

Wireless Convergence

5G Wireless Wireline Converged Core Architecture Technical Report

WR-TR-5WWC-ARCH-V01-190820

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1 SCOPE

1.1 Motivations for Convergence

Operators compete across industries to provide revenue-generating services to their subscribers. Mobile operators are purchasing content and wireline assets, and MSOs are launching or expanding mobile services. The ecosystem response includes exploring the convergence of services, policy, and networks across wireless and wireline domains. The 3GPP R16 5G mobile core includes Wireless Wireline convergence requirements as documented in [3GPP 23.316]. Other industry groups such as the Next Generation Mobile Network (NGMN) Alliance, Wireless Broadband Alliance (WBA), and Broadband Forum (BBF) also have active work in convergence. (See the references [BBF 5GC], [WBA 5G], and [WBA RAN].) To help address the question of whether CableLabs members can benefit from these ecosystem trends towards converged core networks, this document summarizes work within CableLabs on converged cores for wireline and wireless networks. It also identifies requirements for interworking between the 5G core (5GC) and hybrid fiber-coax (HFC) networks.

There are multiple potential motivations for the convergence of core networks supporting wireline and wireless access. Convergence may be a strategic initiative, in which the network evolves towards convergence over time in incremental steps. A converged core may be able to avoid overlapping functions within the network and therefore reduce long-term capital expenditures or operating expenses (CAPEX or OPEX). For example, operators may deploy a converged subscription store rather than a subscription store per access. Convergence may also enable operators to more consistently deliver services and execute policy. Operators have identified several use cases that a converged core must support, as described in Section 8 of this document.

1.2 Elements of Convergence

Motivations for convergence can lead to several initiatives:

- convergence of services and applications,
- convergence of policy, and
- convergence of core networking.

A convergence of services, applications, and policy is essential to the delivery of a consistent user experience regardless of access network. To this end, operators need to have methods to service each user device, including devices behind the residential gateway. Otherwise, convergence may be incomplete, with variable service and segmented policy. (Note that services to Internet of things [IoT] devices are identified for future work.)

3GPP, the BBF, and CableLabs are considering convergence aspects at the core networking layer, an important step towards a complete converged architecture. This level of convergence concerns topics such as subscriptions for network access and policy for traffic management within the mobile core network. 3GPP release 16, scheduled to be finalized in March 2020, addresses this level of core convergence in support of a residential gateway (RG). The scope of this work is focused on linking the RG to the 5GC. It does not provide a complete solution for delivering services to individual devices in the home, but that may be a topic for 3GPP release 17.

Certain stakeholders are considering over-the-top approaches to deliver services and policies to subscriber devices regardless of wireline or wireless access network. This strategy may allow operators to deploy converged services and policy with less dependency upon standards initiatives oriented to specific access networks or without bias towards one access network over another. The Apple ecosystem might be considered an example of a non-standard over-the-top convergence play, achieving a consistent service policy and experience delivery regardless of access network (Wi-Fi vs LTE) serving the iPhone. A forum to develop over-the-top convergence has not yet emerged.

1.3 Scope of This Release

The present scope of this technical report is focused on core convergence leveraging the 3GPP R16 5G converged core network specifications, particularly the convergence requirements for interworking between the 3GPP R16 5G mobile core and the HFC access network.

- Section 5 identifies architectures for convergence.
- Sections 6 and 7 include focus areas and requirements for convergence.
- Section 8 describes member use cases for convergence, which are mapped to convergence requirements in Section 9.
- Section 9 maps use cases to requirements contained in 3GPP specifications and this document. Gaps in 3GPP specifications to support the use cases are also identified.
- Section 10 identifies areas for future work (such as identifying features that could be included in the 3GPP R17 mobile core and support for additional use cases).
- Section 11 describes CableLabs engagement in the 3GPP wireless-wireline convergence work item.

2 REFERENCES

This report uses the following informative references. References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific. For a non-specific reference, the latest version applies.

[3GPP 23.316]	3GPP Technical Specification 23.316, Wireless and Wireline Convergence Access Support for the 5G System (5GS)
[3GPP 23.501]	3GPP Technical Specification 23.501, System Architecture for the 5G System (5GS)
[3GPP 23.502]	3GPP Technical Specification 23.502, Procedures for the 5G System (5GS)
[3GPP 23.503]	3GPP Technical Specification 23.503, Policy and Charging Control Framework for the 5G System (5GS); Stage 2
[3GPP 24.501]	3GPP Technical Specification 24.501, Non-Access-Stratum (NAS) Protocol for 5G System (5GS); Stage 3
[3GPP 26.891]	3GPP Technical Report 26.891, 5G Enhanced Mobile Broadband; Media Distribution
[3GPP 29.500]	3GPP Technical Specification 29.500, 5G System; Technical Realization of Service Based Architecture; Stage 3
[3GPP 29.503]	3GPP Technical Specification 29.503, 5G System; Unified Data Management Services; Stage 3
[3GPP 29.507]	3GPP Technical Specification 29.507, 5G System; Access and Mobility Policy Control Service; Stage 3
[3GPP 29.512]	3GPP Technical Specification 29.512, 5G System; Session Management Policy Control Service; Stage 3
[3GPP 29.531]	3GPP Technical Specification 29.531, 5G System; Network Slice Selection Services; Stage 3
[3GPP 38.413]	3GPP Technical Specification 38.413, NG-RAN; NG Application Protocol (NGAP)
[3GPP 38.414]	3GPP Technical Specification 38.414, NG-RAN; NG Data Transport
[BBF 5GC]	BBF 5G Fixed Mobile Convergence White Paper, submitted to 3GPP and available for download here: https://www.3gpp.org/ftp/tsg_sa/WG2_Arch/TSGS2_129BIS_West_Palm_Beach/Docs/S2-1811672.zip
[WBA 5G]	Wireless Broadband Alliance, Unlicensed Integration with 5G Networks, October 2018, https://wballiance.com/wp-content/uploads/2018/10/Unlicensed-Integration-with-5G-Networks.pdf
[WBA RAN]	Wireless Broadband Alliance, RAN Convergence, January 2019, https://wballiance.com/wp-content/uploads/2019/01/RAN-Convergence-Paper-2019.pdf
[VPI]	Virtual Provisioning Interfaces Technical Report, VNE-TR-VPI-V01-170424, April 24, 2017, Cable Television Laboratories, Inc.
[MULPI]	DOCSIS® 3.1 MAC and Upper Layer Protocols Interface Specification, CM-SP-MULPIV3.1-I18-190422, April 22, 2019, Cable Television Laboratories, Inc.
[PCMM]	PacketCable Multimedia Specification, PKT-SP-MM-I07-151111, November 11, 2015, Cable Television Laboratories, Inc.
[MANO]	ETSI Group Specification (GS) NFV-MAN 001, Network Functions Virtualisations (NFV); Management and Orchestration

2.1 Reference Acquisition

- Cable Television Laboratories, Inc., 858 Coal Creek Circle, Louisville, CO 80027; Phone +1-303-661-9100; Fax +1-303-661-9199; <http://www.cablelabs.com>
- Internet Engineering Task Force (IETF) Secretariat, 46000 Center Oak Plaza, Sterling, VA 20166, Phone +1-571-434-3500, Fax +1-571-434-3535, <http://www.ietf.org>
- 3GPP, www.3gpp.org
- Broadband Forum (BBF), <https://www.broadband-forum.org/>
- Wireless Broadband Alliance (WBA), <https://www.wballiance.com/>

3 TERMS AND DEFINITIONS

This document uses the following terms.

convergence integration	The wireline customer premises equipment (CPE) appears as a user-equipment signaling endpoint to the 5G mobile core, supporting the potential of a single core network to serve HFC, Wi-Fi, LTE, and 5G NR networks.
convergence interworking	Interworking between the HFC network and 5G mobile core is placed within the network, allowing legacy customer premises equipment (CPE) to operate with a converged core network.

4 ABBREVIATIONS AND ACRONYMS

This document uses the following abbreviations.

5G-CRG	5G Cable Residential Gateway
5GC	5G Core
5GCAN	5G Cable Access Network
5QI	5G QoS Identifier
AF	Application Function
AGF	Access Gateway Function
AKA	Authentication and Key Agreement
AMBR	Aggregate Maximum Bit Rate
AMF	Access and Mobility Management Function
AN	access network
AP	access point
ARP	Allocation and Retention Priority
ATSSS	Access Traffic Steering, Switching, and Splitting
BWR	Bandwidth Report
CCAP	Converged Cable Access Platform
CDN	content delivery network
CHF	charging function
CM	cable modem
CMTS	cable modem termination system
COPS	Common Open Policy Service [Protocol]
CP	control plane
CPE	customer premises equipment
CRG	Cable Residential Gateway
CS	circuit switched
DL	downlink
DNAI	Data Network Access Identifier
DNN	Data Network Name
EAP	Extensible Authentication Protocol
EAP-TLS	EAP Transport Layer Security
EAP-TTLS	EAP Tunneled Transport Layer Security
eDVA	embedded digital voice adapter
eMBB	enhanced mobile broadband
eMTA	embedded multimedia terminal adaptor
FN-CRG	Fixed Network Cable Residential Gateway
GBR	guaranteed bit rate
GFBR	guaranteed flow bit rate
GPRS	General Packet Radio Service
GPSI	Generic Public Subscription Identifier
GTP	GPRS Tunneling Protocol

HFC	hybrid fiber-coax
ID	identifier
IGMP	Internet Group Management Protocol
IMEI	International Mobile Equipment Identifier
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IoT	Internet of things
IP	Internet Protocol
IPTV	IP television
LAN	local area network
LTE	Long Term Evolution
MA PDU	Multi-Access PDU
MAC	Media Access Control
MIoT	massive Internet of things
MSO	multiple system operator
NAS	Non-Access Stratum
NFV	network function virtualization
NGAP	Next Generation Application Protocol
NR	New Radio
NSSAI	Network Slice Selection Assistance Information
NSSF	Network Slice Selection Function
N3IWF	Non-3GPP InterWorking Function
PCC	Policy and Charging Control
PCF	Policy and Control Function
PCMM	PacketCable Multimedia
PCRF	Policy and Charging Rules Function
PDB	Packet Delay Budget
PDU	Packet Data Unit
PEI	Permanent Equipment Identifier
PFCP	Packet Forwarding Control Protocol
PHY	physical
PLMN	Public Land Mobile Network
PS	packet switched
QNC	QoS Notification Control
QoS	quality of service
RAN	radio access network
RAT	Radio Access Technology
REST	Representational State Transfer
RFSP	Radio Frequency Selection Priority
RG	residential gateway
Rx	receiver
SBI	Service Based Interface

SCTP	Stream Control Transmission Protocol
SDN	software-defined networking
SIM	subscriber identity module
SIP	Session Initiation Protocol
SM	session management
SMF	Session Management Function
SSC	session and service continuity
SST	Slice Service Type
STB	set-top box
SUCI	Subscriber Concealed Identifier
SUPI	Subscriber Permanent Identifier
TCP	Transmission Control Protocol
TDD	time-division duplex
TLS	Transport Layer Security
UDM	Unified Data Management
UDP	User Datagram Protocol
UE	user equipment
UL	uplink
UP	user plane
UPF	User Plane Function
URLLC	ultra-reliable low-latency communications
URSP	UE Route Selection Policy
VLAN	virtual LAN
VOD	video on demand
VoLTE	Voice over LTE
Vo5G	Voice over 5G
VPI	Virtual Provisioning Interface
VPN	virtual private network
vRAN	virtual RAN
vSRVCC	Single Radio Video Call Continuity
W-5GCAN	Wireline 5G Cable Access Network
W-AGF	Wireline Access Gateway Function
W-CP	Wireline Control Protocol
WAG	wireline access gateway
WAN	wireline access network

5 CONVERGED ARCHITECTURE WITH THE 3GPP 5G CORE

Three 3GPP architectural models for convergence are considered in this document:

- 3GPP R16 interworking model as defined in [3GPP 23.316],
- 3GPP R16 integration model as defined in [3GPP 23.316], and
- Bridged residential gateway (RG) with convergence of services and policy to devices, planned for 3GPP R17.

3GPP has identified reference architecture diagrams for the interworking and integration models of convergence; they are shown in Figure 1 and Figure 2, respectively. The following hybrid fiber-coax (HFC) network components are portrayed in the 3GPP reference architectures.

