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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, including recent efforts to provide cellular Local Area Network (LAN) connectivity, followed by extensions to 5GC's control and user plane to support Packet Data Unit (PDU) sessions from Information-Centric Networks (ICN). In addition, ICN over 5GLAN is also described.

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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.irtf-icnrg-deployment-guidelines], where 5G technology is considered as one of the promising alternatives.

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

- o **Edge Computing:** Multi-access Edge Computing (MEC) is located at the edge of the network and aids several latency sensitive applications such as augmented and virtual reality (AR/VR), as well as the ultra reliable and low latency class (URLLC) of applications such as autonomous vehicles. Enabling edge computing over an IP converged 5GC comes with the challenge of application level reconfiguration required to re-initialize a session whenever it is being served by a non-optimal service instance topologically. In contrast, named-based networking, as considered by ICN, naturally supports service-centric networking, which minimizes network related configuration for applications and allows fast resolution for named service instances.
- o **Edge Storage and Caching :** A principal design feature of ICN is the secured content (or named-data) object, which allows location independent data replication at strategic storage points in the network, or data dissemination through ICN routers by means of opportunistic caching. These features benefit both realtime and non-realtime applications whenever there is spatial and temporal correlation among content accessed by these users, thereby advantageous to both high-bandwidth and low-latency applications such as conferencing, AR/VR, and non-real time applications such as Video-on-Demand (VOD) and IoT transactions.
- o **Session Mobility:** Existing long-term evolution (LTE) deployments handle session mobility using centralized routing using the MME function, IP anchor points at Packet Data Network Gateway (PDN-GW) and service anchor point called Access Point Name (APN) functionality hosted in PDN-GW. LTE uses tunnel between radio edge (eNodeB) and PDN-GW for each mobile device attached to network. This design fails when service instances are replicated close to radio access network (RAN) instances, requiring new techniques to handle session mobility. In contrast, application-bound identifier and name resolution split principle considered for the ICN is shown to handle host mobility quite efficiently [ICNMOB].

In this document, we first discuss 5GC's design principals that allows the support of new network architectures. Then we summarize

the 5GC proposal, followed by control and user plane extensions required to support ICN PDU sessions. This is followed by discussions on enabling IP over ICN over 3GPP proposed 5GLAN service framework. We then discuss deployment considerations for both ICN over 5GC and IP over ICN over 5GLAN.

2. Terminology

Following are terminologies relevant to this draft:

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

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

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

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

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

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

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

Session Management Function (SMF): Performs session management functions for attached users equipment (UE) in the 5G Core. SMF

can thus be formed by leveraging the CUPS (discussed in the next section) feature with control plane session management.

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

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

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

5GLAN Service: A service over the 5G system offering private communication using IP and/or non-IP type communications.

3. 5G NextGen Core Design Principles

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

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

RAN flows to arbitrary core network slices based on service requirements.

- o Non-IP PDU Session Support : A PDU session is defined as the logical connection between the UE and the data network (DN). 5GC offers a scope to support both IP and non-IP PDU (termed as "unstructured" payload), and this feature can potentially allow the support for ICN PDUs by extending or re-using the existing control functions. More discussions on taking advantage of this feature in ICN's context is presented in Section 4.2.2.2.
- o Service Centric Design: 5GC's service orchestration and control functions, such as naming, addressing, registration/authentication and mobility, will utilize API design similar to those used in cloud technologies. Doing so enables opening up interfaces for authorized service function interaction and creating service level extensions to support new network architectures. These APIs include the well accepted Get/Response and Pub/Sub approaches, while not precluding the use of point-to-point procedural approach among 5GC functional units (where necessary).
- o Distributed LAN Support: utilizing the aforementioned unstructured PDU session support, 5GC offers the capability to expose a Layer 2 LAN service to cellular user equipment. Such distributed LAN targets to complement those in fixed broadband, including local WLAN fanouts. Through such LAN capability, services can be realized by being virtually embedded into an intranet deployment with dedicated Internet-facing packet gateway functionality. Examples for such services, among others, are those related to Industrial IoT, smart city services and others. Utilizing this capability for ICN-based services is presented in Section 5.1.

4. 5GC Architecture with ICN Support

4.1. 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 4.2. More exhaustive discussions on the various architecture functions, such as registration, connection and subscription management, can be found in[TS23.501][TS23.502].

