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Network Convergence

A Technical Paper prepared for SCTE•ISBE by

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1 Introduction

1.1 Motivation

Many cable operators operate a combination of wireline (DOCSIS), Wi-Fi, and mobile (LTE, and soon to be 5G) access networks. Each access technology is supported by separate cores with overlapping capabilities. An operator that provides both mobile and wireline services will need to purchase and maintain separate core network elements to manage their corresponding access networks – 5G Core (5GC) for next generation radio access network (NG RAN), and cable core for DOCSIS access. Converging these overlapping capabilities will provide savings for cable operators, while allowing the operators to offer new network services across uncoupled access networks.

Today, mobile and wireline core networks have some obvious disparities. They use

- different credentials to authenticate and authorize devices
- different data management
- different accounting and billing systems in the back office
- different policies to instantiate and manage data sessions

In spite of this, targeted convergence can reduce or bridge many of these differences without the need for massive replacements of customer CPEs. Appropriate updates of infrastructure features can enable the efficiencies realized through core convergence.

While the operators manage their multiple networks, the users should be network agnostic. With converged core networks, the user does not need to know which access network (e.g., fixed, Wi-Fi, cellular) s/he is on, but can expect seamless and consistent user experience.

Finding the sweet spot to converge the functionalities of the two different cores will benefit the operator's capex and opex, while providing the end user with seamless and consistent service experience.

1.2 Key focus

Core network convergence has been discussed in various forums and occasions in recent years. Despite its popularity, we are not aware of any previous work to systematically approach the subject. In this paper, we will approach it in a comprehensive way by exploring various convergence scenarios and architectures. The architectures range from a less involved interworking model, a semi-convergence case to a fully committed integration model.

- Interworking model: Interworking between the HFC network and 5G core is placed in the network. No change to today's DOCSIS CPE is required.
- Integration model: DOCSIS is a type of 5G access network being managed by the 5GC. Some modification to today's modem may be required.

We will address the benefit of each use case in the context of optimizing OPEX, synergy with the new cloud architectures, and implementability by equipment vendors.

1.3 Why now?

LTE EPC uses a point-to-point architecture, where each EPC component talks to another with a dedicated interface and procedure that is defined by the 3GPP. The 5GC, in contrast, uses more modern service based architectural techniques to provide better scaling and network configuration flexibility in comparison to the EPC point to point approach.

For example, while significant work has been done to the LTE protocol to support IoT devices, the new 5G core architecture better addresses the sheer number of devices (e.g., IoT) connecting to network while meeting the key performance indicators (KPIs) of some 5G services, e.g., ultra-reliable low latency communications (URLLC). The 5GC has been armed with the modern techniques to provide flexibility to meet the requirements of different vertical industries.

Even as the mobile operators might be slowly upgrading portions of the EPC to 5GC and not replace the legacy EPC wholesale, the old EPC interface protocols can be containerized and provided as a microservice to allow any network functions to use it.

The trend in the mobile world is synergistic with cable, as cable is also moving towards a cloud native architecture. As we can see, the recent evolution of the 5G mobile core from a point-to-point architecture to a service-based architecture provides a rare opportunity to converge mobile and cable cores.

The international mobile standardization body, the 3GPP, has been keenly working on specifying techniques to take advantage of the new 5GC. The 3GPP has an active study item on wireless-wireline converged core, with the specifications planned to be completed by the end of 2019. Vendors will be providing products soon after. This provides an immediate opportunity to insert HFC operator requirements for convergence in the global mobile ecosystem.

1.4 Where is the party?

The Broadband Forum (BBF), a telco-led organization, is actively studying FMC models, driven by operators and vendors such as Huawei, Nokia, Ericsson, etc. The study is being documented in SD-407 of BBF TR, where several models of how the 5GC and fixed broadband cores interact are being considered. Some solutions have been developed, but the TR is still in process. The BBF has been liaising with the 3GPP SA2 group to communicate the impacts to 5GC, and SA2 is working on incorporating the impact to the Stage 2 5GC specs as part of the "5WWC" study item. 3GPP intends to complete its convergence study in Q4 2018 and develop complete specifications by the end of 2019. There is an opportunity to insert cable industry requirements for convergence into this global scale effort within this time frame.

2 5G Reference Architecture

The 5G architecture is defined in 23.501 [7] and it describes a number of new network functions, some of which are evolutions of 4G functions, while others are new. There are also a number of new tenets, one of which is that non-3GPP access can seamlessly connect to the 5G core. The architecture does not though define what the backhaul requirements are, and choosing the appropriate solution is left to vendors and operators.

For 5G, 3GPP redefined the access network and made a clear separation between the access management and session management, from both node level and logical levels. The UE connects to the access network and the Access and Mobility Management Function (AMF) and from there can establish one or more PDU sessions with the Session Management Function (SMF). The N1 NAS mobility management is handled by the AMF, while the session management of the UE's connections is handled by the SMF. In release 15 of the 3GPP specification, only untrusted non-3GPP access, i.e. connection over an IPSec tunnel over any WLAN access, is possible, however in release 16, support for additional access technologies is being defined in the 5WWC study item in TR 23.716 [11].