- The FN-CRG (Fixed Network Cable Residential Gateway) is, at minimum, the cable modem (CM) customer premises equipment (CPE). It may include a Wi-Fi access point (AP), a voice eMTA (embedded multimedia terminal adapter), or a video set-top box (STB), but the primary focus of convergence is the HFC-based broadband Internet service.
- The 5G-CRG (5G Cable Residential Gateway) adds the 3GPP 5G control plane to the RG so that the RG appears as both a 5G user equipment (UE) and an HFC CM.
- The W-5GCAN (Wireline 5G Cable Access Network) combines the HFC infrastructure, primarily the cable model termination system (CMTS), with the W-AGF interworking function. The W-5GCAN may also include CM initialization servers, PacketCable Multimedia (PCMM) interfaces, and IP address management components.
- The W-AGF (Wireline Access Gateway Function), as identified by 3GPP, is a layer of interworking capabilities between the HFC network and the 5G mobile core infrastructure. It is contained within the W-5GCAN.

5.1 3GPP R16 Interworking Model of Convergence

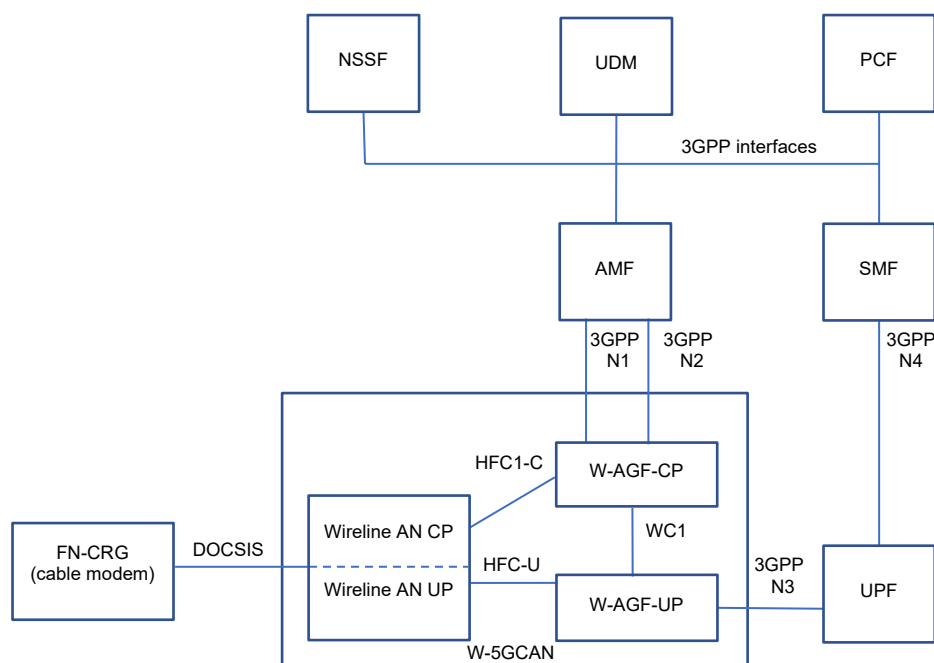


Figure 1 - Interworking Model of Convergence Block Diagram

The interworking model for convergence as depicted in Figure 1 places interworking and translation functions between the 5G core (5GC) and the HFC network within network infrastructure. There is no impact to deployed CPE and no change to CM authentication and network admission. This method provides a means for operators to immediately realize benefits from a shared core while using legacy CMs. It also provides an orderly migration step towards the integrated model of convergence described in Section 5.2.

The HFC network interfaces to the Access and Mobility Management Function (AMF) over the 3GPP N1 and 3GPP N2 reference points per [3GPP 23.501]. The N1 reference point supports UE authentication and network admission signaling, with the 3GPP Non-Access Stratum (NAS) protocol profiled for fixed CPE. The N2 reference point to the AMF carries access network control messaging as specified by 3GPP. This control messaging is translated by the interfaces between the W-AGF and CMTS. The HFC network also needs to support an N3 user plane (UP) reference point (also per [3GPP 23.501]) to the User Plane Function (UPF), which requires 3GPP-specified tunneling. The W-AGF acts as a 5G UE on behalf of the CM CPE in the interworking model. It manages registration into the 5GC, data session management, and slice selection on behalf of the CPE.

The wide area network side interfaces at the CMTS may include vendor-proprietary protocols and interfaces in practical deployments. Therefore, the convergence interworking layer interfaces to the CMTS may be vendor proprietary, whereas the interfaces to the 3GPP 5GC are open-standard interfaces capable of multi-vendor interoperability. Requirements are placed upon the interworking layer interfaces throughout this document. References to 3GPP specifications are made for 5GC interfaces and capabilities.

5.2 3GPP R16 Integration Model for Convergence

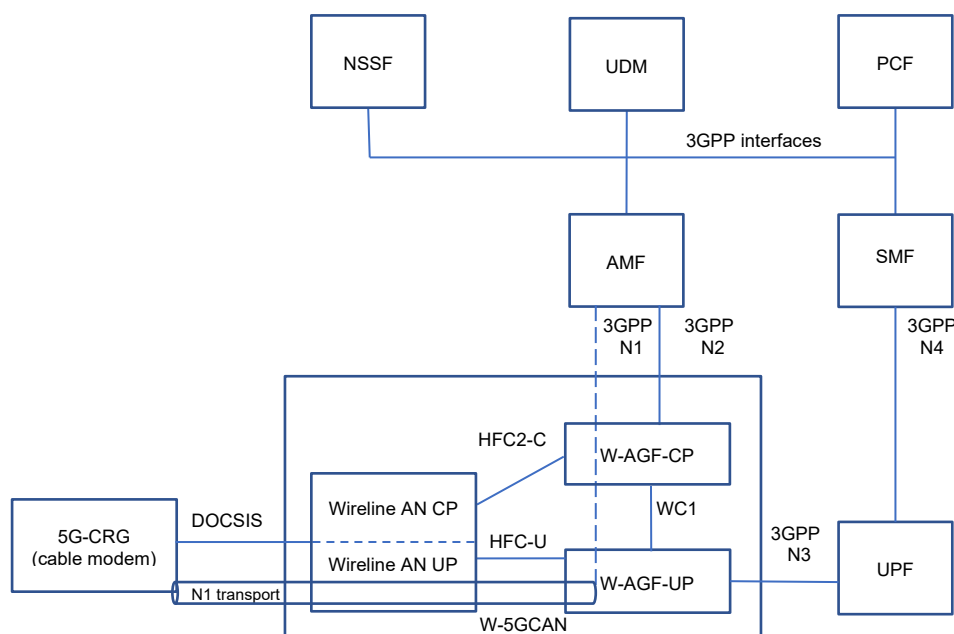


Figure 2 - Integrated Model of Convergence Block Diagram

The integrated model as depicted in Figure 2 places 3GPP 5G network functions throughout the HFC access network in order to support the promise of a single core across access networks. The CPE appears as a 5G UE to the 5GC. This model is also better prepared to support a fuller range of 3GPP features. The 5G control plane (CP) (the N1 interface per [3GPP 23.501]) is transported transparently through the wireline network between the CPE and the 5GC.

Figure 3 illustrates the protocol stacks on the 3GPP reference points for the integrated model. The 3GPP NAS protocol is supported by the CM and is transported through the HFC network to the 3GPP AMF. The NAS protocol is encapsulated in EAP-5G (identified in [3GPP 23.501]) over the DOCSIS[®] protocol until the CPE is authenticated. After a security association is established, the NAS protocol is carried over TLS between the 5G-CRG and the

W-AGF. The combined use of EAP-5G over the DOCSIS protocol and TLS is depicted as the Wireline Control Protocol (W-CP) in Figure 3. See [3GPP 23.316] for a detailed message flow of the process and protocols. The N1 reference point includes the 3GPP NAS protocol. The N2 reference point includes the 3GPP NGAP protocol. The N3 UP reference point employs 3GPP GTP tunneling. The N4 CP-to-UP interface employs 3GPP-defined Packet Forwarding Control Protocol (PFCP). The Service Based Interfaces (SBIs) in the 5GC are specified between the AMF, PCF (Policy and Control Function), and SMF (Session Management Function).

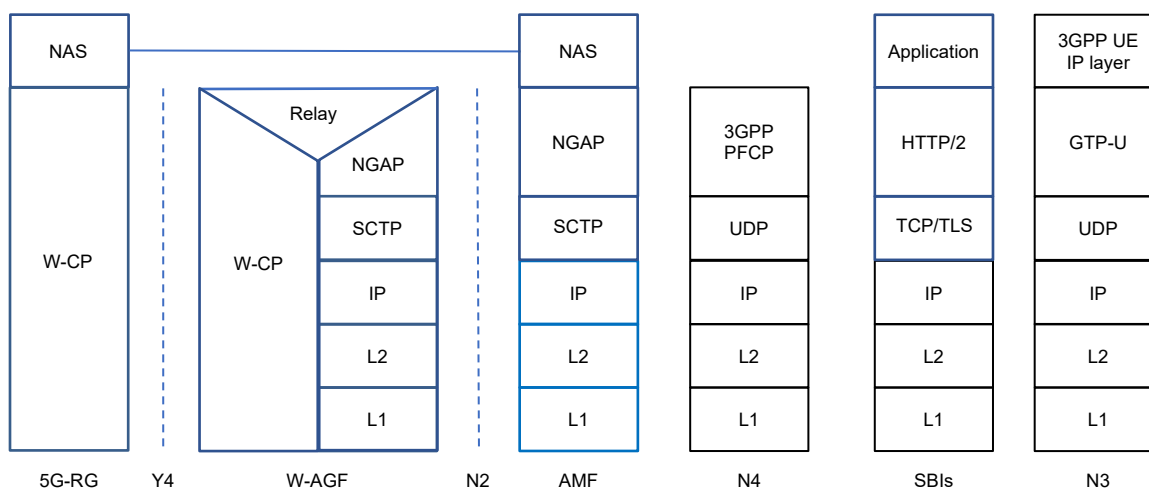


Figure 3 - Protocol Stacks for 5G Converged Core

5.3 Bridged CRG with Convergence of Services and Policy

Figure 4 below illustrates the bridged CRG connected to a 5GC with converged services and policy for devices behind a residential gateway. This CRG may take the form of the FN-CRG or 5G-CRG and also operates in bridged mode as part of a strategy to support the 5G converged core by applying policy, addressing, and services to individual devices. Layer 2 traffic is sent between the user devices and 5G UPF via the CRG and HFC network. The UPF assists in providing visibility of user devices in the 5GC with access router functions. In this way, the 5GC can help assign IP addresses to the user devices. Policy can be applied to each user device via the PCF and SMF control at the UPF. Applications can also influence traffic management to the user devices via the SMF. Converged 5G CP and UP services to both mobile devices and local devices in the residence are delivered via the bridged CRG.

Several enhancements to the R16 converged 5GC are needed to realize this architecture:

- procedures to admit and connect widely available user devices that do not necessarily support 3GPP credentials or 3GPP signaling, such as Wi-Fi-only laptops, into the 5GC,
- procedures for traffic management for widely available user devices via the 5GC, and
- procedures to apply converged policy to user devices with a common policy platform for mobile and fixed network user devices.