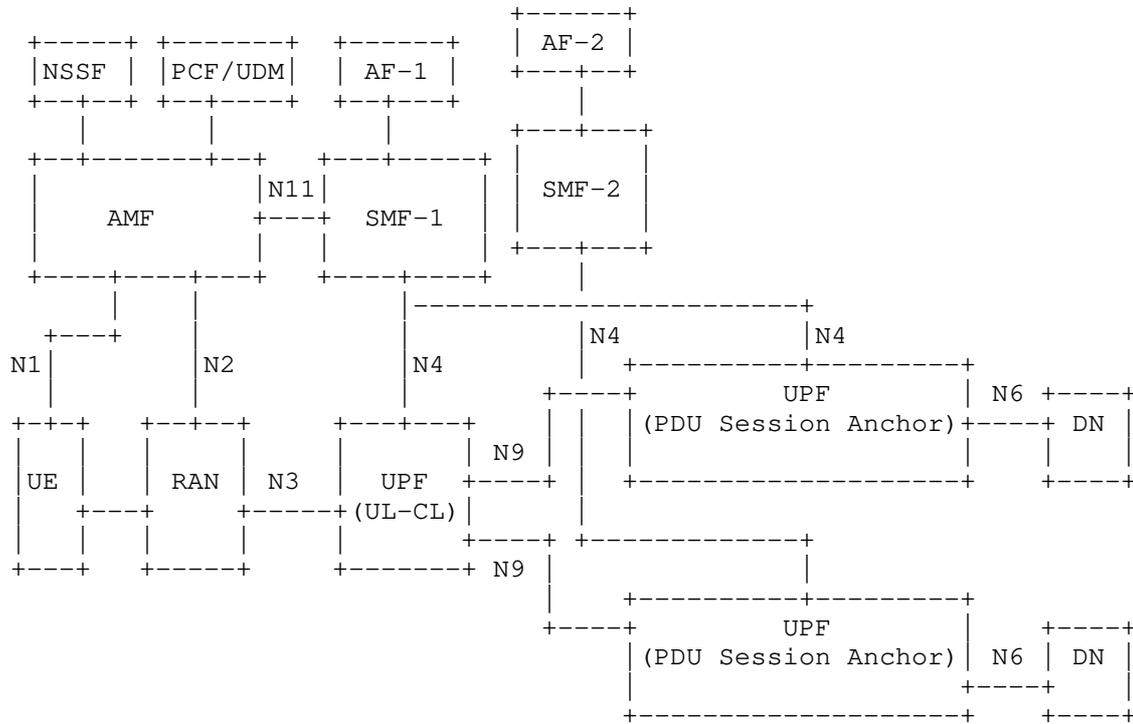


Figure 1: 5G Next Generation Core Architecture

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

- o Common control plane functions that are common to all slices and which include the Network Slice Selection Function (NSSF), Policy Control Function (PCF), and Unified Data Management (UDM) among others.
- o Shared or slice specific control functions, which include the Access and Mobility Function (AMF), Session and Management Function (SMF) and the Application Function (AF).

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

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

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

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

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

4.2. ICN over 5GC

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.

