



IEEE Standard for Licensed/ Unlicensed Spectrum Interoperability in Wireless Mobile Networks

IEEE Communications Society

Developed by the
Mobile Communication Networks Standards
Committee (MobiNet-SC)

IEEE Std 1932.1™-2024

STANDARDS

IEEE Standard for Licensed/ Unlicensed Spectrum Interoperability in Wireless Mobile Networks

Developed by the

Mobile Communication Networks Standards Committee (MobiNet-SC)
of the
IEEE Communications Society

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IEEE SA Standards Board

Abstract: The proliferation of connected users and downloaded applications has driven the development of a new paradigm in wireless mobile networks. Additional air interfaces operating in the unlicensed spectrum serving as supplementary downlinks (SDL) and enhancing end-user throughput are utilized by this paradigm. However, integrating these interfaces into licensed base stations can be challenging, as they are distributed across various domains. WiFi is a key technology for increasing capacity through the user plane interface. Traffic is buffered in WiFi when unlicensed channels become unavailable, and transmissions resume once new radio slots are free. To meet the strict round-time delay requirements of fifth generation (5G) networks, a new virtual controller that resides at the mobile edge cloud is defined in this standard. The multi-connectivity model and traffic sharing between licensed and unlicensed interfaces are coordinated by the controller based on the real-time availability of unlicensed channels for specific user equipment. Two schemes are presented for managing multi-connectivity modes: distributed and centralized. In the distributed scheme, traffic forwarding and steering between distributed radio interfaces across domain sites is managed by the controller. In the centralized scheme, various radio interfaces are co-located in the same base station, and traffic steering is managed by the controller through a new unified 5G media access control (MAC) design. Traffic sharing between different interfaces is ensured by the controller, given that access to operator-deployed WiFi or any other customer WiFi using separate service level agreements (SLAs) is provided by operators. Multi-connectivity modes imply the provision of efficient new services that may require measuring airtime for each interface and changes to user plane topology.

Keywords: 5G core, IEEE 1932.1, licensed band, spectrum utilization, unlicensed band, virtual controller

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Introduction

This introduction is not part of IEEE Std 1932.1-2024, IEEE Standard for Licensed/Unlicensed Spectrum Interoperability in Wireless Mobile Networks.

The framework described in IEEE Std 1932.1™ enables real-time management of multi-connectivity modes in a fifth generation (5G) core-based virtual controller, allowing for efficient handling of various licensed and unlicensed radio interfaces. When making traffic diversion decisions, the availability of participant access points and channels is crucial, particularly in unlicensed base stations. This virtual controller can be seamlessly integrated into the control plane of the network core, specifically in 5G, and is capable of meeting the requirements of automated cloud-native domains. In addition, IEEE Std 1932.1 introduces a new unified air interface that combines licensed and unlicensed air interfaces through carrier aggregation, utilizing bands under different license regimes, and natively supporting new disruptive media access control (MAC) protocols. This new MAC model, named *enhanced dynamic spectrum access (eDSA)*, incorporates built-in features for multi-connectivity and spectrum aggregation.

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IEEE Standard for Licensed/ Unlicensed Spectrum Interoperability in Wireless Mobile Networks

1. Overview

This standard defines the licensed and unlicensed controller (LUC), a virtualized controller aimed at coordinating traffic load transmissions in multi-connectivity modes. The LUC may be initiated at the primary edge cloud or any other cloud within the network and facilitates seamless service management through a unique ID that coordinates with network components. The standard specifies the instantiation and chaining process of the LUC with other fifth generation core (5GC) network functions (NFs). Furthermore, it outlines the installation of enabling reporting mechanisms at the user equipment (UE) or the 5G new radio (NR) unified media access control (MAC).

1.1 Scope

This standard defines a mechanism for communications among entities operating in licensed and unlicensed spectrum. The mechanism includes interoperation among media access control/physical layer (MAC/PHY) protocols designed for unlicensed and licensed spectrum operations and a controller for coordination among communicating entities.

1.2 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall equals is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should equals is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may equals is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can equals is able to*).

⁶The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

3GPP TR 23.791, version 16.2.0, release 16, Study of enablers for network automation for 5G.

3GPP TR 38.801, Technical specification group radio access network; Study on new radio access technology: Radio access architecture and interfaces.