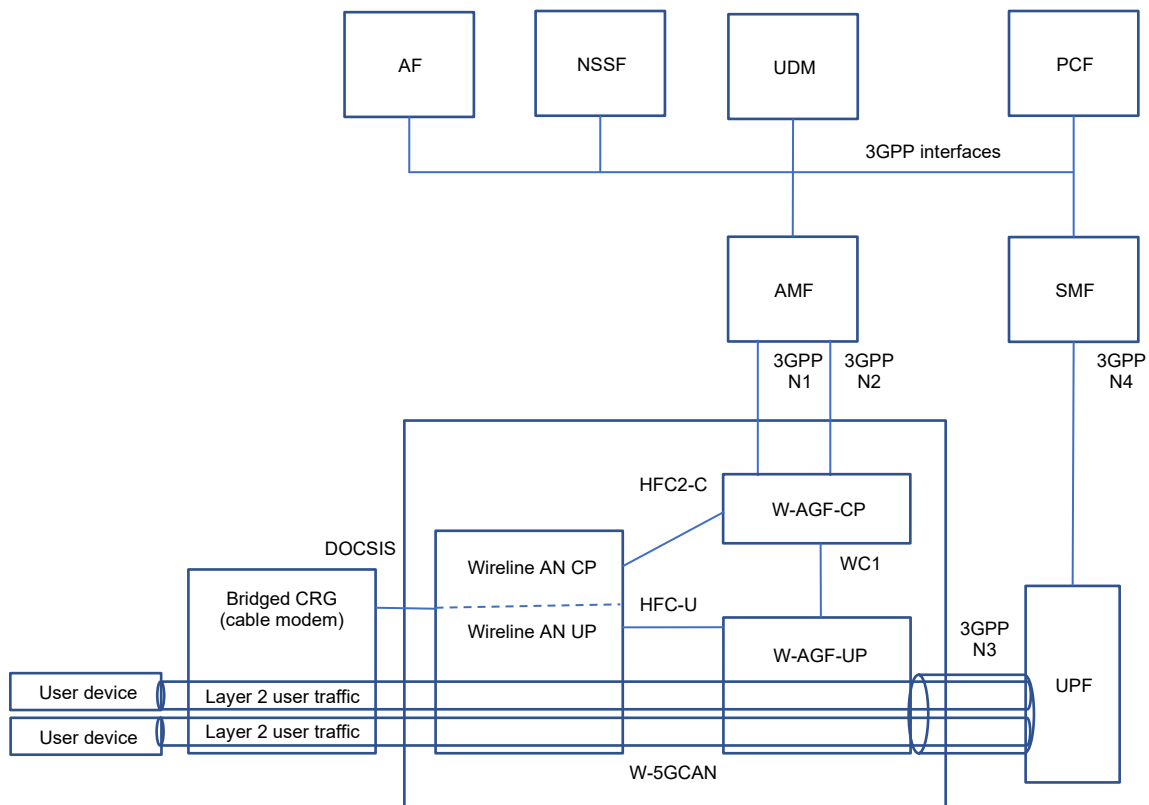


Figure 4 - Bridged CRG for Convergence of Services and Policy

6 CONVERGENCE FOCUS AREAS

6.1 Subscriptions, Authentication, and Admission

The following subsections describe converged subscriptions, which are held within the 5GC Unified Data Management (UDM) network element.

6.1.1 Integration Model Subscription

Wireline CPE appears as 3GPP UEs to the 5GC within the integration model of convergence. More specifically, a wireline CPE that also supports a 3GPP air interface is assigned an International Mobile Subscriber Identity (IMSI) subscription ID and subscription profile, supports Authentication and Key Agreement (AKA) authentication procedures, and is subject to network admission processes similar to the 3GPP UE. The combination of wireline and 3GPP air interfaces is known as a hybrid CPE configuration. A wireline-only CPE may support a variety of operator-determined EAP methods within 3GPP NAS signaling.

The service set reflected in the CPE subscription is relevant to wireline applications such as HFC broadband Internet. Fixed-line voice may leverage the same IP Multimedia Subsystem (IMS) and application subscription elements as Voice over 5G (Vo5G), but this will require eMTA and IMS application server updates from legacy PacketCable systems.

The detailed integrated model subscription profile for wireline CPE is contained within 3GPP R16 specifications.

6.1.2 Interworking Model Subscription

The converged subscription within the UDM for the interworking model links HFC legacy subscription parameters with 5G New Radio (NR) subscriptions. Whereas a mobile 5G NR subscription supports a single person or device, an HFC legacy subscription typically supports a household or enterprise. Therefore, a converged subscription for the interworking model may need to link multiple mobile subscriptions to a single HFC subscription to provide a consistent set of services and user experience across wireline and wireless access networks. Figure 5 illustrates a single HFC subscription being linked to multiple mobile device subscriptions. The wireline portion includes HFC broadband Internet and IPTV (IP television) portions. A base HFC subscriber ID is listed. Certain MSOs may use an HFC account ID per [VPI] as a base subscriber ID, whereas others may use a CM MAC address per [MULPI]. When a CM is authenticated, initialized, and admitted for service using legacy methods, the CM MAC address is listed as registered in the UDM. Similarly, when an STB is authenticated, initialized, and admitted for service using legacy methods, the STB MAC address is listed as registered in the UDM.

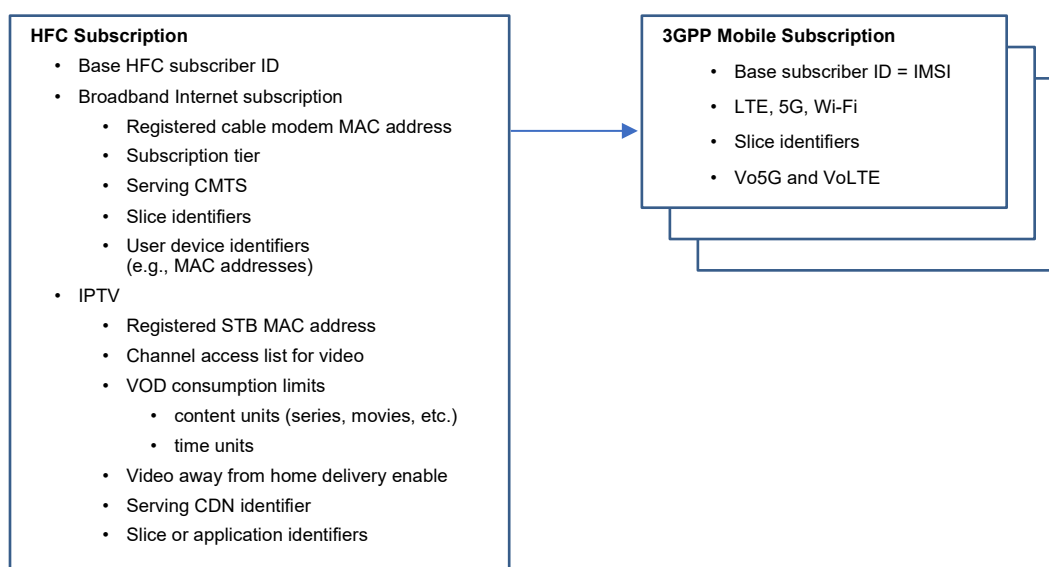


Figure 5 - Subscription Attributes for Convergence Interworking

User devices within the home may also be linked to an HFC subscription for their active registration period. Devices may be identified by MAC addresses. These device identifiers persist across CM registrations only if they are registered into the 5GC by the operator or via a subscriber portal. Note that the inclusion of the user devices in the subscribed service is a topic of 3GPP R17.

Cellular subscription profiles for 5G NR, LTE, and Wi-Fi are contained in the mobile subscription(s), which may be linked to an HFC subscription for the same account. The cellular subscription profile is defined in 3GPP specifications for the UDM and subscription data model.

The 5GC identifies a subscription with the 3GPP Subscriber Permanent Identifier (SUPI). For HFC subscriptions, the SUPI may contain a CM MAC address or an overall HFC account ID.

Figure 6 provides a high-level illustration of the CM registration process. Legacy CM and CMTS processes are used to admit the CM onto the network. The registered CM MAC address is posted in the UDM. The simplified AMF for wireline access shown may be integrated into the HFC infrastructure or instantiated as a separate network element. The result of a successful CM registration is admission of the CM into the converged HFC and 5GC network. A DOCSIS service flow is established for wireline user traffic.

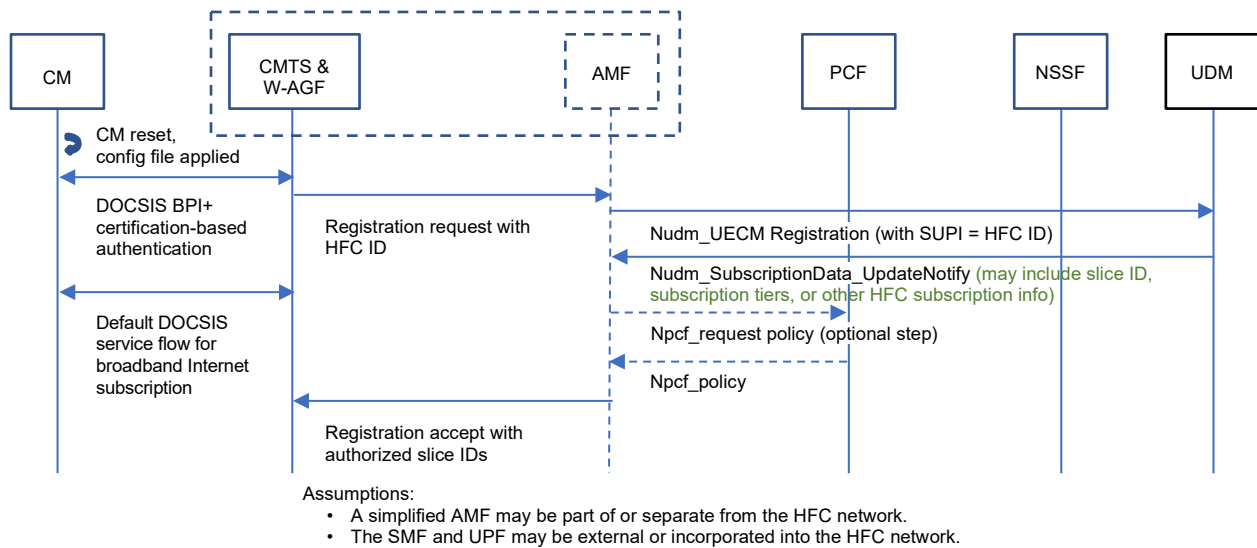


Figure 6 - High-Level Cable Modem Registration Message Flow

6.1.2.1 Voice Services and the Interworking Model

Legacy PacketCable 1.5 and PacketCable 2.0 (IMS) systems use call models and telephony feature sets that are different from those used in Voice over LTE (VoLTE) or Vo5G systems. The PacketCable 2.0 system leverages the 3GPP IMS core components with a PacketCable 2.0-specific Telephony Application Server and eMTA (eDVA, embedded digital voice adapter). Therefore, a single IMS set of core SIP proxies might be leveraged across Vo5G and PacketCable 2.0 systems. However, legacy PacketCable 2.0 CPE will still need to be supported with the PacketCable 2.0 application server. Certain vendor products may be able to execute both PacketCable 2.0 and Vo5G features on a single IMS platform.

6.2 Traffic Bonding and Traffic Switching

6.2.1 3GPP ATSSS, Hybrid Devices, and Hybrid CPE

This section describes the establishment of data sessions capable of supporting traffic bonding and traffic switching among access networks. This process can include scenarios in which traffic flows are delivered to the subscriber device over HFC and 5G NR network segments to a hybrid CPE that incorporates both a CM and 3GPP NR. Operators may also choose to use ATSSS (Access Traffic Steering, Switching, and Splitting) to aggregate 5G NR and Wi-Fi traffic flows on an ATSSS-capable mobile device and to use ATSSS traffic switching to provide highly

available services to hybrid CPE. ATSSS, a 3GPP 5GC feature, is used as the basis for traffic flow management in these multi-segment scenarios. Per 3GPP specifications, the ATSSS feature is executed by a single SMF and UPF combination to manage the multiple traffic legs over wireless and wireline networks. The ATSSS feature will require the HFC access network to interface to an SMF and UPF that also interface to the 5G NR network. The ATSSS traffic management and bonding configuration for the UE is sent during multi-access data session establishment. Figure 7 illustrates the use of traffic bonding to a subscriber CPE that bonds, or aggregates, traffic flows over the HFC and 5G NR network. 3GPP R17 plans to incorporate LTE into enhanced ATSSS services.