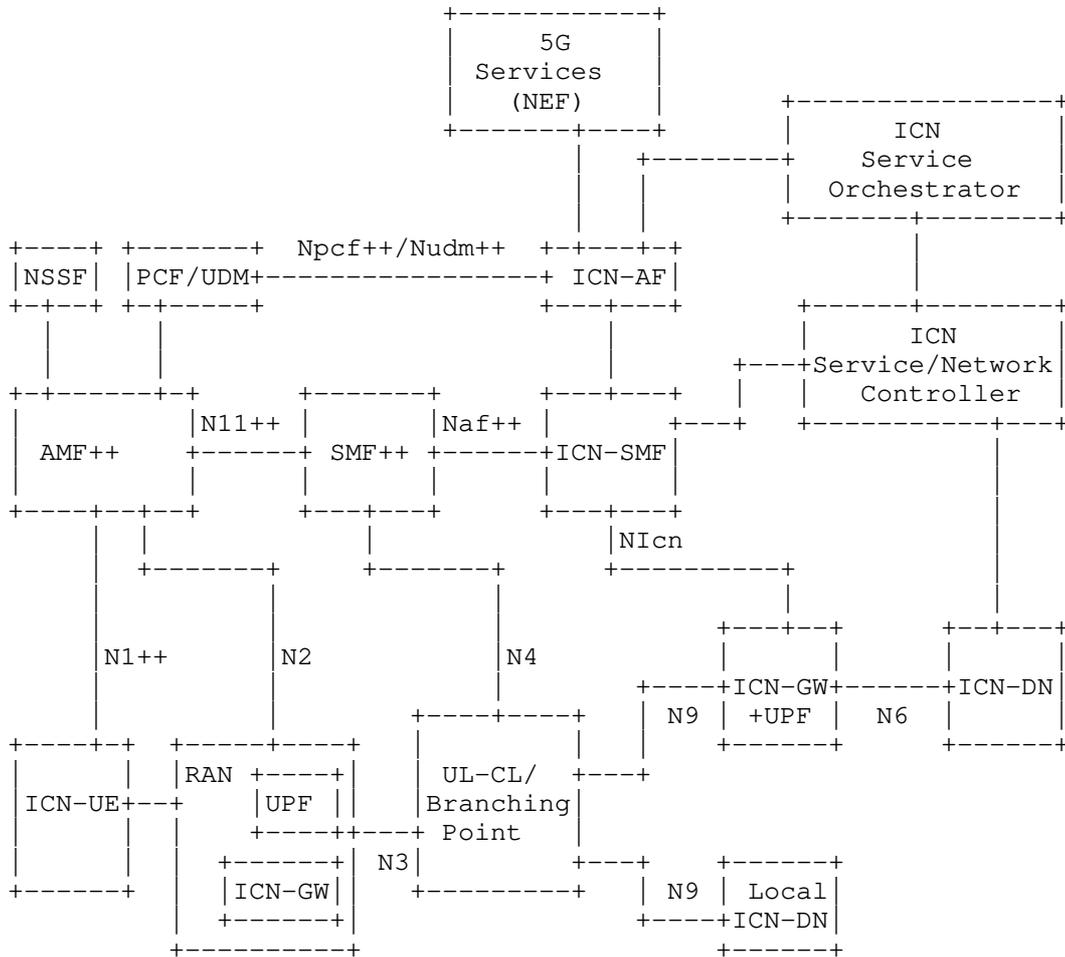


Figure 2: 5G Next Generation Core Architecture with ICN support

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.irtf-icnrg-icn-lte-4g] which is also applicable for 5G UE to enable formal ICN session handling, such as, using a Transport Convergence Layer (TCL) above 5G-NR, through IP address assignment from 5GC or using 5GC provision of using unstructured PDU session mode during the PDU session establishment process, which is

discussed in Section 4.2.2.2. Such convergence layer would implement necessary IP over ICN mappings, such as those described in [TROSSEN], for IP-based applications that are assigned to be transported over an ICN network. 5G UE can also be non-mobile devices or an IOT device using radio specification which can operate based on [TS38.300].

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

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

4.2.1. 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.irtf-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 4.2.2) through the ICN-SMF. For centrally delivered services, ICN-GW could also multiplex as an IP anchor point for IP applications. If MEC is enabled, these two functions would be distributed, as the UL-CL will re-route the flow to a local ICN-DN. 3GPP has defined IP based session management procedures to handle UE PDU sessions in TS23.502. For ICN UE we can either leverage same procedures when ICN is deployed as an overlay protocol. Towards this, SMF++ interfaces with AMF++ over N11++ to enable ICN specific user plane functions, which include tunnel configuration and traffic filter policy to inter-connect UE with the appropriate radio and the core slice. Furthermore, AMF++ sets appropriate state in the RAN and the UE that directs ICN flows to the chosen ICN UL-CL in the core network, and towards the right UE in the downlink.
- o ICN Session Management Function (ICN-SMF): ICN-SMF serves as control plane for the ICN state managed in ICN-GW. This function can be either incorporated as part of SMF++ or as a stand-alone one. This function interacts with SMF++ to obtain and also push ICN PDU session management information for the creation, modification and deletion of ICN PDU sessions in ICN-GW. For instance, when new ICN slices are provisioned by the ICN service orchestrator, ICN-SMF requests a new PDU session to the SMF that extends to the RAN. While SMF++ manages the tunnels to interconnect ICN-GW to UL-CL, ICN-SMF creates the appropriate

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

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

4.2.1.1. Normative Interface Extensions

- o N1++/N11++: This extension enables ICN specific control functions to support ICN authentication, configuration and programmability of an ICN-UE via AMF++ and SMF++, and also impose QoS requirements, handle mobility management of an ICN PDU session in 5GC based on service requirements.
- o N4: Though this signaling is service agnostic, as discussed in Section 4.2.2, future extensions may include signaling to enable ICN user plane features in these network functions. The extension of N4 to RAN is to handle the case when UPF function collocates with the RAN instance to enable localized ICN DNs.
- o N1cn: This extension shall support two functions: (i) control plane programmability to enable ICN PDU sessions applicable to 5GC to map to name based forwarding rules in ICN-GW; (ii) control plane extensions to enable ICN mobility anchoring at ICN-GW, in which case it also acts as POA for ICN flows. Features such as ICN mobility as a service can be supported with this extension [ICNMOB].
- o Naf++: This extension supports 5GC control functions such as naming, addressing, mobility, and tunnel management for ICN PDU sessions to interact with SMF++ and AMF++.

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

4.2.2. User Plane Extensions

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

- o ICN Gateway (ICN-GW): ICN-GW is where the 5GC PDU sessions terminate and ICN service network begins. Compared to the traditional anchor points as in PGW, the ICN-GW is also a service gateway as it can host services or cache content enabled through the ICN architecture. The ICN-GW also includes the UPF functions to manage multiple tunnel interfaces enabling the relay of ICN PDU flows to appropriate UL-CL instances in the DL. Note that there may be multiple ICN-GWs serving different ICN services or slices. ICN-GW also manages other ICN functions such as enforcing the dynamic name based forwarding state, mobility state, in-network service function management, resource management with respect to sharing caching, storage, and compute resources among multiple services[Ravindran].
- o ICN Packet Data Network (ICN-(P)DN): ICN-DN represents a set of ICN nodes used for ICN networking and with heterogeneous service resources such as storage and computing points. An ICN network enables both network and application services, with network services including caching, mobility, multicast, multi-path routing (and possibly network layer computing), and application services including network resources (such as cache, storage, network state resources) dedicated to the application.
- * Considering multiple ICN architecture proposals and multiple ICN deployment models discussed in [I-D.irtf-icnrg-deployment-guidelines], an alternate backward compatible (IP-over-)ICN solution is proposed in [TROSSEN]. Such an ICN-(P)DN can simply consist of SDN forwarding nodes and a logically centralized path computation entity (PCE), where the PCE is used to determine suitable forwarding identifiers being used for the path-based forwarding in the