3GPP TS 23.503, version 16.5.0, release 16, Policy and charging control framework for the 5G system (5GS); stage 2.

3GPP TS 29.244, version 16.5.0, release 16, Interface between the control plane and the user plane nodes.

3GPP TS 29.501, version 15.2.0, release 15, Principles and guidelines for services definition; stage 3.

3GPP TS 33.310, Network domain security (NDS); authentication framework (AF).

3GPP TS 36.331, Radio resource control (RRC) protocol specification.

3GPP TS 33.501, version 16.3.0, release 16, Security architecture and procedures for 5G system.

3GPP TS 36.300, Evolved universal terrestrial radio access (E-UTRA) and evolved universal terrestrial radio access network (E-UTRAN); Overall description; stage 2.

ETSI EN 301 893, V1.7.2 (2012-06), Broadband radio access networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive.⁸

ETSI GS NFV-IFA 010, V3.2.1 (2019-04), NFV release 3; Management and orchestration; Functional requirements specification.

ETSI GS NFV-IFA 011, V4.2.1 (2021-05), NFV release 4; Management and orchestration; VNF descriptor and packaging specification.

ETSI GS NFV-IFA 040, V4.2.1 (2021-05), NFV release 4; Management and orchestration; Requirements for service interfaces and object model for OS container management and orchestration specification.

ETSI TS 123 501, V16.6.0 (2020-10), 5G; System architecture for the 5G system (5GS).

ETSI TS 128 541, V16.6.0 (2020-11), 5G; Management and orchestration; 5G network resource model (NRM); Stage 2 and stage 3.

ETSI TS 129 500, V15.4.0 (2019-07), 5G; 5G system; Technical realization of service based architecture; Stage 3.

ETSI TS 129 511, V16.2.0 (2020-07), 5G; 5G system; Equipment identity register services.

ETSI TS 129 557, V17.1.0 (2022-07), 5G; 5G system; Application function ProSe service; Stage 3.

⁸ETSI publications are available from the European Telecommunications Standards Institute (<https://www.etsi.org/>).

IEEE P802.11-15/0132r17, Specification Framework for TGax.^{9,10,11}

LTE Forum, LTE-U SDL CSAT Procedure Technical Specifications v1.0, Oct. 2015.

OpenAPI Initiative, The OpenAPI Specification (OAS).¹²

RFC 7540, Hypertext transfer protocol version 2 (HTTP/2).¹³

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹⁴

There are no definitions in this standard.

3.2 Acronyms and abbreviations

5G	fifth generation
5G-AIV	fifth generation air interface variant
5GC	fifth generation core
5GRLC	fifth generation radio link control
5GRRC	fifth generation radio resource control
ABS	almost blank sub-frames
AF	application function
AI	artificial intelligence
AKA	authentication and key agreement
AP	access point
API	application programming interface
AUSF	authentication server function
AMF	access and mobility management function
BAR	buffering action rules
BLER	block error rate
BS	base station
C_5GRLC_LMAC	control 5GRLC lower MAC
CA	carrier aggregation

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¹⁰Numbers preceded by P are IEEE authorized standards projects that were not approved by the IEEE SA Standards Board at the time this publication went to press. For information about obtaining drafts, contact IEEE.

¹¹IEEE publications are available from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

¹²Available at <https://github.com/OAI/OpenAPI-Specification/blob/main/versions/3.1.0.md>.

¹³RFC documents are available through the IETF at <https://www.ietf.org/standards/rfcs/>.

¹⁴*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

CCA	clear channel assessment
CDR	call data record
CP	control plane
CP-DRX	cyclic prefix-discontinuous reception
CPU	central processing unit
CIR	container image registry
CISM	container infrastructure service management
cRRM	central radio resource management
CSAT	carrier sense adaptive transmission
CQI	channel quality indicator
CUPS	control and user plane separation
D_5GRLC_LMAC	data 5GRLC lower MAC
DB	DataBase
DL	downlink
DN	data network
DNAI	domain name access identifier
EAP-AKA	extensible authentication protocol-authentication and key agreement
eDSA	enhanced dynamic spectrum access
EMM	EPS mobility management
FARs	forwarding action rules
GS	group specifications
GUTI	global unique temporary identifier
HARQ	Hybrid Automatic Repeat reQuest
HMAC	higher media access control
I-AMF	intermediate access and mobility management function
ID	identifier
IMEI	international mobile equipment identity
IMSI	international mobile subscriber identity
IoT	Internet of Things
IP	Internet protocol
I-UPF	intermediate user plane function
JSON	JavaScript Object Notation
KPI	key performance indicator
LBT	listen before talk
LCM	life cycle management
LAA	licensed-assisted access