The AMF is limited to managing the access layer, which can include:

- New Radio (NR): the 5G air interface
- Non-3GPP Interworking Function (N3IWF): the IPsec gateway for untrusted access in the current release or in release 16, the addition of WLAN
- Wireline 5G Cable Access Network (W-5GCAN): the DOCSIS access network

Authentication and registration of the devices that connect to the access network is performed through the AMF, which communicates with the Unified Data Function (UDM) to get the profile and the AUSF where the connection is authenticated.

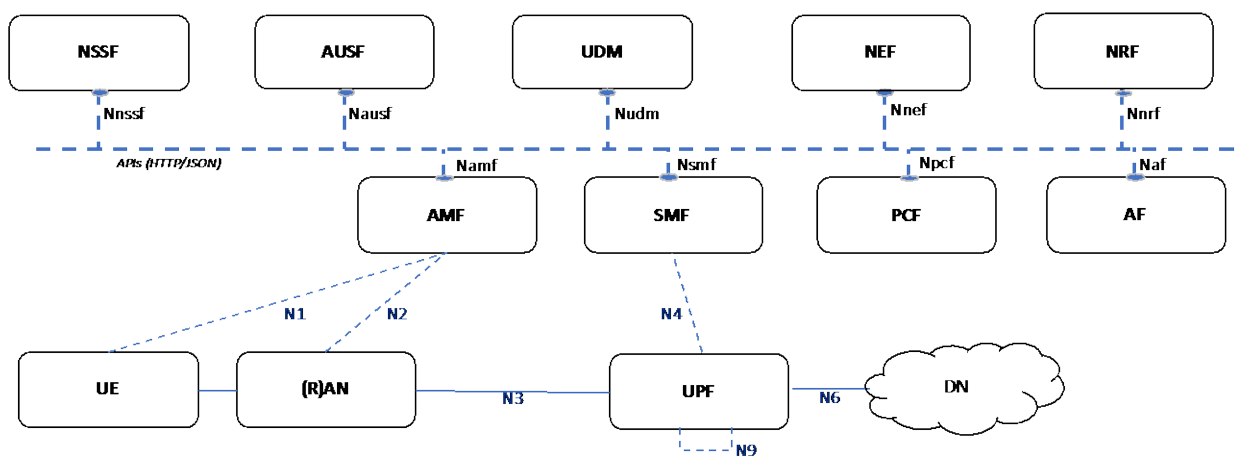

Figure 1 – 5G Reference Architecture

Figure 1 shows the fundamental components of the 5G core. The functions that are applicable to Cable Access are: AMF, SMF, User Plane Function (UPF), UDM, and Policy Control Function (PCF). The Radio Access Network (RAN) is the mobile equivalent to a CMTS in that it is the access part of the network. In addition, the UPF implements some of the functions of a CMTS (such as QoS control) although there are some subtle differences, which are explained in the following sections.

A major goal of wireless and wireline convergence work item is to unify the user experience. This goal can be achieved by applying the same policies from the PCF when the UE connects to either 5G new Radio (NR) or non-3GPP access such as cable. In 5G, the policies such as QoS, content filtering, SD-WAN, etc., are applied to the PDU by the PCF and in some use cases by the Network Exposure Function (NEF) and Application Function (AF).

The N1 interface is between the UE and the AMF and is relayed over the access network, i.e., the NR in 3GPP or cable network. This is a major change compared to 4G which means the 5GC can communicate seamlessly over non-3GPP access. If there are two simultaneous connections, then there are multiple N1 instances. The N1 Non-Access Stratum (NAS) (24.501 [14]) specification applies to untrusted access in release 15 and will be updated to address release 16 converged access requirements. N1 NAS provides authentication and authorization mechanisms, communicates the allowed slices and allows the UE to set up PDU connections with associated IP addresses and polices, including traffic steering, offload, and routing polices. Furthermore, static and dynamic access selection rules to help the UE how best to use both access networks simultaneously are provided by the network.

The N2, also referred to as NGAP [11], interface performs Access Network configuration to associate the AN with the AMF and then manage the UE's connection at the AN. This includes PDU session management, session context which includes the Security Key, Mobility Restriction List, UE capability, etc., and transports N1 NAS messages. In release 16, there may be a new specification to capture the non-3GPP aspects.

The N4 interface, described in TS 29.244 [16] is between the SMF and the UPF. We could consider part of the cable access network as a UPF. The SMF associates with the UPF and exchanges capabilities and configuration if necessary. The PDU set up involves IP address management, policy, charging and service configuration. The specification may need to be updated to accommodate the cable network.

The N3 interface is for user plane traffic and is based on GTP [12] and [13]: The AN and the UPF use a tunnel to encapsulate the UE's datagram to allow the UE to have any IP address or even Ethernet or other non-IP traffic. QoS is marked in the packet so that the AN can prioritized the traffic based on policies applied in the UPF.

3 Mobile and Cable, Commonalities and Key Differences

The following tables outlines the key commonalities and differences between the cable and mobile cores.

Table 1 – Comparisons Between Cable and Mobile

	Cable	Mobile
Goal	Manage access line to home end-users	Manage the end-users directly
Scope and complexity	DOCSIS is an access network protocol that defines the interface between CM and CMTS. The CMTS is a subset of the 5GS. Many 5GC control plane concepts do not apply in the cable environment, such as connection and mobility management. The CMTS is also a "god box", a single entity that implements many functionalities ranging from communicating with the CM on the RF side, and policy enforcement point for a SF. With DAA, at least the RF portion is modularized and some split options in 5G are similar in concept to those in Remote PHY.	3GPP specifies an end-to-end architecture capable to manage registrations, connections, sessions, mobility, reachability, access authentication, policy, as well as charging and authorization.
Subscriber	CMTS manages a CM, which is a connection point to a household	5GC manages a UE which is an individual end-device, similar to a CPE in the cable world.