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

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

4.2.2.1. Normative Interface Extensions

- o N3: Though the current architecture supports heterogeneous service PDU handling, future extensions can include user plane interface extensions to offer explicit support to ICN PDU session traffic, for instance, an incremental caching and computing function in RAN or UL-CL to aid with content distribution.
- o N9: Extensions to this interface can consider UPFs to enable richer service functions, for instance to aid context processing. In addition extensions to enable ICN specific encapsulation to piggyback ICN specific attributes such as traffic or mobility data between the UPF branching point and the ICN-GW.
- o N6: This interface is established between the ICN-GW and the ICN-DN, whose networking elements in this segment can be deployed as an overlay or as a native Layer-3 network.

4.2.2.2. ICN over non-IP PDU

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

- o Attach Procedures for UE with Non-IP PDN: Assuming a 5GC can support both IP and non-IP PDN, this requires control plane support. In a typical scenario, when UE sends an attach message to 5GC, the type of PDU connection is indicated in the PCO-IE field, for e.g. in this case as being non-IP PDN to invoke related control plane session management tasks. ICN over non-IP PDU session will allow the UE to attach to 5GC without any IP configuration. 5GC attach procedures specified [TS23.501] can be used to support authentication of UE with PDN type set to non-IP, using existing AUSF/UDM functions in coordination with the ICN-AF function discussed earlier if required.
- o User Plane for UE with Non-IP PDN: Without any IP tunnel configuration and ICN's default consumer agnostic mode of operation requires ways to identify the ICN-UE in the user plane, this can be enabled by introducing network identifier in the lower layers such as in the PDCP or MAC layer, that can assist for functions such as policy and charging at the BS and related session management tasks. These identifiers can also be used to demultiplex the DL traffic from the ICN-GW in the BS to the respective ICN-UEs. Also, ICN extensions can be incorporated in control plane signaling to identify an ICN-UE device and these parameters can be used by SMF to conduct non-IP routing. The policing and charging functions can be enforced by the UPF function in the BS which obtains the traffic filtering rules from the SMF. To enable flat ICN network from the BS requires distributed policy, charging and legal intercept which requires further research. Further ICN slice multiplexing can be realized by also piggybacking slice-ID (NSSI) along with device ID to differentiate handover to multiple ICN slices at the base station. Inter-working function (IWF) is required if services based on non-IP UE has to transact or communicate with transport, applications functions or other UE based on IP services. This also has implications on how mobility is managed for such PDU sessions.
- o Mobility Handling: Considering mobility can be support by ICN, it is inefficient to traverse other intermediate IP networks between the BS and the next ICN hop. This requires ICN PDU to be handled by an ICN instance in the BS itself, in association with UL-CL function local to the BS as shown in Figure 2. Control plane extensions discussed in Section 4.2.1 can be used in tandem with distributed mobility protocols to handle ICN mobility, one such solution for producer mobility is proposed in [ICNMOB]
- o Routing Considerations: Flat ICN network realizations also offers the advantage of optimal routing, compared to anchor point based realization in LTE. This also leads to optimal realization of the data plane considering the absence of overhead due to tunneling

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

- o IP over ICN: Native support of ICN in the RAN raises the possibility of leveraging the mobility functions in ICN protocols as a replacement for GTP tunneling in the 5GC, as described in [I-D.white-icnrg-ipoc] and [TROSSEN].
- o Mobile Edge Computing: Another significant advantage is with respect to service-centric edge computing at the ICN-GW or other ICN points, either through explicit hosting of service functions[VSER] in ICN or in-network computing based on NFN proposal[NFN]. A certain level of orchestration 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.