LMAC	lower media access control
LTE	long-term evolution
LUC	licensed and unlicensed controller
LUT	look up table
LWA	long-term evolution wireless local area network aggregation
MA	multiple access
MAC	media access control
MA-PDU	multiple access protocol data unit
MEC	multi-access edge computing
MSC	message sequence chart
MU-MIMO	multi-user multiple input multiple output
NEF	network exposure function
NFS	network function service
NFV	Network Functions Virtualization
NOMA	non-orthogonal multiple access
NR	new radio
NRF	network repository function
Nsmf	network slice management function
NSSAI	network slice selection assistance information
NSSF	network slice selection function
NWDAF	network data analytics function
OAM	operations, administration, and maintenance
OFDMA	orthogonal frequency division multiple access
OSS	operations support systems
OTA	over-the-air
OTT	over-the-top
PCF	policy control function
PDRs	packet detection rules
PDU	protocol data unit
PFCP	Packet Forwarding Control Protocol
PHY	physical layer
PLMN	public land mobile network
QERs	quality of service (QoS) enhancement rules
QoS	quality of service
RACH	random access channel
RAN	radio access network

RAT	radio access technology
RB	resource block
RBC	radio bearer control
RLC	radio link control
RRC	radio resource control
SAP	service access point
SBA	service-based architecture
SBI	service-based interface
SC	scheduler controller
SDL	supplementary downlinks
SDR	software defined radio
SINR	signal-to-noise-and-interference ratio
SLA	service level agreement
SMF	session management function
S-NSSAI	subscribed network slice selection assistance information
SUCI	subscriber concealed identifier
SUPI	subscription permanent identifier
TTI	transmission time interval
UDM	unified data management
UDSF	unstructured data storage function
UE	user equipment
UL	uplink
UP	user plane
UPF	user plane function
VNF	virtual network function
YAML	Yet Another Markup Language

4. LUC technology

4.1 General

The following subclauses explain the high-level architecture of licensed and unlicensed controller (LUC) network function (NF), functions, and interfaces.

This standard defines a new virtualized controller, the LUC, which may be initiated at the primary edge cloud or any other cloud to coordinate the different traffic load transmissions in multi-connectivity modes. The virtual LUC shall have a unique identifier (ID) that shall coordinate with the network components for service management. The standard shall define how the LUC is instantiated and chained with other fifth generation core (5GC) NFs. Furthermore, the standard shall define the enabling reporting mechanisms that shall be installed at the UE or the fifth generation (5G) new radio (NR) unified media access control (MAC). The framework for this standard can be found in [Figure 1](#).