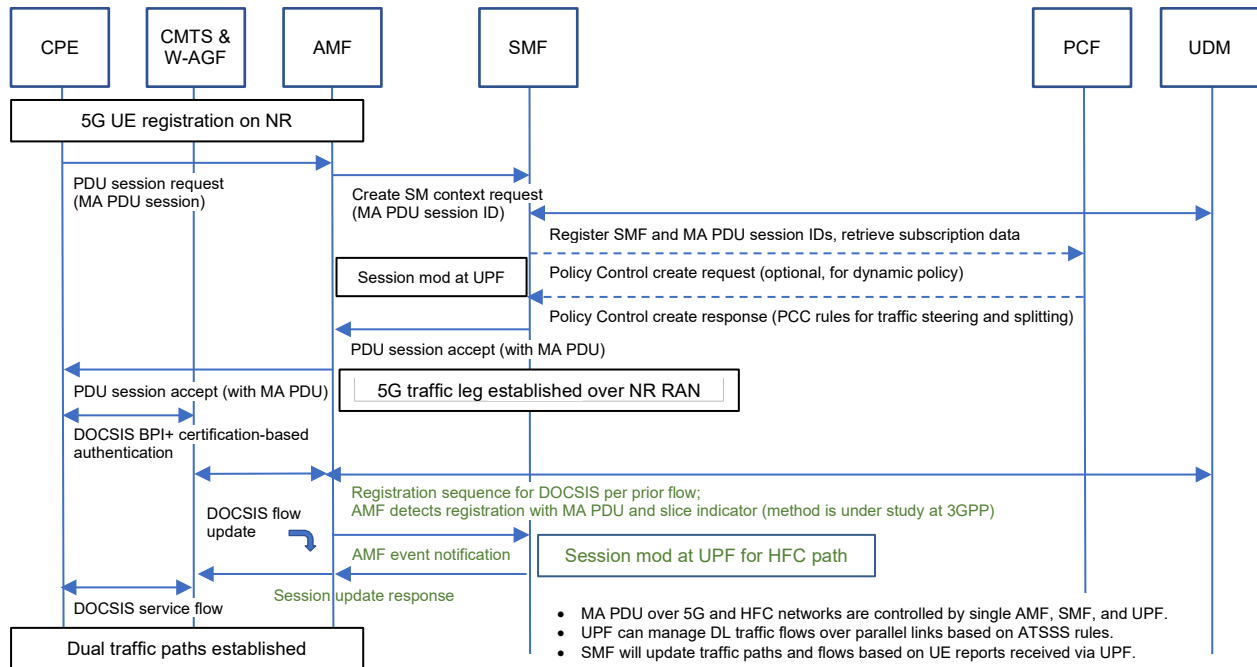


Figure 7 - Traffic Bonding over Wireline and Wireless with ATSSS for the Hybrid CPE

6.2.2 3GPP Session and Service Continuity (SSC)

3GPP R15 includes session and service continuity (SSC) capabilities in three modes of operations, listed below. The data service characteristics and SSC mode chosen for a data session depend on the application.

In SSC1, the network preserves the connectivity service provided to the UE, as well as the UE IP address assigned to the data session.

In SSC2, the network releases the connectivity service delivered to the UE as well as the data session(s) when the UE moves across networks. IP addresses are not preserved. Given this break in data sessions and connectivity, it is expected that the higher level application layer will play a substantial role in maintaining continuous service.

In SSC3, changes to the user plane are visible to the UE, but connectivity to the UE is not lost. The UE IP address is not preserved, but the prior IP address/prefix is maintained for some time after the new IP address on the new access network is assigned. The timeframe for preserving the prior IP address is indicated to the UE via NAS signaling. Therefore, SSC3 can help provide a continuous user experience for applications capable of withstanding IP address changes. The message flow diagram in Figure 8 provides an overview of SSC3.

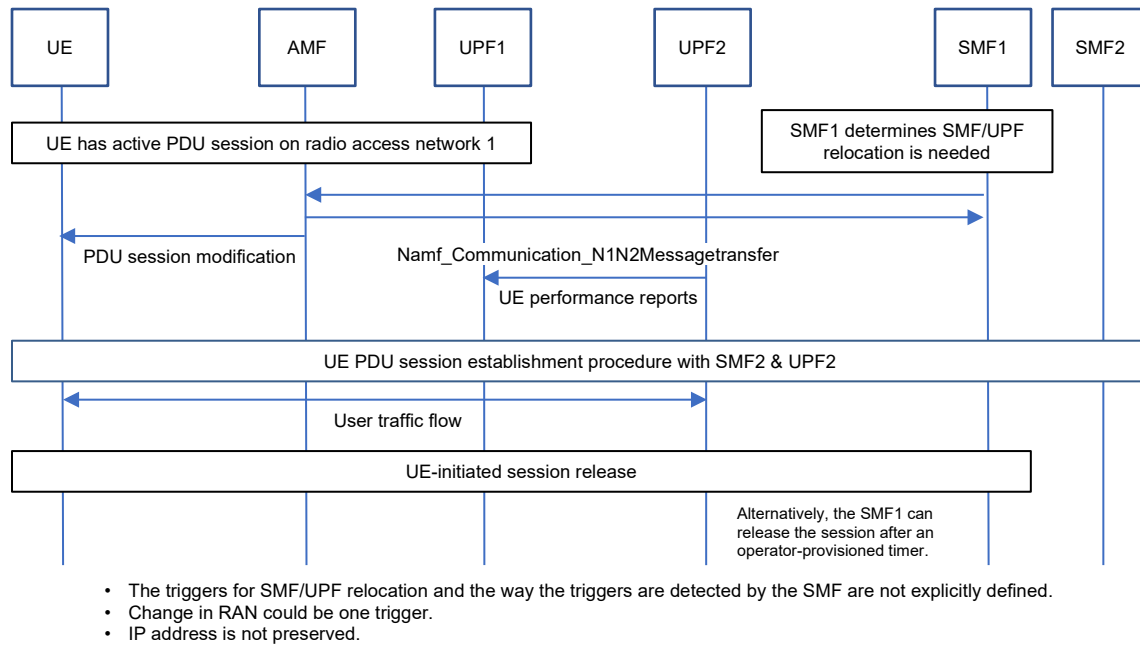


Figure 8 - 3GPP Session and Service Continuity Mode 3

6.3 UE Routing Selection Policy

Routing selection priorities for the UE as delivered from the 5GC are specified by 3GPP as UE Route Selection Policy (URSP). The policy rules are contained within the PCF and are initially transferred to the UE during network registration or Packet Data Unit (PDU) session establishment. Updates can be subsequently pushed by the network. The UE uses these policies to help determine which cellular or non-3GPP access to prefer when multiple options are available. As such, the URSP can assist in mobile data offload to Wi-Fi. The URSP can also help the UE select network slices and PDU sessions for user traffic. Therefore, URSP can play a role in routing fixed CPE traffic to specific network slices.

URSP is optional for wireline operation and is deployed per operator configuration. The URSP is delivered to the 5G-CRG or to the W-AGF in the case of the FN-CRG. The URSP is stored for the duration of a CRG registration to the 5GC. Operators may configure the W-AGF to store the URSP for a duration of time after the CRG deregisters and prior to its next registration.

6.4 Continuous Services

Continuous services, particularly real-time services, across access networks require fast transitions, often with IP address preservation. Transitions across cellular and Wi-Fi air interfaces is a primary example. Over-the-top traffic approaches employing tunneling or traffic aggregation can achieve continuous real-time services; however, these solutions may be largely proprietary. Therefore, this section considers 3GPP approaches that leverage the standardized 5G UE and 5GC. Although this use case may not primarily rely on convergence aspects, a successful converged architecture needs to support this use case.

Continuous real-time services with the 3GPP 5GC may combine the ATSSS traffic steering feature with UE URSP. URSP provides the overall network selection criteria, and ATSSS steers traffic flows to the UE over the available access networks. This combined solution provides an end-to-end network layer view of continuous service capabilities. It does not, however, address certain UE or access network aspects of continuous service requirements, i.e., mandated PHY layer UE air interface thresholds or actions needed for quality continuous service across networks. Therefore, operators may need to rely upon UE vendors and their chip suppliers to fill in potential gaps on UE behavior at the PHY layer.

It should be noted that 3GPP defines methods for the base stations to direct UEs to certain air interfaces, as an alternative to approaches similar to URSP or ATSSS. However, the interaction of these radio access network (RAN) direction methods and URSP with ATSSS for continuous service is not yet fully addressed in 3GPP. Careful network planning for feature interactions may be needed.

Figure 9 illustrates a high-level message flow for continuous services implemented with 3GPP ATSSS. It can also be applied to hybrid CPE for which 5G NR or LTE is used to deliver highly available HFC broadband Internet.

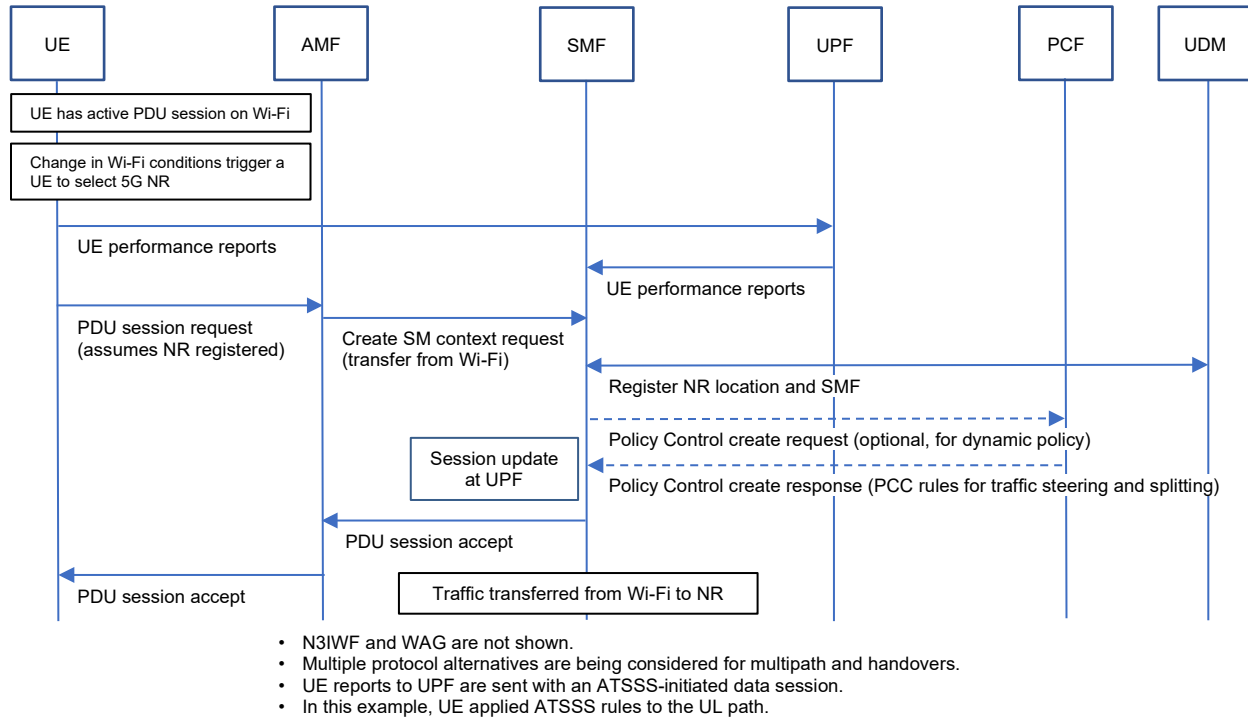


Figure 9 - Continuous Services with ATSSS Traffic Steering

6.5 Converged Policy

6.5.1 Goals and Characteristics

Converged policy is foundational for operators to deliver the subscribed user experience across multiple devices and regardless of access network. The following are example considerations for converged policy:

- traffic management, such as the proper quality of service (QoS) and traffic priority for applications;
- subscribed services, such as parental control to specific users;
- subscribed tiers of service and throughput limits based on billing or usage;
- user identification;
- device identification within the home that can be linked to a subscription; and
- addressing and packet filtering of data flows destined for devices.

To meet converged policy objectives, the converged architecture needs to support the following:

- network authentication and admission of devices behind a bridged CRG,
- access router functions for the CRG and devices behind a bridged CRG,
- policy enforcement points for data flows that may traverse wireline or wireless access, and
- operator-configurable policy rules that can apply to subscriber devices on wireline and wireless access.

3GPP R16 supports many of the objectives and architectural aspects listed above, but a number of gaps remain that may be addressed in R17:

- support for bridged CRGs and service to devices behind the bridged CRG,
- router and traffic management functions for devices in the home, and
- policy enforcement points that support the aspects above in addition to policy over wireless access networks.

6.5.2 QoS and the 3GPP PCC Architecture

The 3GPP Policy and Charging Control (PCC) architecture specified in [3GPP 23.503] provides a standardized method for the operator to set traffic priorities and QoS characteristics for individual traffic flows within mobile networks. Policy creation and enforcement points are defined. The operator may configure PCC rules held within the 5GC PCF. These rules can take information from applications, the AMF, and the SMF in order to determine traffic priorities specific to access networks. QoS for the converged core will consider how PCC rules can be applied and mapped to HFC QoS. HFC-specific parameters are identified as needed.