	Cable	Mobile
Provisioning	CM is provisioned via TFTP config file server. DHCP hands out IP address. A CM can have only 1 IP address.	UE gets IP address from the SMF, or via the SMF acting as a DHCP relay, and UE can have multiple IP addresses, one per data network.
Identity, authentication	Each CM is identified by its MAC address. Uses "implied" authentication, because the CM is provisioned by the backend. Although the IP address of devices directly behind the CM are visible to the CMTS, individual user identity in the home is not visible to DOCSIS in a typical deployments because of the presence of gateways and NATs. Only the cable modem identity is established	SIM is used for identity; each UE has a separate SIM and may have multiple SIMs in the near future. Note this is the end user identity, not the "access device identity" which is the case in cable.
Policy	Focused on providing bandwidth policy / QoS for a service flow in order to provide an SLA. QoS policy is defined per service flow. CMTS implements network admission control, i.e., it is focused on bandwidth to the home and its allocation, rather than end user. In principle, a policy per device behind the CM can be defined. However, since the home devices are typically behind a gateway, a direct mapping is not easy (especially in the case of NAT). For FMC, cable may borrow some of the mobile policy concepts, with the understanding that they apply to access to the subscriber rather than the subscriber him/herself.	Encompasses resource and traffic management for subscription tiers and applications. QoS policy can be applied per PDU session.
Accounting and charging	Operators account for data usage. IPTV and voice are accounted but is zero-rated. Billing is per household, not per device / user. CMTS reports accounting records on bytes used. Billing is done by the back office.	Charging can be done per device, or 3GPP can link accounting records of multiple subscribers, i.e., "shared" billing plan, which is similar to cable. 3GPP has collapsed online and offline charging into a single Charging Function.
Vendor ecosystem	Because the CMTS is a combination of complex RF level implementation as well as user and control plane management all in one, this limits CMTS vendors to the traditional 4 players.	The network infrastructure side supports an ecosystem dominated by cellular vendors. However, with innovation going on to disaggregate the eNBs and the gNBs, MNOs, particularly MSOs who are also MNOs, will have the opportunity to deploy

	Cable	Mobile
	Particularly the space of silicon vendor for the RF components is extremely limited. "Cloudifying" the CMTS and converging with mobile will allow new vendors to emerge and enable product differentiation.	interoperable components from multiple, smaller vendors. On the core side, as the 5GC architecture moves to containers and microservices, the new 5GC may start to enable modularity and interoperability between vendors.

Although the table shows that the concepts and ecosystem of 5G and cable are different, we are now at the cusp of a wave of innovations enabled by virtualization and disaggregation of components. Now is the time to explore the convergence between 5G and cable. Let us start with some obvious areas of convergence, such as the area of bandwidth management and QoS, and how they can be managed by a 5G toolkit.

4 Mobile Backhaul

4.1 Benefits

One of the major costs incurred in building a mobile network is the mobile backhaul. Indeed, among the major cost components in deploying a small cell network, including spectrum, network equipment, site lease, and power, backhaul alone accounts for 61% of the cost per GB [1]. The existing DOCSIS networks have been enhanced [2] to provide a backhaul service that is comparable to fiber performance but at a significant economic advantage [3]. Key use cases for mobile operators are:

- A cable operator building a mobile infrastructure
- A cable operator leasing backhaul capacity to a mobile operator
- In-home small cell, with "inside out" coverage

In [3], the authors explain in detail the market opportunity for a DOCSIS mobile backhaul, as well as options to optimize the DOCSIS protocol for mobile backhaul applications.

This paper focuses on the system level integration of DOCSIS backhaul in a 5G ecosystem.

It is worth noting that the DOCSIS technology can effectively backhaul, mid-haul, or fronthaul (for most splits) mobile traffic. This is contrary to what the fiber optical vendors have been telling the mobile and cable industries. Fronthaul is no longer synonymous to Common Public Radio Interface (CPRI), a closed specification created for macrocells by traditional radio vendors. DOCSIS has been shown to support lower layer splits such as MAC-PHY or intra-PHY [4] (Option 7 defined by 3GPP). Below that, the capacity requirements may become too high for DOCSIS to support. For the sake of brevity, we will focus on the backhaul use case in this paper.

4.2 Architecture

The 3GPP specifications focus on the RAN and the packet core. There is not much discussion about the backhaul as they are generally thought of as being part of the N3 transport interface. In Figure 2, the DOCSIS network is embedded inline with N3 (see Section "5G Reference Architecture" for more detail on N3). The UE has a PDU session on the RAN which is backhauled over the DOCSIS network. The UE may also have hybrid access capability which means that it can reach the data network via a traditional macrocell network that is backhauled by an MNO's traditional transport.