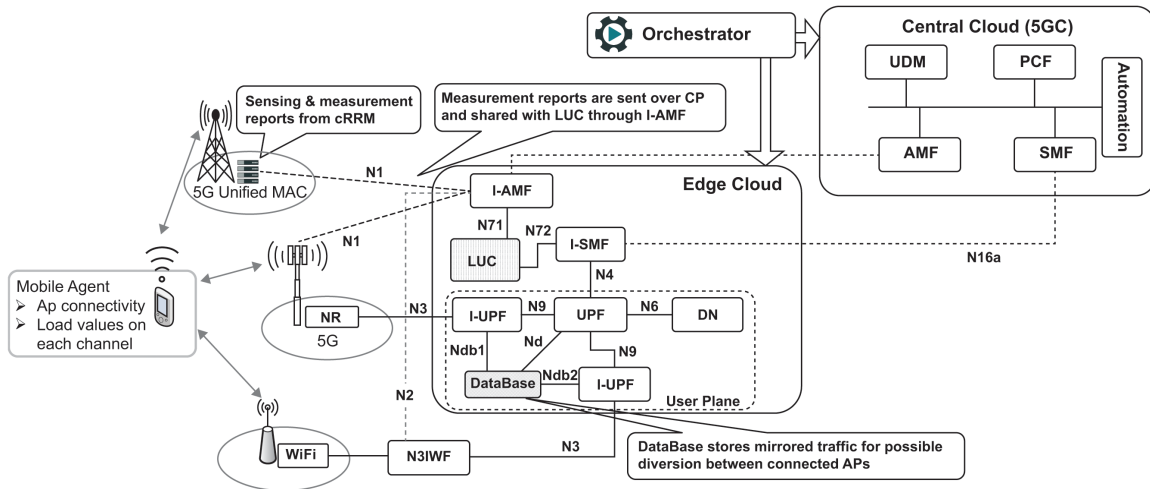


Figure 1—The framework for interfacing the LUC with 5GC network functions

4.2 Network function and interfaces

The 5G architecture shall be a service-based architecture (SBA), wherein a service-based representation of network functions within the control plane enables other authorized network functions to access their services, as specified in 3GPP TS 33.501.¹⁵ The licensed and unlicensed controller (LUC) may be deployed at over-the-top (OTT) additional network functions that comply with the SBA domain, including HTTP/2 as outlined in ETSI TS 129 500 and application programming interface (API) design principles, as outlined in 3GPP TS 29.501. The LUC network function shall operate and support the fifth generation core (5GC) operations as outlined in ETSI TS 123 501. In reference point interactions, the LUC interfaces shall be represented as point-to-point links with other 5GC network functions, as outlined in ETSI TS 123 501.

The proposed LUC-integrated 5G architecture describes several network functions, some of which will be detailed later in this document, including the following:

- Licensed and unlicensed controller (LUC)
- Access and mobility management function (AMF)
- Intermediate access and mobility management function (I-AMF)
- User plane function (UPF)
- Intermediate user plane function (I-UPF)
- Policy control function (PCF)
- Session management function (SMF)
- Unified data management (UDM)
- User equipment (UE)
- (Radio) access network ([R]AN)
- Application function (AF)
- Network exposure function (NEF)

¹⁵Information on references can be found in [Clause 2](#).

- Network repository function (NRF)
- Data network (DN), e.g., operator services, Internet access, or third-party services
- Unstructured data storage function (UDSF)
- Authentication server function (AUSF)
- Network slice selection function (NSSF)

The LUC shall use dedicated new interfaces to communicate with other 5GC NFs. These interfaces are defined as follows:

- N70: Interface between LUC and another LUC within the same domain
- N71: Interface between LUC and AMF
- N72: Interface between LUC and SMF
- N73: Interface between LUC and PCF
- N74: Interface between LUC and UDM
- N75: Interface between LUC and NSSF
- N76: Interface between LUC and network data analytics function (NWDAF)
- N77: Interface between LUC and NWDAF

The LUC may influence the amount of user plane traffic allocated to each access point (AP) in multi-connectivity mode, where the UE is able to perform downloading from multiple surrounding APs concurrently. The LUC decisions shall be determined using real-time measurement reports that may be obtained from either an agent installed at the UE or through the sensing mechanism of the common radio resource management (cRRM) in 5G unified media access control (MAC). The measurement reports can be sent over the N1 interface to the access and mobility management function (AMF) and then consumed by the LUC.

4.3 Enabling components

There are three prime component enablers for this standard as explained below:

- a) LUC NF
The LUC coordinates with other virtual functions to enable multi-connectivity process and traffic diversion between participant APs, as presented in [Clause 6](#).
- b) DataBase
Buffering mirrored traffic from various UPFs that support the multi-connectivity model, as described in [6.5.2](#).
- c) Measurement and reporting mechanisms
This component provides information on the availability and capacity status of each channel. There are two types of reporting systems, as follows:
 - 1) Mobile installed agent
The installation of this agent in the UE shall provide real-time status updates of the connected APs and available channels. This agent may be utilized in a distributed scenario where operator APs are located around the UE in a distributed model, as detailed in [7.3.1](#).
 - 2) Measurement and sensing module in cRRM

This module shall provide information on channel availability and connected UE within the base stations that employ multiple radio interfaces managed by 5G unified MAC technology. This module shall be integrated into the cRRM and can access the N1 interface, as presented in 8.4.3.