Policy creation and enforcement are defined in DOCSIS specifications but vary in practical deployments across vendor solutions. Figure 10 illustrates three of the more common QoS architectures specified or used in HFC deployments. The first option is a vendor-proprietary use of DOCSIS QoS; it is presently deployed. The second option, PacketCable Multimedia per [PCMM], is well-specified and aligned with the 3GPP Policy and Charging Rules Function (PCRF), but it has fewer deployments. The third option shown is a recent Virtual Provisioning Interface (VPI), as documented in the CableLabs [VPI] specification, that is not yet widely implemented. Convergence aspects in this report will focus on the use of the 3GPP PCC architecture with standard interfaces for HFC QoS.

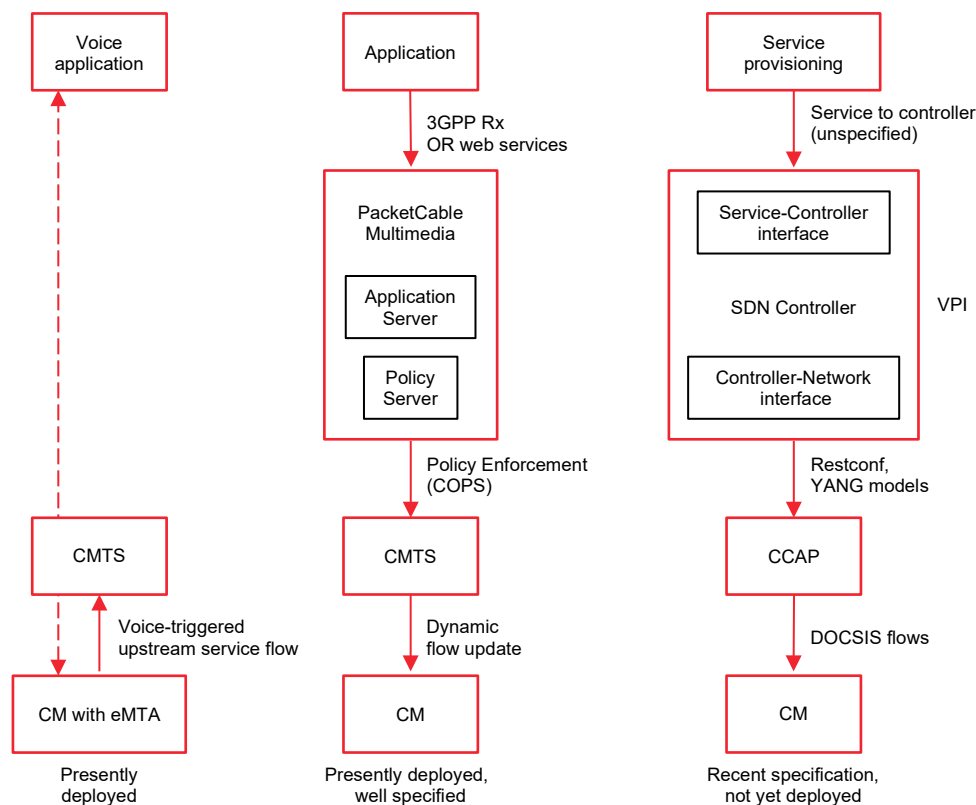


Figure 10 - HFC Architecture Alternatives for QoS

6.5.3 PCC Application to HFC QoS

Per [3GPP 23.503], sources of input into the PCC rules include

- operator-managed applications,
- AMF, and
- SMF.

The PCF accepts application requests for network resources and then uses the input list above within PCC rule sets to identify data flow qualities for the application. The following subsections list the parameters from each source and whether they need to carry HFC-specific information, as well as PCC rules and their HFC considerations.

6.5.4 Input from Operator-Managed Applications

Application media types and connection characteristics are input into the PCF via either the 3GPP Rx interface or a PCF web services interface. The PCF selects candidate QoS classes needed to support the application media types and connection characteristics.

The Rx interface used between the application and the PCF is brought forward from the 3GPP PCRF, which is also leveraged by [PCMM]. As such, 3GPP 5GC standards for the Application Function (AF)-to-PCF interface can be used without updates or parameter additions for HFC networks.

6.5.5 Input from the AMF

Table 1 lists the parameters made available from the AMF to the PCF for input into PCC rules in response to application requests for network resources. HFC-associated values for certain parameters are also listed.

Table 1 - Input from the AMF into the PCF for HFC Access Network

3GPP Parameter from AMF	Applied to HFC Network for Interworking	Applied to HFC Network for Integration
SUPI	HFC Subscriber ID (see Section 7.2)	5G IMSI subscription ID, or HFC Subscriber ID for wireline-only CRGs
PEI	CM MAC address	CM MAC address
Location of subscriber	HFC Node ID, or MAC address + HFC Node ID	HFC Node ID, or MAC address + HFC Node ID
Service area restriction	Collection of Node IDs	Collection of Node IDs
RFSP index	Not applicable	Not applicable
RAT type	HFC network	HFC network
GPSI	External ID per 3GPP 23.008 (username@realm)	External ID per 3GPP 23.008 (username@realm)
Access type	non-3GPP	non-3GPP
Serving PLMN ID	Not applicable	PLMN ID

6.5.6 Input from the SMF

Table 2 lists the parameters made available from the SMF to the PCF for input into PCC rules in response to application requests for network resources. No additional parameter types are identified for use with HFC access networks, but the HFC-associated values for certain parameters are listed below.

Table 2 - Input from the SMF into the PCF for HFC Access Network

3GPP Parameter from SMF	Applied to HFC Network for Interworking	Applied to HFC Network for Integration
SUPI	HFC Subscriber ID (see Section 7.2)	5G IMSI subscription ID, or HFC Subscriber ID for wireline-only CRGs
PEI	CM MAC address	CM MAC address
IPv4 address of UE	IPv4 address assigned to CM	IPv4 address assigned to CM
IPv6 network prefix of UE	IPv6 network prefix assigned to CM	IPv6 network prefix assigned to CM

3GPP Parameter from SMF	Applied to HFC Network for Interworking	Applied to HFC Network for Integration
Default 5QI and default ARP	Default DOCSIS service flow ID	Default DOCSIS service flow ID
Request type (initial, modification)	3GPP request type	3GPP request type
Type of PDU session	3GPP PDU session type	3GPP PDU session type
Access type	non-3GPP	non-3GPP
RAT type	HFC network	HFC network
GPSI	External ID per 3GPP 23.008 (username@realm)	External ID per 3GPP 23.008 (username@realm)
Internal-group identifier	Not applicable	Not applicable
Location of subscriber	HFC Node ID, or MAC address + HFC Node ID	HFC Node ID, or MAC address + HFC Node ID
DNN	3GPP DNN	3GPP DNN
PLMN ID	Not applicable	PLMN ID of operator
Application ID	3GPP Application ID	3GPP Application ID
Allocated application instance ID	3GPP Application ID instance	3GPP Application ID instance
Detected service data flow descriptions	Not supported	3GPP service flow descriptions
UE support of reflective QoS	Not supported	Not supported
3GPP PS data off status	Not applicable	Not applicable

6.5.7 PCC Rule Parameters

Table 3 indicates HFC-related values that can be applied within the 3GPP PCC rules parameters. References to 3GPP specifications or specific HFC parameters are indicated in the table.

Table 3 - PCC Rules Parameters for HFC Access Network

Information name	Description	Interworking with HFC Network	Integrated with HFC Network
Rule identifier	Uniquely identifies the PCC rule within a PDU session. Used between PCF and SMF to reference PCC rules.	3GPP	3GPP
Service Data Flow Detection	<i>Method for detecting packets belonging to a service data flow</i>		
Precedence	Determines the order in which the service data flow templates are applied at service data flow detection, enforcement, and charging. (Application filter detection is not applicable.)	3GPP	3GPP
Service data flow template	For IP PDU traffic: Either a list of service data flow filters or an application ID that references the corresponding application detection filter for detecting the service data flow. For Ethernet PDU traffic: Combination of traffic patterns of the Ethernet PDU traffic. Defined in [3GPP 23.501], clause 5.7.6.3.	3GPP	3GPP
Mute for notification	Defines whether the application's start or stop notification is to be muted.	Not applicable	3GPP
Charging	<i>Identities and instructions for charging and accounting required for an access point where flow-based charging is configured</i>	<i>Conditional: if operator applies 3GPP charging to HFC network</i>	3GPP
Charging key	The charging function (CHF) uses the charging key to determine the tariff to apply to the service data flow.	Conditional	3GPP
Service identifier	Identity of the service or service component that the service data flow in a rule relates to.	3GPP	3GPP

Information name	Description	Interworking with HFC Network	Integrated with HFC Network
Sponsor identifier	ID provided from the AF that identifies the sponsor, used for sponsored flows to correlate measurements from different users for accounting purposes.	Conditional	3GPP
Application service provider identifier	ID provided from the AF that identifies the application service provider, used for sponsored flows to correlate measurements from different users for accounting purposes.	Conditional	3GPP
Charging method	Indicates the required charging method for the PCC rule. Values: online, offline, or neither.	Not applicable	3GPP
Service data flow handling while requesting credit	Indicates whether the service data flow is allowed to start while the SMF is waiting for the response to the credit request. Only applicable for charging method online. Values: blocking or non-blocking	Not applicable	3GPP
Measurement method	Indicates whether the service data flow data volume, duration, combined volume/duration, or event shall be measured. Applicable to reporting if the charging method is online or offline. Note: Event-based charging is only applicable to predefined PCC rules and PCC rules used for application detection filter (i.e., with an application ID).	Not applicable	3GPP
Application function record information	ID provided from the AF that correlates the measurement for the charging key/service ID values in this PCC rule with application-level reports.	Not applicable	3GPP
Service identifier-level reporting	Indicates that separate usage reports shall be generated for this service ID. Values: mandated or not required	3GPP	3GPP
Policy Control	<i>How to apply policy control for the service data flow</i>		
Gate status	Indicates whether the service data flow, detected by the service data flow template, may pass (Gate is open) or shall be discarded (Gate is closed).	Not applicable	3GPP
5QI	ID for the authorized QoS parameters for the service data flow.	3GPP values: 5G QoS to HFC QoS mapping in W-AGF	3GPP values: 5G QoS to HFC QoS mapping in W-AGF
QNC	Indicates whether notifications are requested from 3GPP RAN when the GFBR can no longer (or can again) be guaranteed for a QoS flow during the lifetime of the QoS flow.	Not applicable	Not applicable
Reflective QoS control	Indicates to apply reflective QoS for the service data flow.	Not applicable	Not applicable
UL-maximum bitrate	Uplink maximum bitrate authorized for the service data flow.	3GPP; mapped to service flows in W-AGF	3GPP; mapped to service flows in W-AGF
DL-maximum bitrate	Downlink maximum bitrate authorized for the service data flow.	3GPP; mapped to service flows in W-AGF	3GPP; mapped to service flows in W-AGF
UL-guaranteed bitrate	Uplink guaranteed bitrate authorized for the service data flow.	3GPP; mapped to service flows in W-AGF	3GPP; mapped to service flows in W-AGF
DL-guaranteed bitrate	Downlink guaranteed bitrate authorized for the service data flow.	3GPP; mapped to service flows in W-AGF	3GPP; mapped to service flows in W-AGF
UL sharing indication	Indicates resource sharing in uplink direction with service data flows having the same value in their PCC rule.	Not applicable	Not applicable
DL sharing indication	Indicates resource sharing in downlink direction with service data flows having the same value in their PCC rule.	Not applicable	Not applicable
Redirect	Redirect state of the service data flow (enabled/disabled).	Not applicable	Not applicable
Redirect destination	Controlled address to which the service data flow is redirected when redirect is enabled.	Not applicable	Not applicable
ARP	The Allocation and Retention Priority for the service data flow consisting of the priority level, the preemption capability, and the preemption vulnerability	3GPP	3GPP
Bind to QoS flow associated with the default QoS rule	Indicates that the dynamic PCC rule shall always be bound to the QoS flow associated with the default QoS rule.	Not applicable	3GPP