To provide backhaul service comparable to fiber, the DOCSIS network needs to match the QoS on the backhaul to what is required for the PDU session. This can be done either dynamically after the session has been set up, and actively allocating resources on the DOCSIS side as proposed in [3], or semi-statically during session setup. The advantage of the latter is that it provides flexibility to the backhaul operator to define policies on when to admit / reject a PDU session request from the UE. For example, depending on how the DOCSIS backhaul is configured, it may be able to provide better or worse quality of service (QoS) compared to the other access networks such as the macrocell network. One open question is how can the DOCSIS system signal to the 5G ecosystem that there is excess resource, or the lack of, on the DOCSIS backhaul side? The following section outlines a possible solution based on an interworking function (IWF) between the DOCSIS backhaul and the 5GC.

4.2.1 Converged Transport Network QoS

To perform network resource optimization in order to achieve system-level QoS, one potential solution is a converged transport QoS framework which includes an IWF that talks to the wireless and the DOCSIS networks, and works with the AMF to determine best path for the UE's PDU session to the data network. It also provides session information to the AMF and therefore the UE, should a handover be initiated when an alternative path is deemed more optimal.

The IWF is a resource coordinator, shown in Figure 2. The IWF acts as a controller that reads various utilization information from the gNBs and with this information, it makes decisions on how to optimally balance resource usage across the wireless network. In order to do that it communicates with the AMF, SMF, and PCF. The IWF needs to talk to an AMF to discover the SMF associated with a UE's PDU session. The IWF can then retrieve the PDU session QoS information from the SMF. The information it needs in the mobile backhaul case is the utilization of the DOCSIS backhaul link and some policy associated with it (e.g. move UEs if the utilization crosses a certain percentage).

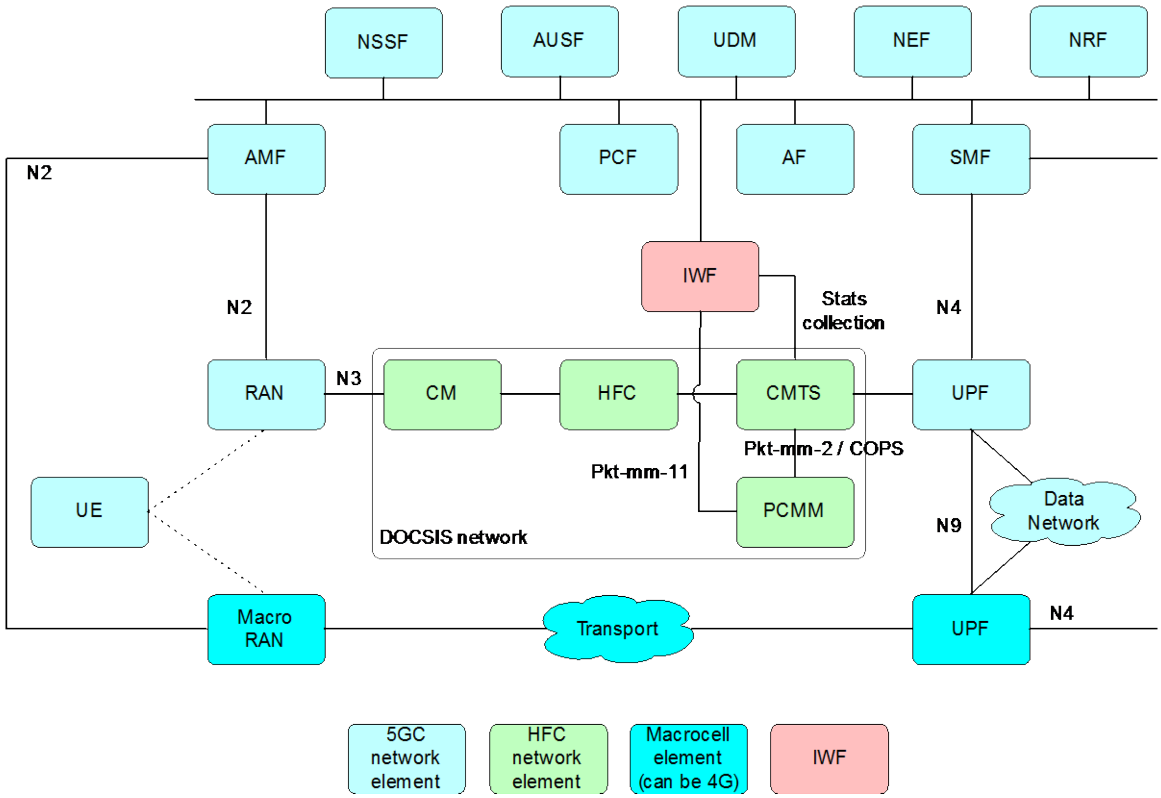

Figure 2 – DOCSIS For Mobile Backhaul

As depicted in Figure 2, the IWF can help deciding when to carry UE traffic over DOCSIS backhaul vs. other mobile options (e.g. macro RAN).

The interfaces pkt-mm-11 and pkt-mm-2 are standard Packet Cable Multimedia (PCMM) interfaces as explained in [6]. The “stats collection” interface can be any existing interface that the CMTS has to report service flow utilization, e.g. SNMP/IPDR etc.

Rather than a separate entity, the coordinator may be implemented as part of the CMTS control plane, although this might require tighter integration between the backhaul and the 5GC.