4.4 Associations

The LUC shall be a new entity of the SBA of the 5GC. The main functions and responsibilities of the LUC shall be:

- a) Managing the registration of topology for NFs and APs serving a multi-connectivity domain.
- b) Providing traffic forwarding by analyzing measurement reports obtained from the mobile agent and sensing module.
- c) Managing traffic through the session management function (SMF).

The LUC may provide services to the SMF and shall share analytics with the network data analytics function (NWDAF). The LUC can also exchange services with other network functions via SBA, as shown in Figure 2.

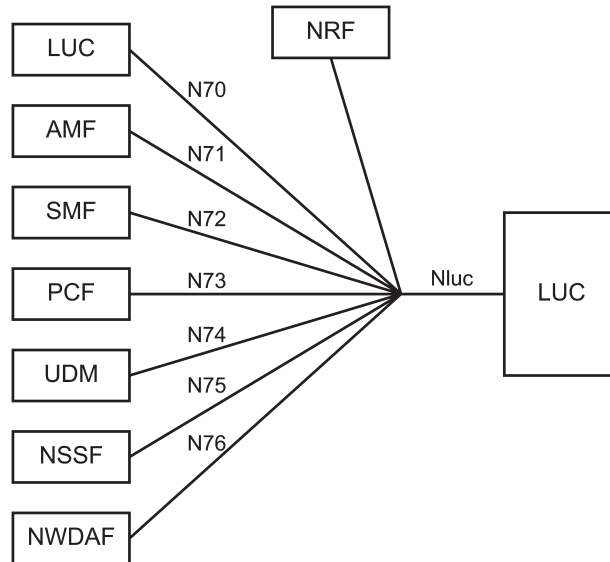


Figure 2—The LUC interfaces and association with 5GC NFs

Table 1 summarizes some of the services that LUC shall process with other core NFs.

Table 1—LUC network function services

NF	Network function service (NFS)	Description
LUC	Nluc_SMTopologyControl	The SMF may use this NFS for the selection of UPF serving the APs engaged in a multi-competitiveness model. This NFS shall provide the following key functions: — Since the APs topology may change at any time, the SMF shall act as the DHCP server to manage the call flows toward the UE. — The SMF shall instruct the PDU session anchor UPF serving the PDU session to forward DHCP packets between the UE and the SMF over the user plane, as specified in ETSI TS 123 501.
	Nluc_AMTopologyControl	The AMF may use this NFS to associate a certain UE profile with LUC. This NFS shall provide the following key functions: — The LUC shall generate the topology association based on the UE information provided by the AMF and shall deliver the policy association to the AMF. — Based on the provided topology, the LUC shall either maintain the current AMF or select a new AMF using information obtained from PCF. — If a topology change occurs, the LUC shall use this NFS to select a new AMF after policy updates with PCF.
	Nluc_UEPolicyControl	The LUC shall use this NFS to request a topology association with a certain set of policies from the PCF. This NFS shall provide the following key functions: — The PCF shall generate a set of policies based on the topology associated with the UE as provided by the LUC. — The LUC shall request policy updates from the PCF each time there is a change in the topology serving that UE. This update may include different sets of AMFs or SMFs. — The PCF may trigger a policy change that enforces changes to the LUC topology to meet the other requests from within the slice.

5. LUC topology registration and NF assignment

5.1 General

Once a request is received from the UE, the AMF shall perform the NAS encryption and user verifications with UDM. The following operations shall take place on the 5GC side during topology registration:

- The AMF shall abstract the measurement report (acquired from the UE or the sensing module on the 5G unified MAC) to identify all the available surrounding APs. This information shall be consumed by the LUC to generate the topology association.
- The LUC shall generate topology (e.g., topology [TO] #1) that shall be associated with UE identifiers (e.g., subscription permanent identifier [SUPI]). This topology, in this case, shall refer to the APs available for that UE.
- The LUC may obtain the available SMF NF from the NRF.
- The LUC shall inform the SMF to create the N4 interfaces and UPF mesh that can serve the AP topology (e.g., TO #). The SMF may establish the necessary interconnections with other NFs to ensure the proper functioning of the network.
- The standard mandates the use of the N4 interface for the communication between the SMF and the LUC. This interface shall be used to exchange information related to the UPF mesh and to provide any necessary updates. In case of any changes in the topology, the LUC shall inform the SMF, which may trigger updates in the network to ensure optimal performance.

The above procedure is shown in [Figure 3](#).