4.2.3. Dual Stack ICN Deployment

4.2.3.1. 5G User Plane Protocol Stack

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

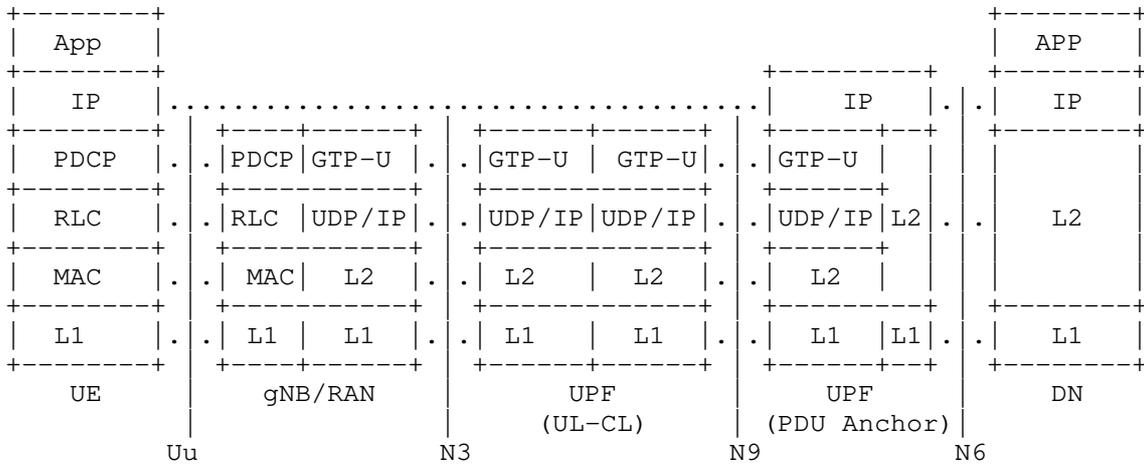


Figure 3: 5G User Plane Protocol Stack

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

4.2.3.2. Protocol Stack for ICN Deployment in 5G

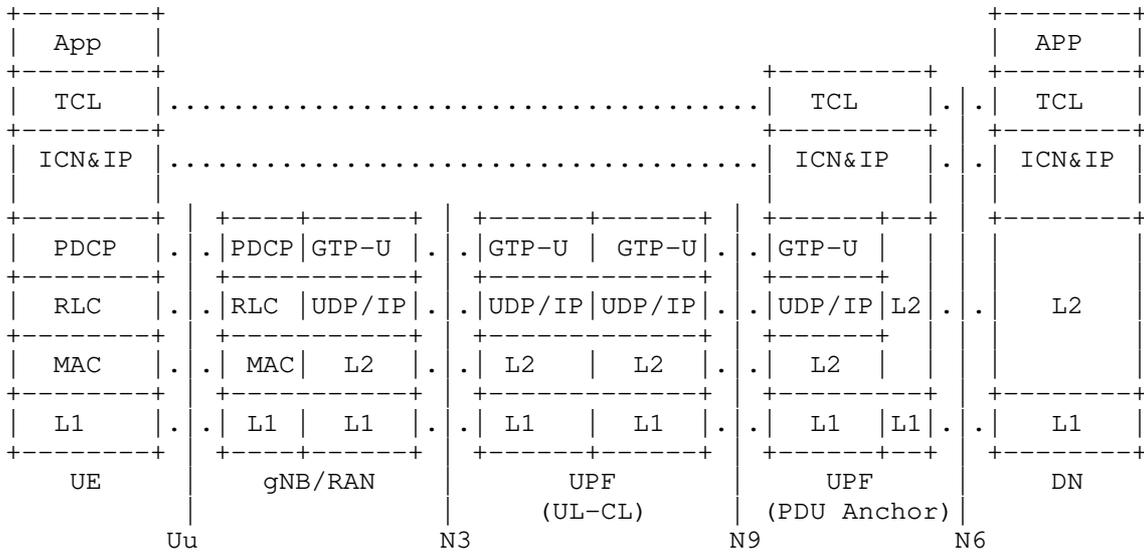


Figure 4: Dual Stack ICN Deployment

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

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

Case 1. IP over IP (IPoIP)

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

Case 2. ICN over ICN (ICNoICN)

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

Case 3. ICN over IP (ICNoIP)

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

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

Case 4. IP over ICN (IPoICN)