The IWF decisions can be very fine grained and based on a session-by-session input. Additional capacity can be added or subtracted as needed on the DOCSIS side based on session information on the mobile side. Another simplified and coarse-grained solution is to view DOCSIS as a static link, e.g., the DOCSIS backhaul presents a static capacity, and in that sense behaves in a similar way to any static peer-to-peer link, such as microwave or fiber. The IWF monitors the utilization on this fixed link, and as it approaches a certain threshold IWF can take a corrective action.

4.3 Example use case

A simple use case is one where UEs keep joining a small cell with a DOCSIS backhaul. At some point (depending on how the backhaul is configured) the utilization of the DOCSIS backhaul link may get too high. Monitoring such utilization is easy for the CMTS because it has service flow statistics and the backhaul traffic is carried over one or multiple service flows. The utilization statistics can be communicated to the IWF in the form of percentage. The IWF can have a local policy, for example, “take action if the DOCSIS backhaul utilization exceeded 90%". The form of the action is contained in the IWF, and the associated policies are outside the scope of the DOCSIS backhaul. For example, the IWF can start moving calls to an adjacent cell or a macrocell. The elegance of such a solution is that all the DOCSIS system has to do is to report the backhaul link utilization and from that point on the IWF can take over.

5 5GC Control of Devices in the Home

5.1 Benefits

If an operator considers merging policy of the two network domains, then a common use of policy appears to be an obvious choice. One option for 5GC is to control the connected devices in the home as if they were regular mobile devices.

The benefits of using 5GC to control devices in the home are:

- Consistent policy definition framework
- Consistent policy enforcement point (device and/or GiLan for the most part)
- Easy handover from a wired/Wi-Fi cable network to a mobile network and consistent behavior across these fixed/mobile handoffs

5.2 Architecture

In Figure 3 the devices in the home access the data network via a fixed line access network (AN). All the other surrounding 5G components are kept so that now we have a consistent control framework for both 5G and fixed AN.

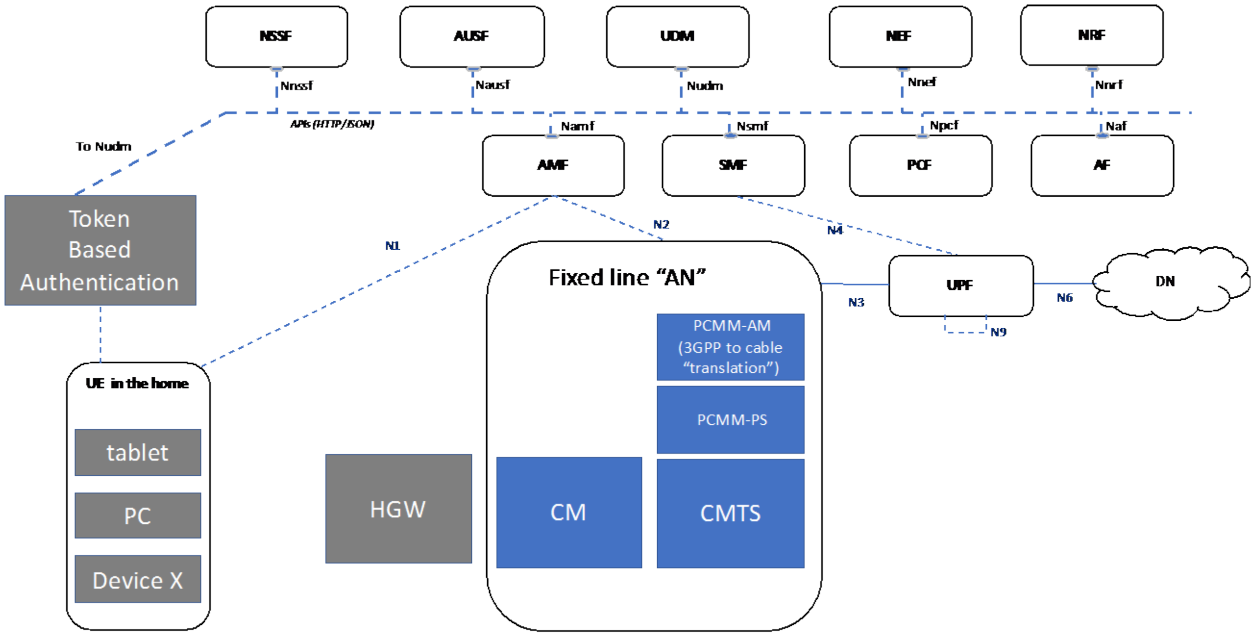

Figure 3 – 3GPP control of devices in the home

Note that we are not replacing anything within the DOCSIS system itself, i.e. the cable modem registration, policy control of CMTS and CM are still all DOCSIS based. This is because DOCSIS system is still the best set of standards to handle cable access at this time. However, when it comes to control of devices in the home, which is outside the scope of DOCSIS system anyway, it makes sense to align with wireless.

Because the home devices can access the internet without a SIM, an alternative identifier may need to be selected for the devices. An identifier can be communicated with the UDM, and from that point on the normal 5G processes can be executed. Note that token-based authentication is one of multiple solutions being explored. An alternative may be selected for standardization.

Token-based authentication is fairly common in commerce these days. It typically involves sending a unique code to a trusted device (e.g. a mobile phone) that a user can then type into an authorization page in order to prove that she is indeed the user authorized to use the device.