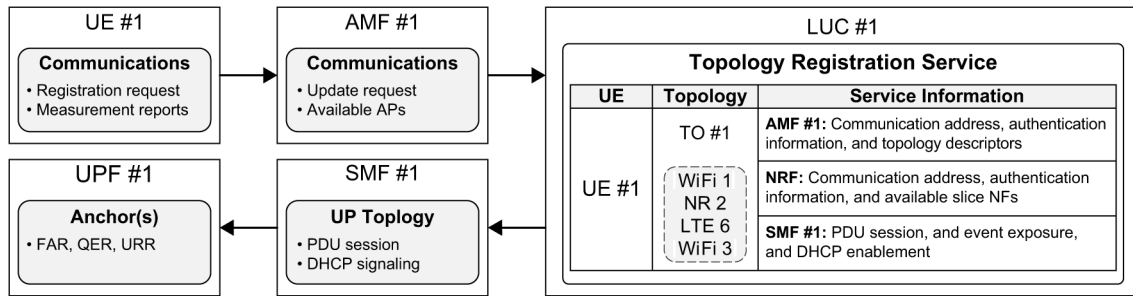


Figure 3—Topology registration and NF association

5.2 Topology update

The topology update shall occur when any of the following events take place:

- The UE moves away from its current domain, and connectivity with one or more surrounding APs is lost.
- One or more connected WiFi networks become unavailable due to changes in channel availability.
- One or more UPFs become faulty, triggering lifecycle transitions at the core side.
- For events a) and b), the AMF shall obtain the topology change from the measurement reports. In the case of event c), the SMF shall provide the topology update.

If a topology update is necessary, the LUC shall perform the following operations:

- The LUC shall remove the impacted AP(s) from the list of available APs in the topology.
- The updated topology information shall be published and made available to the AMF, SMF, and NRF NFs.
- The SMF shall update the N4 interface to provide connectivity to the new UPF(s).

Note that in the event of a topology update, the LUC shall promptly initiate the necessary changes to ensure the smooth operation of the network.

5.3 Topology deletion

The LUC shall remove the created topology if one of the following events occurs:

- The UE request is completed, and resources shall be released for other users.
- Only one AP remains in the topology, and LUC can transfer the connectivity management to AMF.
- The UE moves to another domain and loses connectivity with APs associated with the topology.
- The connected UE switches to private network mode.

The LUC shall perform the following operations when the topology is removed:

- The LUC shall detach all APs.
- The LUC shall inform the SMF to detach all UPFs and terminate any PDU sessions.

- The LUC shall inform the AMF and NRF about NFs dissociations.

6. Licensed and unlicensed controller (LUC)

6.1 General

In multi-connectivity mode, the LUC is responsible for managing the establishment of PDU sessions between the UE and the SMF. To accomplish this, the LUC shall invoke the Nsmf_PDUSession service of the SMF, as shown in Figure 4, which provides the necessary functionality for establishing and maintaining PDU sessions.

In some cases, the LUC may not know which SMF to connect to in order to establish the PDU session. In these situations, the LUC may request the SMF to perform a service discovery to identify an SMF that can provide the necessary service. The service discovery process involves sending a request to the NRF to obtain information about the available SMFs and their capabilities. Once the LUC has identified the appropriate SMF, it shall use the Nsmf_PDUSession service to establish the PDU session. The service provides a range of functions, including the establishment of bearers, the allocation of resources, and the management of session states.

It is important to note that while the LUC shall invoke the Nsmf_PDUSession service during PDU session establishment, it may also need to interact with other NFs to ensure the proper functioning of the overall network. For example, the LUC may need to coordinate with the AMF to ensure the proper management of UE context and mobility, or with the UPF to manage data traffic and quality of service (QoS) requirements.