Information name	Description	Interworking with HFC Network	Integrated with HFC Network
Bind to QoS flow associated with the default QoS rule and apply PCC rule parameters	Indicates that the dynamic PCC rule shall always be bound to the QoS flow associated with the default QoS rule. Also indicates that the QoS-related attributes of the PCC rule shall be applied to derive the QoS parameters of the QoS flow associated with the default QoS rule instead of the PDU-session-related parameters authorized default 5QI or ARP.	Not applicable	3GPP
PS-to-CS session continuity	Indicates whether the service data flow is a candidate for Single Radio Video Call Continuity (vSRVCC).	Not applicable	Not applicable
Priority level	Indicates a priority in scheduling resources among QoS Flows (optional).	3GPP	3GPP
Averaging window	Represents the duration over which the guaranteed and maximum bitrate shall be calculated (optional).	Not applicable	3GPP
Maximum data burst volume	Denotes the largest amount of data that is required to be transferred within a period of 5G-AN PDB (optional).	Not applicable	Not applicable
Access Network Information Reporting	<i>Access network information to be reported for the PCC rule when the corresponding bearer is established, modified, or terminated</i>		
User location report	Serving cell of the UE is to be reported. When the corresponding bearer is deactivated, information on when the UE was last known to be in that location is also to be reported, if available.	Not applicable	Not applicable
UE timezone report	Time zone of the UE is to be reported.	3GPP	3GPP
Usage Monitoring Control	<i>Identities required for Usage Monitoring Control</i>		
Monitoring key	The PCF uses the monitoring key to group services that share a common allowed usage.	Not applicable	3GPP
Indication of exclusion from session-level monitoring	Indicates that the service data flow shall be excluded from PDU session usage monitoring.	3GPP	3GPP
Traffic Steering Enforcement Control	<i>Identities required for Traffic Steering Enforcement Control</i>		
Data network access identifier(s)	ID(s) of the target Data Network Access. Defined in [3GPP 23.501], clause 5.6.7.	3GPP	3GPP
Traffic steering policy identifier(s)	Reference to a preconfigured traffic steering policy at the SMF (UL and DL may have separate IDs).	3GPP	3GPP
N6 traffic routing information	Describes the information necessary for traffic steering to the DNAI. Described in [3GPP 23.501], clause 5.6.7.	3GPP	3GPP
Information on AF subscription to UP change events	Indicates whether notifications of change in user plane path are requested (as defined in [3GPP 23.501] clause 5.6.7).	3GPP	3GPP
RAN Support Information	<i>Information supporting the RAN for e.g. handover threshold decision</i>		
UL maximum packet loss rate	Maximum rate for lost packets that can be tolerated in the uplink direction for the service data flow. Defined in [3GPP 23.501], clause 5.7.2.8.	Not applicable	3GPP
DL maximum packet loss rate	Maximum rate for lost packets that can be tolerated in the downlink direction for the service data flow. Defined in [3GPP 23.501], clause 5.7.2.8.	Not applicable	3GPP

The PCC rules are envisioned to use 5G QoS service classes, indicated with standardized 5QI (5G QoS Identifier) values. These classes need to be mapped to applicable HFC QoS traffic management mechanisms. HFC QoS can be organized around HFC Service Class Names or around a set of HFC service flow parameters. Both Service Class Names and groupings of HFC service flow parameters are operator deployment settings in HFC systems. A

minimum common set of HFC service classes is not identified. The mapping is placed within the interworking layer for the interworking model or within the HFC infrastructure for the integration model.

Charging with the interworking model will follow existing DOCSIS models. Online charging is not required for the interworking model and may optionally apply to the integrated model.

6.5.8 5GC and PCMM for the Interworking Model

This section considers how an HFC PCMM system may link into the 5GC within the interworking model. The 5G SMF interfaces to the 5G UPF, which is the bearer policy enforcement point. The UPF (using policy from the PCF via SMF) conveys 5G QoS to the W-AGF. The W-AGF maps the 5G QoS to HFC QoS and manages the HFC service flows at the CMTS accordingly. For the interworking model, in scenarios for which a UPF is not required, an interworking function is needed between the SMF and the CMTS Common Open Policy Service (COPS) Protocol interface as shown in Figure 11. The W-AGF as identified in [3GPP 23.316] provides the interworking between the 3GPP N4 interface and the CMTS. The CMTS pkt-mm-2 COPS interface, as defined in the CableLabs [PCMM] specification, provides the HFC bearer enforcement point in HFC systems. Higher levels of combination, including placing an HFC-dedicated SMF in the interworking function, is not precluded. As seen in Figure 11, the PCF and SMF replace the PCMM platform for the interworking model. PCC rules within the PCF will need to accommodate HFC parameters as described in the subsections above.

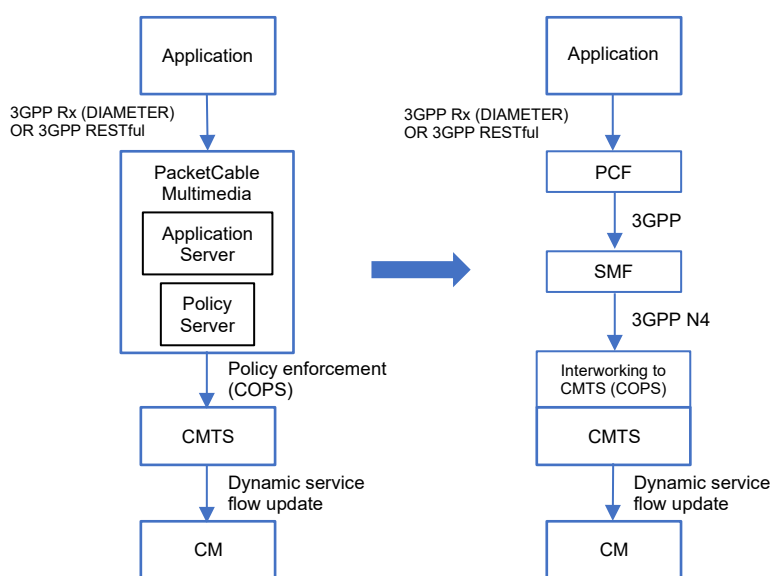


Figure 11 - Use of PCF with PCMM CMTS Interface

6.6 Network Slicing

Network slicing allocates and configures a portion of network resources to support a specific set of characteristics for an application or a subscriber set. 3GPP has standardized the slice types shown in Table 4. The 3GPP slicing architecture is extensible. The Slice Service Type (SST) values 128–256 are reserved for operator- or vendor-defined slice types. That is, an MSO-defined slice type that includes HFC characteristics may be assigned an SST value of 128 or greater.

Table 4 - Standard Slice Service Types

SST	SST Value	Characteristics
eMBB	1	Suitable for 5G enhanced mobile broadband
URLLC	2	Suitable for ultra-reliable low-latency communications
MIoT	3	Suitable for massive IoT

Slice service types are linked to subscriptions in the UDM and are initially authorized for use by the UE at network registration. UE traffic flows are placed into a network slice as part of PDU session establishment. The UE requests a data session with a slice ID suitable for the application requested by the subscriber. In response to a data session request, the AMF selects an SMF that manages the data session within a slice instance and completes the user data path for the session within the network slice. QoS for the flow may be applied per PCC rules contained in the PCF. The HFC link to the CM can form part of the user data path within a slice that includes the wireline network. The interworking function in the HFC network can invoke HFC configuration or DOCSIS traffic flow characteristics based on the slice ID received from the UDM via the AMF.

6.7 Virtualization and SDN

3GPP specifications recommend the ETSI specification on network function virtualization (NFV) management and orchestration, [MANO], although vendors go further to customize NFV methodologies in their implementations. The HFC ecosystem has not yet converged towards a common NFV approach. Furthermore, initial virtualization efforts in the HFC network and, separately, in mobile cores have not always resulted in cost savings for operators. As such, a common NFV and software-defined networking (SDN) methodology is not within the scope of this document. A converged and mature NFV and SDN methodology across wireless and wireline networks may ultimately result in more efficient networks in the longer term.

6.8 5G Core Delivery of Media and IPTV

A goal of the 5GC support of IPTV is to ensure quality delivery of high-definition media over the 5GC without impact to the content delivery network (CDN) system. The 5GC should be agnostic to the CDN architecture. Therefore, the architecture of the CDN system is not addressed, and impact to the CDN system is minimized.

This subsection considers how the 5GC can be part of an overall solution to deliver high-quality media to support IPTV services. 3GPP has completed study items that provide a vision of IPTV support within the 5GC (see [3GPP 26.891]). The converged core further defines 5GC support of IPTV. This subsection first describes how high-quality media delivery for IPTV can be supported by the 5GC per 3GPP specifications. Interworking these 5GC capabilities to the HFC network is then considered.

A subset of IPTV subscription parameters is held within the UDM (see Section 7.2). The subscription parameters placed within the UDM support the 5GC capability to deliver IPTV with mobility and location considerations and to organize multicast groups within the 5GC for the sake of linear TV delivery. The UDM holds the following information:

- IPTV account ID or STB MAC address;
- channel access list;
- service authorized only within the home, within the MSO footprint, or while roaming; and
- content caps per month per account regardless of device.

The STB MAC address network admission should be indicated in the UDM when the STB is admitted to the network. This requires an interworking function to note the registration in the UDM. No impact to STB authentication or network admission procedures is required.

Figure 12 illustrates the establishment 5GC PDU session suitable to deliver IPTV via unicast, such as video on demand (VOD).

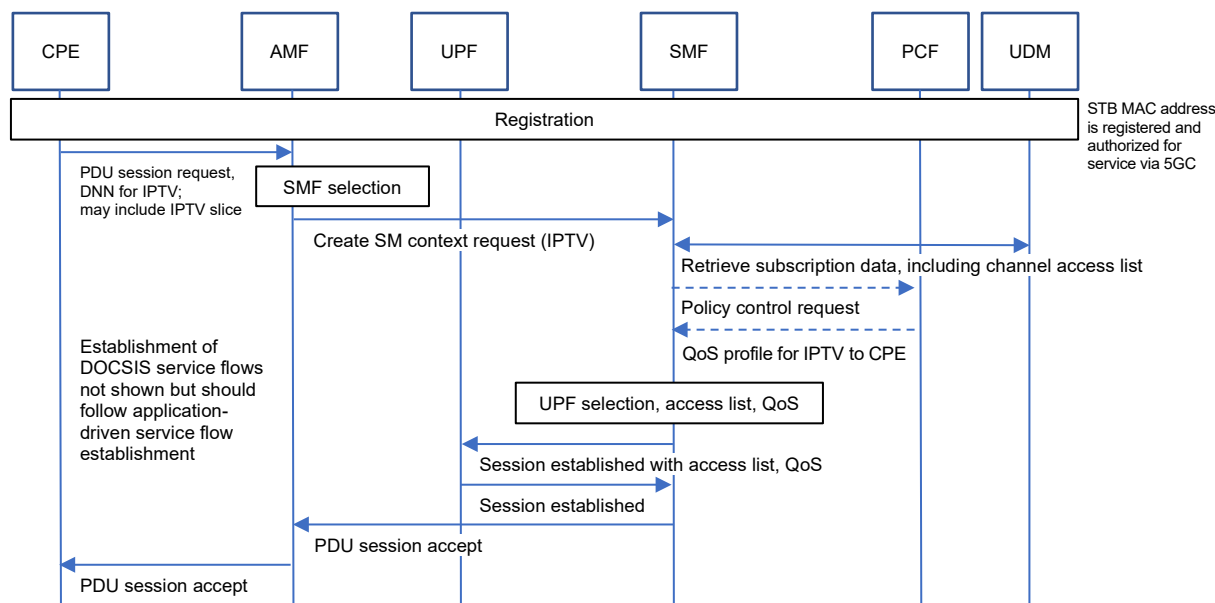


Figure 12 - PDU Session Establishment for IPTV

The STB MAC address is authenticated and admitted per legacy systems. Its admission status is then indicated in the UDM. The CPE requests a PDU session with a Data Network Name (DNN) for IPTV. The 5GC applies a 5QI suitable for IPTV as controlled by the PCF based on the DNN. The 5GC data flow is established. A DOCSIS service flow with the proper QoS is established by linking the PCF to the HFC QoS mechanism as described in Section 7.8.

Figure 13 illustrates the use of multicast groups in the 5GC to deliver linear TV. In this case, a multicast group transports a specific IPTV linear channel.