5.3 Example use case

Consider parental control as a policy example. In the current ecosystems, parental control rules that are defined on a mobile device do not automatically apply in the home. Therefore, a website that cannot be accessed from a mobile device might be accessed in the home over Wi-Fi – unless a separate policy is defined on the home gateway to block it. With the approach outlined in this section, a single parental control policy would apply to both mobile devices using SIM-based authentication and the home Wi-Fi environment.

Consider two separate use cases to illustrate this in more detail:

Use case 1: A mobile phone authenticated with a SIM is subject to the mobile policy rules. Once the same phone is in the home it will switch to Wi-Fi and be subject to the set of rules in the fixed access network. It is the same device with the same SIM so identity is easy to establish and we just have to make sure the policies are coordinated across the mobile and fixed access networks.

Use case 2: Certain parental controls are defined for a child. The same child can own several devices. One of them will have a SIM (the mobile) and therefore, a clear identity and a parental control policy associated with it. Other devices that may be used by the same child, e.g. an iPad in the home, that do not have a SIM, and token-based authentication is used to establish identity instead. Once identity is established it can be associated in the UDM to the primary SIM based identity and the same policies will be applied across several devices.

6 5GC Control of The Home Gateway

6.1 Benefits

Instead of controlling the home devices directly with the 5G infrastructure, it is possible to control the home gateway, and the home gateway in turn controls the devices in the home.

The benefits of using 3GPP to control devices in the home through the home gateway are:

- No need to change anything about the home device operation (i.e. token-based authentication) because they are not directly controlled by 5G
- Centrally managed policies

6.2 Architecture

A common protocol for controlling the Customer Premise Equipment (CPE) is TR-69. With this architecture, the 5GC is controlling the ACS server as if it were a UE. This will require the ACS server to have middleware written for it to translate N1 messages into a format that the home gateway will recognize. Note that TR-69 is nothing but a secure transport, it does not mandate the actual message format. And since every home gateway vendor might have different definitions, each home gateway vendor will need to create their own “N1 to ACS translator”. The actual business arrangement and implementation issues are outside the scope of this paper.

For this use case, authentication is required because the home gateway does not have a SIM. A token-based authentication, similar to the one used for the “5GC Control of Devices in the Home” can be used as well.

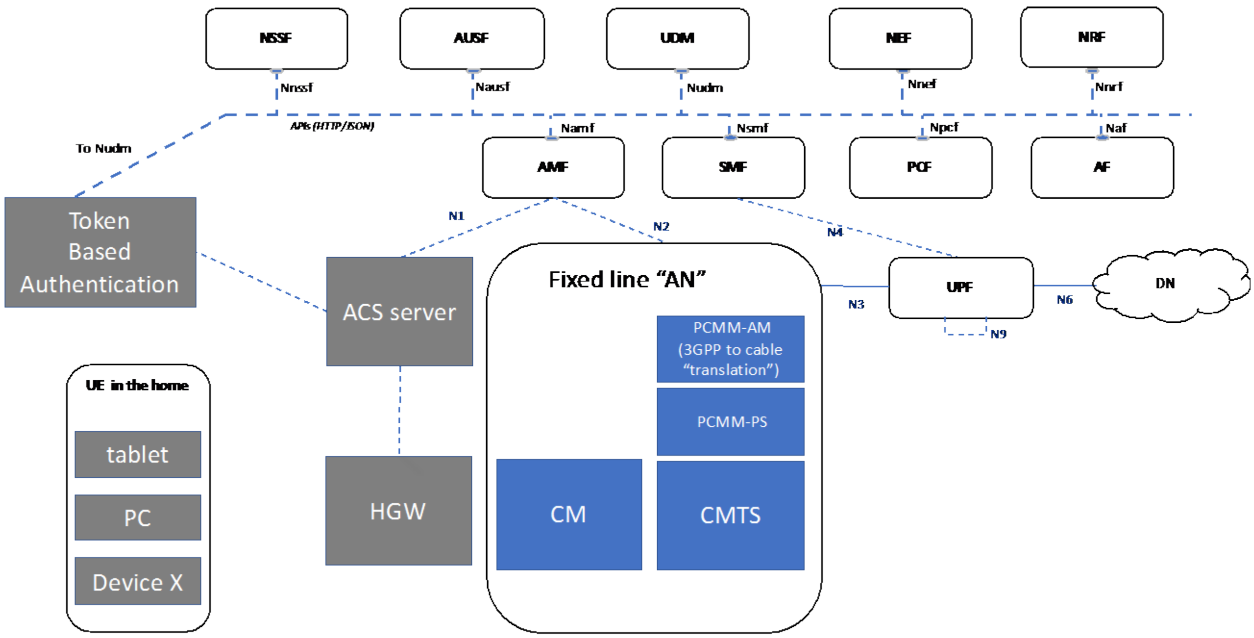

Figure 4 – 5G control of the home gateway

It is possible to have a hybrid model of N4 control of both HGW and GiLan. But such a model is out of scope for this paper for simplicity.

6.3 Example use case

The same "parental control" use case as in "5GC Control of Devices in the Home" applies to this use case as well.

One advantage the home gateway control method has is that devices in the home are controlled by the home gateway, so there is no need for a token-based authentication on the home devices. However, this means that someone has to configure the home gateway to associate identities to devices (and it is likely that many of the readers of this paper are the "IT manager" at home and are up to the task of doing exactly that). This also means that if you have visitors to your home, an identity will have to be established for them, otherwise their "parental control" rules will be subject to the default policy on the home gateway.