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

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

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

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

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

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

4.2.3.3. Protocol Interactions and Impacts

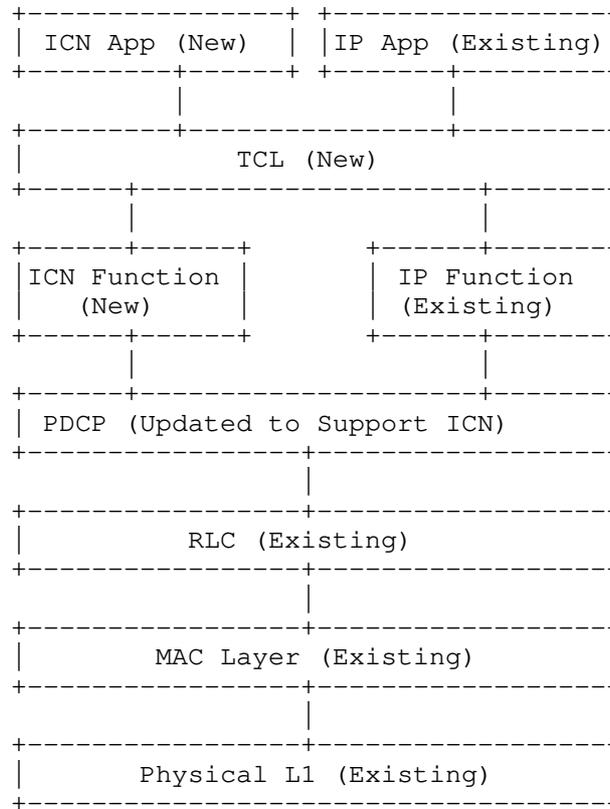


Figure 5: Dual Stack ICN Protocol Interactions at UE

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

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

- o The TCL helps determine what type of transport (e.g. ICN or IP) as well as type of radio interface (e.g. 5G NR or WiFi or both), is used to send and receive the traffic. Application layer can make the decision to select a specific transport based on preference e.g. content location, content type, content publisher, congestion, cost, quality of service etc. There can be an Application Programming Interface (API) to exchange parameters required for transport selection. The southbound interactions of TCL will be either to IP or ICN at the network layer. When selecting the IPoICN [TROSSEN] mode, the TCL is responsible for receiving an incoming IP or HTTP packet and publishing the packet under a suitable ICN name (i.e. the hash over the destination IP address for an IP packet or the hash over the FQDN of the HTTP request for an HTTP packet) to the ICN network. In the HTTP case, the TCL maintains a pending request mapping table to map returning responses to the originating HTTP request. The common API will provide a common 'connection' abstraction for this HTTP mode of operation, returning the response over said connection abstraction, akin to the TCP socket interface, while implementing a reliable transport connection semantic over the ICN from the UE to the receiving UE or the PGW. If the HTTP protocol stack remains unchanged, therefore utilizing the TCP protocol for transfer, the TCL operates in local TCP termination mode, retrieving the HTTP packet through said local termination. The southbound interactions of the Transport Convergence Layer (TCL) will be either to IP or ICN at the network layer.
- o ICN function (forwarder) is introduced in parallel to the existing IP layer. ICN forwarder contains functional capabilities to forward ICN packets, e.g. Interest packet to gNB or response "data packet" from gNB to the application.
- o For dual stack scenario, when UE is not supporting ICN at network layer, we use IP underlay to transport ICN packets. ICN function will use IP interface to send Interest and Data packets for fetching or sending data using ICN protocol function. This interface will use ICN overlay over IP using any overlay tunneling mechanism.
- o To support ICN at network layer in UE, PDCP layer has to be aware of ICN capabilities and parameters. PDCP is located in the Radio Protocol Stack in the 5G Air interface, between IP (Network layer) and Radio Link Control Layer (RLC). PDCP performs following functions [TS36.323]:
 - * Data transport by listening to upper layer, formatting and pushing down to Radio Link Layer (RLC).

- * Header compression and decompression using Robust Header Compression (ROHC).
- * Security protections such as ciphering, deciphering and integrity protection.
- * Radio layer messages associated with sequencing, packet drop detection and re-transmission etc.
- o No changes are required for lower layer such as RLC, MAC and Physical (L1) because they are not IP aware.

5. 5GLAN Architecture with ICN Support

5.1. 5GC Architecture Extensions for 5GLAN Support

In this section, we present an overview of ongoing work to provide cellular LAN connectivity over a 5GC compliant network for Release 16 and above deployments.

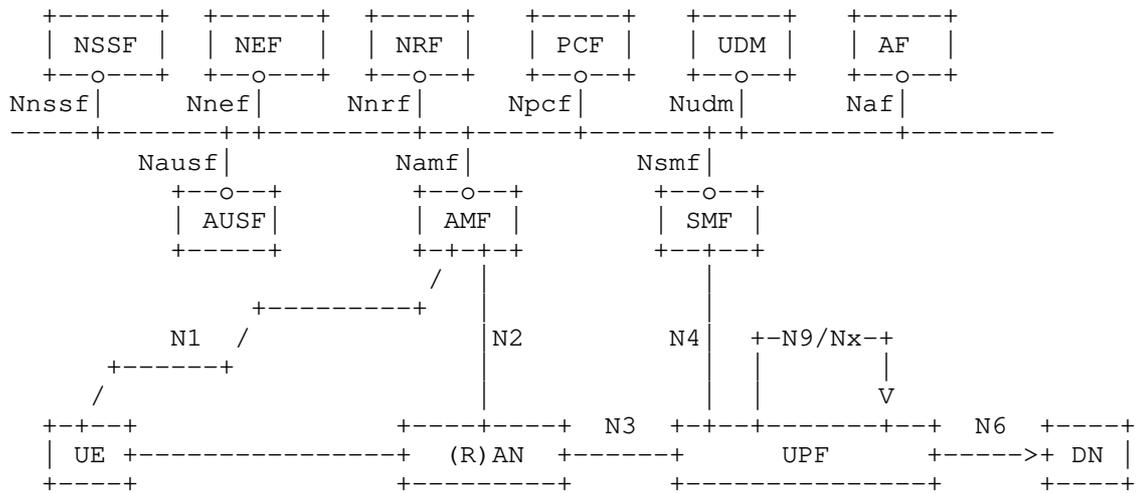


Figure 6: 5G Core Network with Vertical_LAN (5GLAN) Extensions

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

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

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

5.1.1.1. Realization of Nx Interface

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

For sending a packet from one Layer 2 device (UE) connected to one UPF (via a RAN) to a device connected to another UPF, we provide the MAC address of the destination and perform a header re-write by

providing the destination MAC address of the ingress UPF when sending from source device to ingress and placing the end destination MAC address in the payload. Upon arrival at the egress UPF, after having applied the path-based forwarding between ingress and egress UPF, the end destination address is restored while the end source MAC is placed in the payload with the egress L2 forwarder one being used as the L2 source MAC for the link-local transfer. At the receiving device, the end source MAC address is restored as the source MAC, creating the perception of a link-local L2 communication between the end source and destination devices.

