NRS (directly or through ICN-GW-2) to update the UE-ID resolution information, which now points to ICN-GW-2 [ICNMOB].

Note that, inter-RAN handover mapping to the same UL-CL represents a special case of the above scenario.

6.4. Cloud-native (mobile) Operator Environments

At the recent NGMN (next generation mobile networks) Forum in Paris in April 2018, a so-called 'cloud-native environment' for mobile operators was presented. This view on the realization of both the control and eventually also the data plane in 5G networks foresees the use of regionalized data centres over a software-defined wide area network. Here, traditional network control functions are re-interpreted as 'services' over an HTTP application layer protocol, i.e., moving the network function view (based on peer relations) to a fully fledged service-based architecture. The NGMN presentation included a demonstration of a first fully SDN-based realization of such view, utilizing IP-over-ICN [TROSSEN] routing capabilities for HTTP-based control plane service invocations. The benefits of utilizing such capabilities lie in the flexible and fast redirection capability to the nearest service instance, for which the demo used container-based virtualization techniques. Although the demo itself was not (yet) integrated into the 5G sub-system according to Figure 2, it showed the capabilities of utilizing ICN as an underlay. Although the focus of the demonstration lied on control plane service, the same solution has successfully demonstrated data plane services, such as those discussed in Section 6.1.3 and Section 6.2.

7. Conclusion

In this draft, we explore the feasibility of realizing future networking architectures like ICN within the proposed 3GPP's 5GC architecture. Towards this, we summarized the design principles that offer 5GC the flexibility to enable new network architectures. We then discuss 5GC architecture along with the user/control plane extensions required to handle ICN PDU sessions formally. We then apply the proposed architecture to two relevant services that ICN networks can enable: first, mobile edge computing over ICN versus the traditional IP approach considering a connected car scenario, and argue based on architectural benefits; second, handling ICN PDU session mobility in ICN-DN rather than using IP anchor points, with minimal support from 5GC.

8. IANA Considerations

This document requests no IANA actions.

9. Security Considerations

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

10. Acknowledgments

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