7 5GC Control of DOCSIS Network as an Access Network

7.1 Benefits

If cable and wireless were developed together from ground zero, we could have modeled the CMTS as a type of UPF and AMF, and the CM as a type of a UE. The HFC could have been considered a type of access network. This is in fact what the 3GPP System Architecture 2 (SA2) group has been working on since early this year, in collaboration with the Broadband Forum (BBF). After all, the NG RAN, the LTE air interface, Wi-Fi, and in our case, the cable HFC are all access networks that push bits to the end user (and receive bits on the return path).

The emergence of 5GC with a service-based architecture enables us to converge selected network functions with less dedicated infrastructure, and to exploit new 5G network services across uncoupled access networks. Later in this section, we discuss a list of potential use cases.

7.2 Architecture

7.2.1 Interworking Model

As stated in “Introduction”, there are two models for converging the cable network and the 5GC. The less impactful interworking model is shown in Figure 5. Fundamentally, the key principles include:

- No impact on CPE
- Burden of interworking is largely placed on the HFC infrastructure
- HFC authenticates CMs with existing mechanisms, registrations posted into the UDM

With an interworking function implemented by the cable operators and vendors, some enhanced services can be enabled without any impact to the HFC network or changes to the 5GC components:

- Converged QoS: this has already been discussed in “Mobile Backhaul” earlier
- PCF links into the north side of HFC policy platforms
- HFC charging records can be updated for better correlation with 5GC records
- HFC infrastructure may communicate with NSSF, NEF and NRF for 5GC services

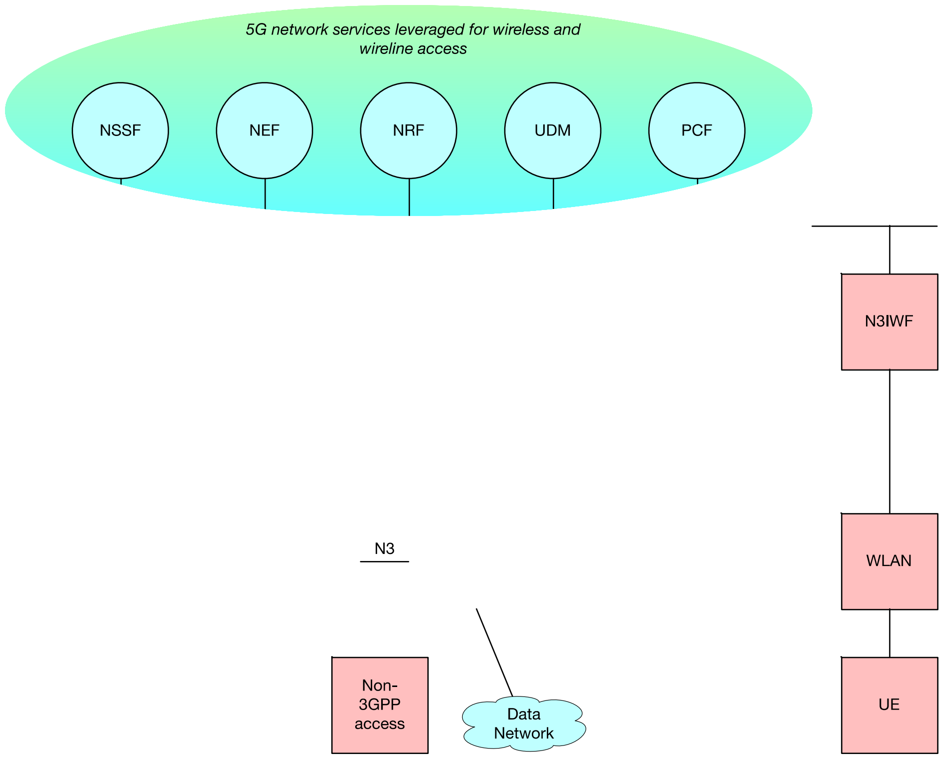

Figure 5 – Convergence of 5GC and DOCSIS Functions for Legacy Devices

7.2.2 Integration Model

In the longer term, the operators should evaluate the business case for a fully integrated model. A possible architecture is shown in Figure 6, in which the CM appears as a 3GPP UE to the 5GC. This means the next generation CM needs to support a “profiled” version of N1 interface, labeled as N1’. The HFC network on the other hand will need to support a “profiled” version of N2 interface, which links into the AMF.