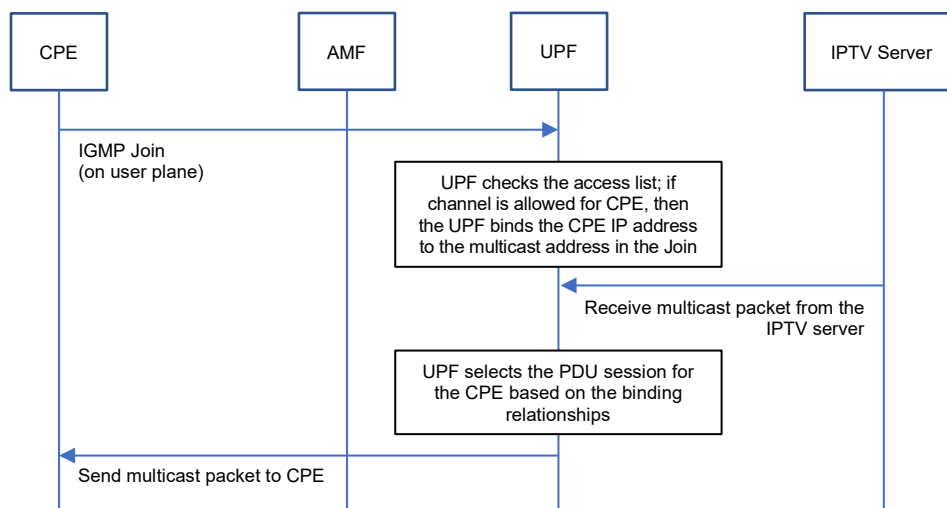


Figure 13 - IP Multicast Within the 5GC for Linear IPTV

The CPE (STB) maps an IPTV channel to a multicast group (according to mechanisms that are outside the scope of this report) and requests to join the appropriate multicast group per the channel requested by the subscriber. The UPF binds the CPE to the multicast group then directs multicast group packets to flow from the IPTV server to the CPE.

7 REQUIREMENTS

7.1 Introduction

Convergence requirements within the 5GC are specified in the 3GPP specifications referenced in this document. Additional requirements placed upon the W-AGF and other network elements to support HFC requirements are documented in the following subsections.

7.2 UDM Requirements

5G network admission, slice authorization, and the application of policy are all enabled by the pre-provisioned subscription in the UDM. Registration status is also held within the UDM. The UDM must support the requirements defined in [3GPP 29.500] and [3GPP 29.503]. In addition, the UDM must support the subscription parameters in Table 5 that link

- multiple user devices to a residential HFC Internet broadband account and
- multiple mobile devices to an HFC Internet broadband account.

Table 5 - Subscription Parameters

Subscription Parameter	Format	Normative	Syntax
HFC Subscription			
HFC subscriber ID	CM MAC address @ realm	Mandatory	See [3GPP 23.316]
Subscription tier (in Mbps)	Integer or 3GPP AMBR	Optional	Integer, [3GPP 23.501]
Slice identifiers	NSSAI per 3GPP specifications	Optional	See [3GPP 23.501]
User device identifiers	MAC address	Optional	Per [MULPI] specification
User device identifiers	Application indicator	Optional	Operator defined
3GPP Mobile Subscriptions			
per IMSI	See 3GPP specifications	Mandatory	See 3GPP specifications
IPTV Support in 5G Core			
Registered STB ID	See [3GPP 23.316]	Optional	See [3GPP 23.316]
Channel access list	See [3GPP 23.316]	Optional	See [3GPP 23.316]
VOD consumption limits	See [3GPP 23.316]	Optional	See [3GPP 23.316]
Video away from home delivery	See [3GPP 23.316]	Optional	See [3GPP 23.316]
Serving CDN	See [3GPP 23.316]	Optional	See [3GPP 23.316]
Slice identifiers	See [3GPP 23.316]	Optional	See [3GPP 23.316]

The UDM may support the IPTV parameters in Table 5.

As described in [3GPP 23.316], the CM MAC address, per [MULPI], appended with the operator realm is registered into the UDM when the W-AGF detects a CM authorization by the CMTS. Subscription tiers are applied at the time of registration per 3GPP specifications. A subscription tier or throughput maximum under operator-identified conditions may determine the value of the Aggregate Maximum Bit Rate (AMBR) parameter in the UDM. The 3GPP Network Slice Selection Assistance Information (NSSAI) parameters indicate the slices authorized for use to an authenticated CM by their assignment in the subscription. User device IDs are registered at the time of their detection on the HFC-enabled local-area network (LAN).

7.3 CPE Requirements

7.3.1 5G-CRG

A wireline-only 5G-CRG combines the 3GPP UE control plane with an HFC cable modem. The wireline-only 5G-CRG must support the 3GPP 5G N1 protocol as specified in [3GPP 23.316]. The wireline-only 5G-CRG must

populate the 3GPP Permanent Equipment Identifier (PEI) reported with the CM MAC address. The wireline-only 5G-CRG must use either the HFC account ID or a CM MAC address with operator realm for the CRG SUPI. The HFC account ID is described in the CableLabs Virtual Provisioning Interfaces Technical Report, [VPI]. The CM MAC address is specified in [MULPI].

The 5G-CRG that supports 3GPP NR must comply to [3GPP 23.316], which includes requirements for the Subscription Concealed Identifier (SUCI), SUPI, and PEI populated with the International Mobile Equipment Identifier (IMEI).

7.3.2 FN-CRG

The FN-CRG is a legacy cable modem. No convergence requirements are placed on the FN-CRG. Within the interworking model for convergence, the W-AGF provides convergence functions on behalf of legacy cable modems.

7.3.3 Bridged CRG and Devices on the Subscriber LAN

The bridged CRG must support layer 2 traffic forwarding between the subscriber LAN and the 5GC user plane. The bridged CRG must identify the subscriber LAN with an appropriate identifier such as a virtual LAN (VLAN) ID. The bridged CRG must preserve user device MAC addresses as a source address when traffic forwarding so that the 5GC is able to apply services to each user device individually.

7.4 High Level W-AGF Requirements

The W-AGF must support the 3GPP N1 reference point as specified in [3GPP 23.316].

The W-AGF must support the 3GPP N2 reference point as specified in [3GPP 23.316].

The W-AGF must support the 3GPP N3 reference point as specified in [3GPP 23.316].

The W-AGF must support the W-AGF requirements specified in [3GPP 23.316].

Each residential gateway may be assigned its own VLAN between the CMTS and the W-AGF to complete the user plane traffic flow between the HFC access network and the W-AGF. The W-AGF must support individual VLANs per residential gateway as received via the CMTS.

7.5 Registration, Authentication, and CPE Status

For the FN-CRG, the W-AGF must detect CM registration into the CMTS. The W-AGF must report CM registrations and de-registrations per FN-CRG requirements specified in [3GPP 23.316]. The W-AGF must be able to detect CM unreachability by the CMTS and report the idle status to the 5GC per [3GPP 23.316]. The method by which the W-AGF detects CM registration and reachability status from the CMTS is per vendor implementation. See the CableLabs [MULPI] specification for how the CMTS detects CM reachability.

The 5G-CRG must support 3GPP N1 NAS encapsulated in EAP-5G for initial registration procedures via the DOCSIS network. When the EAP-5G registration is complete and a security association is established between the 5G-CRG and the W-AGF, then the 5G-CRG must support NAS over TLS to the W-AGF for the balance of registration. See [3GPP 23.316] for a message diagram sequence that illustrates the use of EAP-5G and TLS.

7.6 Slicing

The 5G-CRG must support network slicing and NSSAI as specified in [3GPP 23.316].

The W-AGF must support network slicing and NSSAI on behalf of individual FN-CRGs. The W-AGF must allow the operator to configure the way in which the W-AGF selects slices for the FN-CRG based on slice IDs received during FN-CRG registrations, DOCSIS flows initiated by the FN-CRG, or FN-CRG application. Upon FN-CRG registration, when no other information is available for network slice selection, the W-AGF must select either the enhanced mobile broadband (eMBB) network slice specified by 3GPP for the 5GC to connect to default DOCSIS service flows or an operator-provisioned default slice in the W-AGF for the FN-CRG. The W-AGF must support operator configuration of slice types to FN-CRGs and DOCSIS service flow settings.

7.7 Session Management

The 5G-CRG must support the session management procedures specified in [3GPP 23.316].

The W-AGF must support session management procedures for each FN-CRG. The W-AGF must establish an IP PDU data session within the eMBB slice per operator configuration upon the CMTS completing default DOCSIS service flows for the FN-CRG. If the operator has configured the FN-CRG to be a bridged gateway, then the W-AGF must establish an Ethernet PDU data session within the eMBB slice. The W-AGF must execute a PDU session modification when the FN-CRG or the CMTS completes a dynamic DOCSIS service flow update. The method by which the W-AGF detects the CMTS service flows and service flow updates for an FN-CRG is per vendor implementation. The W-AGF must be able to support multiple PDU sessions for the FN-CRG and to map an individual PDU session to a specific DOCSIS service flow. The W-AGF may use the CMTS COPS PCMM interface to manage network-initiated DOCSIS service flow updates on behalf of the FN-CRG.

7.8 Policy

The W-AGF must support mapping of DOCSIS service flow QoS classifiers to 5GC 5QI values as configured by the operator. The mapping is flexible and determined by the operator, but Table 6 provides a few examples. See [3GPP 23.501], table 5.7.4-1, for 3GPP standardized 5QI values mapped to 5G QoS characteristics.

Table 6 - Examples of 3GPP 5QI Mapped to DOCSIS QoS

Application (Example)	DOCSIS Scheduling Type	Flow Spec Service Number	DOCSIS Service Class Name (Example)	3GPP 5QI Standard Value	3GPP Resource Type	3GPP Priority Level
Real-time voice	Unsolicited Grant	2 (guaranteed)	"Real time voice"	1	GBR with 100 ms delay budget	20
VPN	Real-Time Polling Service	2 (guaranteed)	"Guaranteed delay and throughput"	2 or 4 (example)	GBR with 150 or 300 ms delay	40 or 50
General data service	Best Effort	5 (controlled load)	"Best Effort Data"	9 (example)	Non-GBR	90

The W-AGF must be able to receive 5GC 5QI indicators and, as mapped by the operator, set the DOCSIS service flow QoS. The W-AGF may use the CMTS COPS PCMM interface, per the CableLabs [PCMM] specification, to set the QoS of DOCSIS service flows. (See the [MULPI] and [PCMM] specifications for how HFC QoS may be defined and applied to DOCSIS service flows by the CMTS.) Otherwise, the W-AGF may use vendor solutions to update DOCSIS service flow QoS. The W-AGF must be able to detect DOCSIS service flow QoS updates initiated by the FN-CRG and use PDU session modification procedures per [3GPP 23.316] to update the QoS used within the 5GC.

HFC subscription service tiers may be provisioned in the UDM assigned to HFC subscription. Upon receiving subscription parameters for a CM registration into the 5GC, the W-AGF updates the DOCSIS service flows to the CM to regulate the delivered throughput to the CM per the subscribed HFC service tier.

8 USE CASES AND CAPABILITIES

The exemplary use cases and priority network capabilities described below illustrate the potential value of convergence to the delivery of subscriber services. Subsections include an explanation of how the use case may be executed with a converged core and an assessment of the value and implications of applying convergence to the use case.

8.1 Consistent User Experience Across Access Networks

A successful converged architecture is capable of delivering a consistent user service set and consistent operator policy across wireless and HFC access networks. For example, users can set parental controls once and expect them to be executed consistently on mobile devices over 5G or Wi-Fi or on in-home LAN devices for a given user. Video content selection with operator-managed volume limits applicable across access networks is another example service. The goal is to deliver the same user experience and applications on wireless and wireline networks.

8.2 Continuous Real-Time Services

With continuous real-time service, transitions across 5G, 4G, Wi-Fi, and other access networks are transparent to the user experience. It requires PHY and MAC layer procedures during transitions to be rapid and reliable, and real-time applications often require a persistent IP address. Although this use case may not necessarily rely upon wireless-wireline convergence features, it remains a high-priority use case for operators that need to be supported by the RAN and by core networks.

Mobile devices also play an essential role in continuous services, including actions triggered by PHY parameter thresholds. Although the converged core does not assist in UE PHY procedures, it contributes to continuous real-time service across RANs for mobile devices through its use of 3GPP ATSSS and its support for access network priority selection per operator policy, QoS, and IP address preservation. Section 6.4 describes the use of ATSSS for transitions across 5G NR and Wi-Fi radio networks.

8.3 Traffic Bonding

Traffic bonding is the aggregation of two data flows across separate access networks. It can deliver greater bandwidth to the subscriber device. It can also increase service availability because it allows one data flow to deliver user traffic while the second is impaired or diminished. Traffic bonding is executed by UE and core network capabilities. The 3GPP ATSSS feature, per [3GPP 23.501], supports the 5G version of traffic bonding. Section 6.2.1 describes the use of 3GPP ATSSS for traffic bonding.