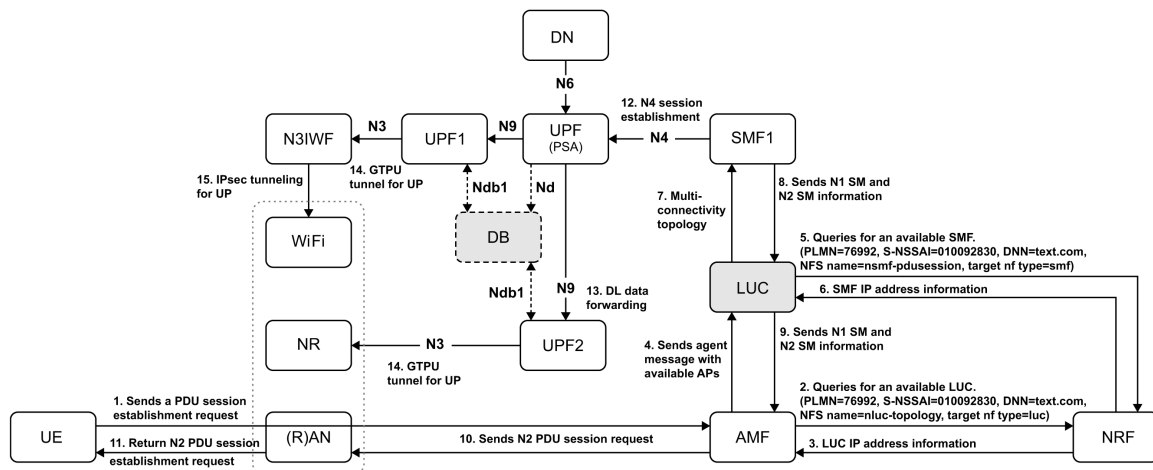


Figure 4—Enforcing topology by LUC

The PDU session establishment procedure shall be performed as follows:

- A UE shall send a PDU session establishment request message to the AMF. The message may include a measurement report, DNN, and the subscribed network slice selection assistance information (S-NSSAI).
- The AMF shall determine the multi-connectivity mode based on the presence of multi-APs Internet protocols (IPs) in the measurement report. If multi-connectivity mode is required, the AMF shall invoke a topology request to the LUC.
- The LUC shall create a topology file that lists all available APs for the multi-connectivity mode. The LUC may query the NRF for available SMFs. The query request shall contain the DNN, type of the

requester NF, requested public land mobile network (PLMN), target NFS name, S-NSSAI, and target NF type.

- d) If all the SMFs registered on the NRF support the Nsmf_PDUSession service, the NRF shall select an available SMF based on the DNN and S-NSSAI in the request and shall return the SMF IP address and endpoint information about the Nsmf_PDUSession service to the AMF, as shown in Figure 4.
- e) The LUC shall invoke the Nsmf_PDUSession service of the SMF to establish a PDU session.
- f) The SMF shall initiate an N4 session establishment procedure toward the selected UPF.
- g) The SMF shall notify the AMF through LUC of the N2 session management information and the N1 session management information.
- h) The AMF shall send an N2 PDU session request message to the RAN to request the RAN to allocate the N3 tunnel access network address and radio resources.
- i) The RAN shall forward the PDU session establishment response to the UE. The PDU session shall be established successfully.

6.2 Specifications

6.2.1 General

The following subclauses shall provide a summary of the compliance and functionality of the LUC network function within the 5GC.

6.2.2 Compliance with 5GC

The new LUC NF shall comply with the specification outlined in ETSI TS 123 501 and other security features mandated by the 5GC design, such as TLS1.3 as explained in 6.7. The LUC NF shall utilize service-based interfaces (SBIs) and access control plane (CP) information through predefined interfaces in the reference point architecture or via the message bus in the SBA model.

Specifically, the LUC NF shall:

- a) Register with the NRF responsible for managing the core, slice, or PLMN upon instantiation
- b) Send status update messages to the NWDAF of the slice, PLMN, or cluster
- c) Subscribe to multiple NFs (AMF, UDM, SMF, etc.) to consume services required for creating the topology to support multi-connectivity for a specific UE
- d) Serve multiple UEs and provide service coordination based on location, domain, or any other use case defined by the system administrator
- e) Act as a complementary component to the 5GC, managing complex networks and reducing signaling and status update activities in the CP domain

6.2.3 Control and user planes

The LUC NF shall be responsible for coordinating the UP services provided to a certain UE in a multi-connectivity model via the SMF NF. The LUC shall maintain a registry of UPFs associated with the multi-connectivity model. This implies that a certain LUC NF shall obtain the identity of UPFs that provide the service in a multi-connectivity model.

- a) The UPFs shall be chained as an anchor UPF with multiple I-UPFs that are meshed to distribute traffic to multiple APs.