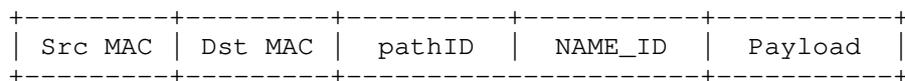


Figure 7: General Packet Structure

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

5.1.2. Bitfield-based Forwarding in Existing Transport Networks

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

As shown in [Reed], efficient path-based forwarding can be realized in SDN networks by placing the aforementioned path identifiers into the IPv6 source/destination fields of a forwarded packet. Utilizing the IPv6 source/destination fields allows for natively supporting 256 links in a transport network. Larger topologies can be supported by extension schemes but are left out of this paper for brevity of the presentation. During network bootstrapping, each link at each switch is assigned a unique bitnumber in the bitfield (through the SMF function of the 5GC). In order to forward based on such bitfield path information, the NR instructs the SDN controller to insert a suitable wildcard matching rule into the SDN switch. This wildcard

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

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

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

5.2. ICN over 5GLAN

ICN aims at replacing the routing functionality of the Internet Protocol (IP). It is therefore natively supported over a Layer 2 transport network, such as Ethernet-based networks. Deployments exists over WiFi and local LAN networks, while usually overlaying (over IP) is being used for connectivity beyond localized edge networks.

With the emergence of the 5GLAN capability in (future) Release 16 based 5G networks, such cellular LAN connectivity to provide pure ICN could be utilized for pure ICN-based deployments, i.e. without the dual stack capability outlined in Section 4.2.3.2. With this, the entire 5G network would be interpreted as a local LAN, providing the necessary Layer 2 connectivity between the ICN network components. With the support of roaming in 5GLAN, such '5G network' can span several operators and therefore large geographies.

Such deployment, however, comes without any core network integration, similar to the one outlined in Section 4.1, and therefore does not utilize ICN capabilities within the overall 5G core and access network. Benefits such as those outlined in the introduction, e.g., caching, would only exist at the endpoint level (from a 5GLAN perspective).

However, ICN components could be provided as SW components in a network slice at the endpoints of such 5GLAN connectivity, utilizing in-network compute facilities, e.g., for caching, CCN routing capabilities and others. Such endpoint-driven realization of a specific ICN deployment scenario is described in more detail in [I-D.trossen-icnrg-IP-over-icn], focusing on the provisioning of IP-based services over an ICN, which in turn is provided over a LAN (and therefore also 5GLAN) based transport network.

6. Deployment Considerations

The work in [I-D.irtf-icnrg-deployment-guidelines] outlines a comprehensive set of considerations related to the deployment of ICN. We now relate the solutions proposed in this draft to the two main aspects covered in the deployment considerations draft, namely the 'deployment configuration' (covered in Section 4 of [I-D.irtf-icnrg-deployment-guidelines]) that is being realized and the 'deployment migration paths' (covered in Section 5 of [I-D.irtf-icnrg-deployment-guidelines]) that are being provided.

The solutions proposed in this draft relate to those 'deployment configuration' as follows:

- o The integration with the 5GC, as proposed in Section 4.2, follows the 'Clean-slate ICN' deployment configuration, i.e., integrating the ICN capabilities natively into the 5GC through appropriate extensions at the control and user plane level.
- o The utilization of the 5GLAN capabilities, as proposed in Section 5.2, follows the 'ICN-as-an-Overlay', interpreting the 5GLAN as an overlay capability with no 5GC integration being considered (as in the 'Clean-slate ICN' configuration).
- o The deployment of 5GLAN based ICN capabilities can be realized following the 'ICN-as-a-Slice' deployment configuration, i.e., the 5GLAN connectivity is provided to a 'vertical 5G customer' which in turn provides the ICN capability over 5GLAN within said network (and compute) slice at the endpoints of the 5GLAN connectivity, as proposed in Section 5.2.

In relation of the 'deployment migration paths', the solutions in this draft relate as follows:

- o The integration with the 5GC, as proposed in Section 4.2, facilitates 'edge network migration' (interpreting the cellular sub-system here as an edge network albeit a possibly geographically large one).
- o The dual-stack deployment, as proposed in Section 4.2.3, facilitates 'application and services migration' through not only supporting ICN applications but also IP-based applications through the proposed IP-over-ICN mapping in the terminal.
- o The ICN over 5GLAN deployment, possibly combined with an ICN-as-a-Slice deployment, facilitates the 'content delivery networks migration' through a deployment of ICN-based 5GLAN connected CDN elements in (virtualized) edge network nodes or POP locations in the customer (5G) network.

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 aspects along with the user/control plane extensions required to handle ICN PDU sessions formally to realize ICN with 5GC integration as well as ICN over a pure 5GLAN connectivity.