8.3.1 Traffic Bonding to the Mobile Device

User traffic is delivered to the mobile device through parallel data flows over 5G NR and Wi-Fi. The traffic flows are aggregated at the mobile device for use by applications. Though this use case may not necessarily rely on wireless-wireline convergence features, it remains a high-priority use case for operators that need to be supported by the RAN and by core networks

8.3.2 Traffic Bonding to Broadband Internet CPE

User traffic is delivered to the broadband Internet CPE through parallel data flows over 5G NR and the HFC network. The traffic flows are aggregated at the CPE for use by applications. This use case leverages the converged core with the 3GPP ATSSS feature. It is referred to as the hybrid use case within the 3GPP study item.

8.4 Ultra-Low Latency

3GPP has standardized the ultra-reliable low-latency communication (URLLC) slice type for low-latency use cases. Operators can use the standard 3GPP slice type or an alternative operator-defined low-latency slice type to invoke low-latency configuration on 5GC network elements and low-latency features on the HFC network.

Potentially, an ultra-low-latency use case may need to leverage 3GPP URLLC capabilities in combination with HFC low-latency features. A slice ID of a low-latency slice type will need to be applied to the subscriber profile in the UDM and invoked upon CM registration. A slice type is authorized for a CPE and then applied to the HFC network during network registration, as shown in Figure 14.

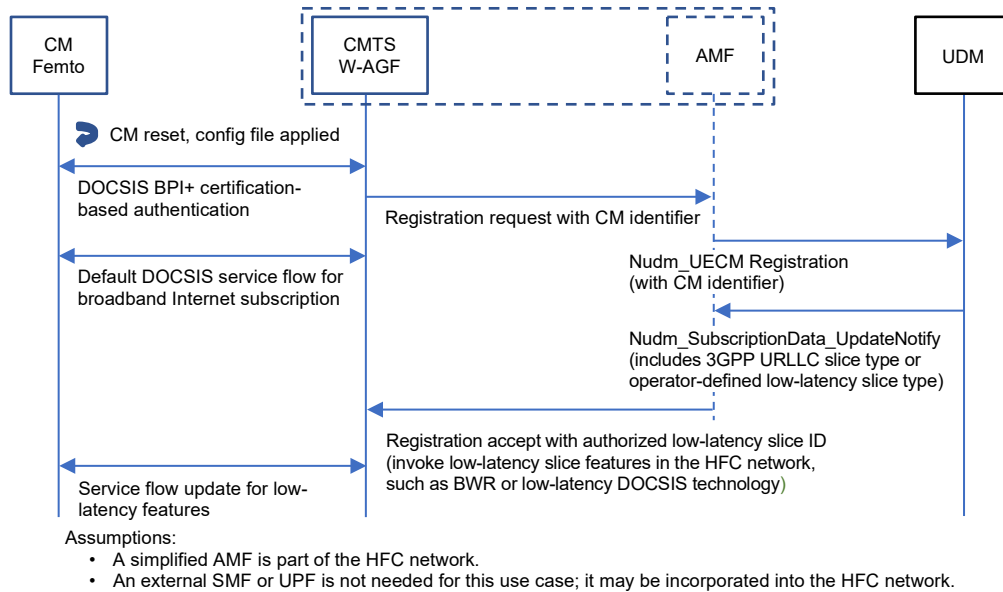


Figure 14 - Low-Latency Slice ID Applied to HFC Access Network

8.5 Mobile Xhaul

The mobile xhaul use case considers using the HFC network as transport from the core network to small cells in the home, in the enterprise, or distributed in metro areas (such as strand units). Mobile xhaul may also consider the use case of HFC transport between remote radio heads and virtualized baseband units. The CM in the residential or enterprise use case may simultaneously serve both subscriber broadband Internet services and mobile backhaul between small cells and the mobile core. In this case, the CPE supports two HFC service flows—one suitable for the residential/enterprise subscriber and a second suitable for the small cell. Traffic routing and uplink/downlink (UL/DL) symmetry to support the small cell need to be enforced on the HFC service flow used as backhaul. This second HFC service flow can be invoked by one of two alternative methods.

- **Network slice:** In this case, an operator network slice type for xhaul is defined. The slice type is authorized for the CM when the CM registration is indicated to the UDM. The slice type is sent from the UDM to the AMF, where it is then sent to the HFC network. The HFC interworking layer then invokes the xhaul service flow with the proper policy for the small cell. Figure 15 illustrates the concept of a network slice type used for backhaul.

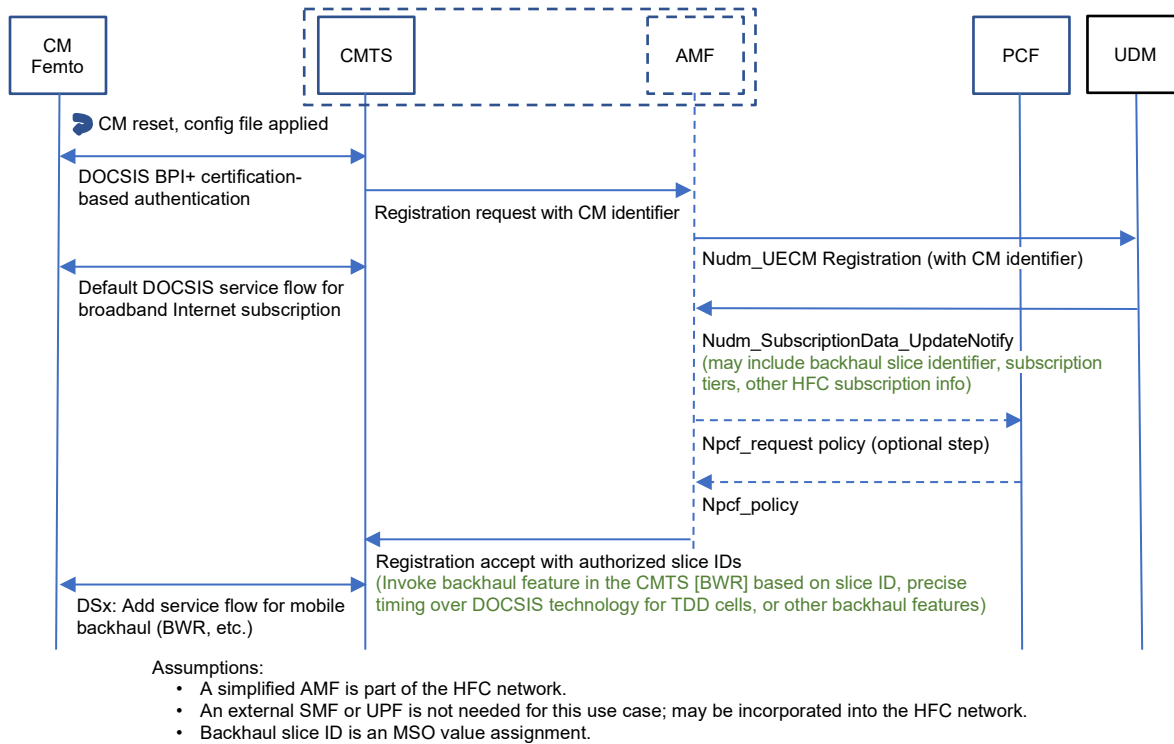


Figure 15 - CPE for Broadband Internet and Small-Cell Backhaul

- **Subscribed feature:** Alternatively, a backhaul feature could be defined that is assigned to the HFC subscription in the UDM. The UDM profile links the backhaul feature to the CM MAC address. The subscriber feature parameters are sent to the AMF, which then initiates a network-pushed secondary PDU session per the backhaul feature to the CM with a policy suitable for backhaul.

The mobile fronthaul use case considers using the HFC network as transport between radio heads in the enterprise or metro areas and virtualized baseband units. Mobile fronthaul is implemented with a converged core methodology similar to that of mobile backhaul, with two primary differences:

- location of the HFC transport between the mobile network components and
- differences between fronthaul and backhaul throughput and latency performance requirements. (Note that variations of virtual RAN [vRAN] architectures may have specific fronthaul performance needs.)

8.6 IPTV

The IPTV use case considers the delivery of linear video over IP and VoD to fixed and mobile clients. The scope of the use case focuses on converged IPTV subscriptions and converged traffic management policy capable of delivering high-definition video. The characteristics of the video content delivery system are not within the scope of this use case given the numerous video architectures employed in the cable industry. The implementation of 5GC support for media delivery of IPTV is described in Section 6.8.

8.7 Broadband Internet Portability (Nomadic CM)

Broadband Internet portability supports a subscriber moving from one residence to another within the same MSO service area without the need for subscriber or MSO intervention. That is, the subscriber is able to relocate their CM and expect it to be operational and online upon power-up. Procedures for this so-called nomadic CPE are not yet specified by 3GPP but are anticipated in the 3GPP R17 work plan.

8.8 Subscription Tiers

Subscription tiers are often included in broadband Internet product lines. A subscription tier for mobile may include advertised speeds that depend on the total traffic volume consumed by the user in a given time period. The mobile subscriber would receive full cellular speeds until reaching a volume limit, which would trigger a lower maximum delivered throughput for the remainder of the time period.

A converged subscription tier would support a set of speed targets and traffic volume thresholds for a given subscriber regardless of access network or device.

A subscription tier is directly reflected in the existing 3GPP PCC rules described in Sections 6.5.3 and 6.5.8 and can be enforced at the UPF.

8.9 Business Services

Business services may provide private networking for the enterprise. In support of private networking, a converged core enables private IP addressing space, traffic segregation, and enterprise-level security. The 5GC natively supports private addressing for properly configured DNNs. In this case, businesses may want to control the subscription and authentication used for network admission, which may motivate non-SIM solutions for private isolated networks. The EAP-over-NAS authentication option described in [3GPP 23.501] can be used to carry EAP-TLS for certificate-based authentication or EAP-TTLS for username and password authentication.

9 USE CASES MAPPED TO REQUIREMENTS

Operator use cases are addressed by several requirements contained in this technical report and in the referenced 3GPP specifications. Table 7 identifies how the 3GPP specifications and this CableLabs report support each operator use case. Gaps in either 3GPP specifications or CableLabs documents are identified.

Table 7 - Requirements Mapped to Use Cases

Use Case	3GPP Specifications	CableLabs Technical Report	Gaps
Consistent user experience	Partially in 23.316	Sections on subscription, bridged RG, and policy	Support for bridged RG and user devices in 3GPP
Continuous real-time services	23.501, 23.502	3GPP specification references	
Traffic bonding: mobile devices	ATSSS specified in 23.501 and 23.502	3GPP specification references	Support for UDP traffic needs further detail
Traffic bonding: fixed CPE	ATSSS specified in 23.501, 23.502, and 23.316	Sections on ATSSS and W-AGF	
Ultra-low latency	23.501 on slicing	HFC slices, slice ID identified	HFC configuration needs further work
Mobile xhaul	Not applicable	HFC configurations include mobile backhaul with BWR	
IPTV	23.316	3GPP specification references	
Nomadic CM	To be determined	To be determined	Planned for 3GPP R17 of [3GPP 23.316]
Subscription tiers	UDM specs	Sections on UDM and policy mapping	
Business services	Similar to residential LAN case	Similar to residential LAN case	Support for bridged RG and user devices in 3GPP

10 FUTURE WORK

Areas of future work anticipated for the 5G converged core includes

- 3GPP R17 5G core support for bridged CRGs in which each user device is served by the core with a consistent set of services and policy,
- convergence with MSO-operated optical networks,
- converged security appliances, and
- requirements for converged fixed and mobile IoT devices.

11 3GPP ENGAGEMENT

CableLabs is participating directly in the 3GPP Study Item and Work Item for R16 of [3GPP 23.316]. CableLabs has submitted or actively cosigned and supported contributions on the following topics within 3GPP technical working groups.

- Architecture block diagrams and protocol stacks for the FN-CRG
- Registration procedures for the 5G-CRG and FN-CRG
- Authentication and network admission for MSO-subscriber CPE and devices
- Identifiers for the HFC network, including SUPI, SUCI, PEI, and service areas
- Solutions to support bridged CRGs
- ATSSS applied to the hybrid use case
- Distribution of policy on and configuration updates to the 5G-CRG and FN-CRG
- QoS mapping between the 5G core and DOCSIS service flows
- PDU session management linked to DOCSIS service flows
- 3GPP R17 convergence study item areas

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