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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11. Informative References

- [H2020] H2020, "The POINT Project", <https://www.point-h2020.eu/> .
- [I-D.galis-anima-autonomic-slice-networking]
Galis, A., Makhijani, K., Yu, D., and B. Liu, "Autonomic Slice Networking", draft-galis-anima-autonomic-slice-networking-05 (work in progress), September 2018.
- [I-D.irtf-icnrg-deployment-guidelines]
Rahman, A., Trossen, D., Kutscher, D., and R. Ravindran, "Deployment Considerations for Information-Centric Networking (ICN)", draft-irtf-icnrg-deployment-guidelines-06 (work in progress), May 2019.
- [I-D.irtf-icnrg-icn-lte-4g]
suthar, P., Stolic, M., Jangam, A., Trossen, D., and R. Ravindran, "Native Deployment of ICN in LTE, 4G Mobile Networks", draft-irtf-icnrg-icn-lte-4g-03 (work in progress), March 2019.
- [I-D.muscariello-intarea-hicn]
Muscariello, L., Carofiglio, G., Auge, J., and M. Papalini, "Hybrid Information-Centric Networking", draft-muscariello-intarea-hicn-01 (work in progress), December 2018.
- [I-D.white-icnrg-ipoc]
White, G., Shannigrahi, S., and C. Fan, "Internet Protocol Tunneling over Content Centric Mobile Networks", draft-white-icnrg-ipoc-01 (work in progress), June 2018.
- [ICNMOB] Azgin, A., Ravidran, R., Chakraborti, A., and G. Wang, "Seamless Producer Mobility as a Service in Information Centric Networks.", 5G/ICN Workshop, ACM ICN Sigcomm 2016, 2016.
- [Jacobson]
Jacobson, V. and et al., "Networking Named Content", Proceedings of ACM Context, , 2009.
- [Khalili] Khalili, R., Poe, W., Despotovic, Z., and A. Hecker, "Reducing State of SDN Switches in Mobile Core Networks by Flow Rule Aggregation", IEEE ICCCN 2016, Hawaii, USA, August 2016.

- [lteversus5g] Kim, J., Kim, D., and S. Choi, "3GPP SA2 architecture and functions for 5G mobile communication system.", ICT Express 2017, 2017.
- [NFN] Sifalakis, M., Kohler, B., Christopher, C., and C. Tschudin, "An information centric network for computing the distribution of computations", ACM, ICN Sigcomm, 2014.
- [OpenFlowSwitch] Open Networking Foundation, available at <https://www.opennetworking.org/wp-content/uploads/2014/10/openflow-switch-v1.5.1.pdf>, "OpenFlow Switch Specification V1.5.1", 2018.
- [Ravindran] Ravindran, R., Chakraborti, A., Amin, S., Azgin, A., and G. Wang, "5G-ICN : Delivering ICN Services over 5G using Network Slicing", IEEE Communication Magazine, May, 2016.
- [Reed] Reed, M., AI-Naday, M., Thomos, N., Trossen, D., Petropoulos, G., and S. Spirou, "Stateless Multicast Switching in Software Defined Networks", IEEE ICC 2016, Kuala Lumpur, Malaysia, 2016.
- [RFC8279] Wijnands, IJ., Ed., Rosen, E., Ed., Dolganow, A., Przygienda, T., and S. Aldrin, "Multicast Using Bit Index Explicit Replication (BIER)", RFC 8279, DOI 10.17487/RFC8279, November 2017, <<https://www.rfc-editor.org/info/rfc8279>>.
- [SA2-5GLAN] 3gpp-5glan, "SP-181129, Work Item Description, Vertical_LAN(SA2), 5GS Enhanced Support of Vertical and LAN Services", 3GPP , http://www.3gpp.org/ftp/tsg_sa/TSG_SA/TSGS_82/Docs/SP-181120.zip.
- [SDNDef] Open Networking Foundation, available at <https://www.opennetworking.org/sdn-definition/>, "Software-Defined Networking (SDN) Definition", 2018.
- [TROSSEN] Trossen, D., Reed, M., Riihijarvi, J., Georgiades, M., and G. Xylomenos, "IP Over ICN - The Better IP ?", EuCNC, European Conference on Networks and Communications , July, 2015.

- [TS23.501] 3gpp-23.501, "Technical Specification Group Services and System Aspects; System Architecture for the 5G System; Stage 2 (Rel.15)", 3GPP , December 2018.
- [TS23.502] 3gpp-23.502, "Technical Specification Group Services and System Aspects; Procedures for the 5G System; Stage 2 (Rel. 15)", 3GPP , January 2019.
- [TS23.799] 3gpp-23.799, "Technical Specification Group Services and System Aspects; Study on Architecture for Next Generation System (Rel. 14)", 3GPP , 2017.
- [TS33.899] 3gpp-33.899, "Study on the security aspects of the next generation system", 3GPP , 2017.
- [TS36.323] 3gpp-36.323, "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification (Rel. 15)", 3GPP , January 2019.
- [TS38.300] 3gpp-38-300, "Technical Specification Group Radio Access Network; NR; NR and NG-RAN Overall Description; Stage 2 (Rel.15)", 3GPP , January 2019.
- [VSER] Ravindran, R., Liu, X., Chakraborti, A., Zhang, X., and G. Wang, "Towards software defined ICN based edge-cloud services", CloudNetworking(CloudNet), IEEE International Conference on, IEEE International Conference on CloudNetworking(CloudNet), 2013.

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