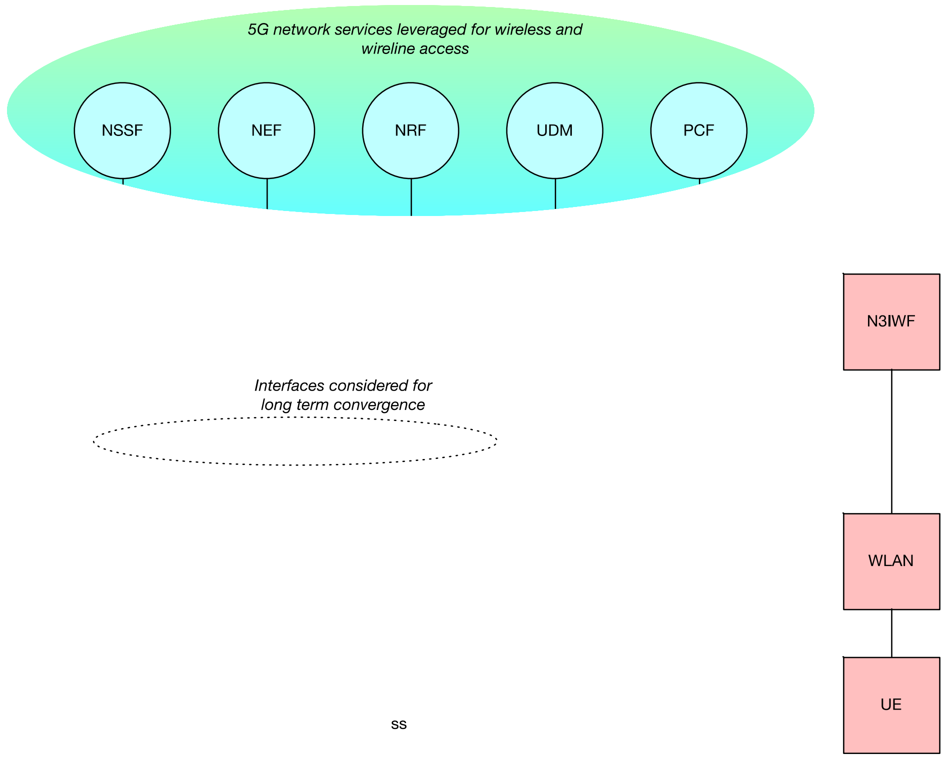

Figure 6 – Convergence of 5GC and DOCSIS Functions

While N1 and N2 interfaces encompass a large number of services, some of these services, such as mobility support, are not applicable to fixed AN. So the additional 5GC functionalities that need to be supported by the HFC network can be tailored and reduced.

Since the AMF and the UPF are control and user plane functions, respectively, and the CMTS already has control plane and user plane separation, the CMTS can implement a profiled AMF, labeled as AMF', and a profiled UPF, labeled as UPF', without exposing the N2 and N3 interfaces externally.

In 5GC, the AMF discovers the SMF that is associated with a PDU session, in order to obtain the set of QoS policies associated with the session. In the collocated case where the CMTS implements the SMF', these will become internal procedure to the CMTS.

The HFC network could be updated to generate 5GC accounting records. The AMF' and the SMF' will have to appear to the NSSF, NEF and NRF with 3GPP standard network element interfaces, so that the HFC can directly query these functions.

The network functions NSSF, NEF, NRF, UDM, PCF could be leveraged to enable converged services between cable and mobile, to enable:

- Integrated fixed (CM) and mobile subscriptions
- Converged accounting record system
- Fixed access aware network slicing
- Fixed access aware network exposure function for higher value data intelligence
- Converged service discovery
- Fixed network aware 5G traffic steering and splitting

Cable access and mobile NG RAN will manage its own

- Customer devices
- PHY and MAC layers
- Credential and authentication centers

It may be beneficial for the operators to start with the interworking model, while evaluating the benefit and the effort in the long run for the integration model.

7.3 Example use case

Some of the example scenarios that can be enabled by the integration model include:

- Correlation between fixed and mobile networks for an end-to-end user service (unified subscription, QoS and charging)
- End-to-end network slice that applies network resources across fixed and mobile segments for residential or industrial customer applications
- End-to-end data exposure
    - Improved data about your network and subscriber data patterns
    - Opportunity to monetize the data
- Converged traffic steering and traffic splitting across access networks (5G, 4G, Wi-Fi via HFC)
    - Steering and splitting native features in UDM, PCF, SMF and UPF
    - Continuous services across access networks

While the concept of integrating the 5GC and the DOCSIS network enables systematic convergence at the network element level, some of the use cases that are of interests to the operators can be enabled individually without a full-on convergence between the 5GC and the DOCSIS network.

For example, for the case of uniform parental control through "5GC Control of Devices in the Home", all we need is for the cable operator to provide an interworking function that can link the token-based identity (or alternative identity) to the IMSI on the UDM. As such, the use case can be enabled as part of the interworking model, without a complete integration between fixed and mobile network elements.

It is important for the operator to identify high value use cases and analyze the short-term and the long-term benefit in light of the cable network updates.

7.4 Brief Overview of Other Forms of ConvergenceUnified Infrastructure for Cable and 5G

7.4.1 Benefits

With the advent of virtualization technologies, both ETSI-NFV and cloud Native approaches, it's possible to host both cable and wireless network functions and cloud functions on the same physical hardware because there are cloud/virtual versions for both. Fortunately, more than the hardware can be shared. Many of the software infrastructure components for these functions are open source and are common to many different use cases, from firewalls to virtual routers. In this world of common HW and common SW infrastructure cable and mobile are simply two different types of applications sharing many resources and expertise across different domains. Furthermore, operational methods, such as devops can now be shared across these functions so that an expert can easily handle devops in one domain and with little training master the other.

7.4.2 Architecture

Figure 7 is a high-level capture from the cloud native foundation (cncf.io) of the various tools used for developing cloud applications. An implementor may choose any subset of the tools here. See Ref [5] for an interactive map.

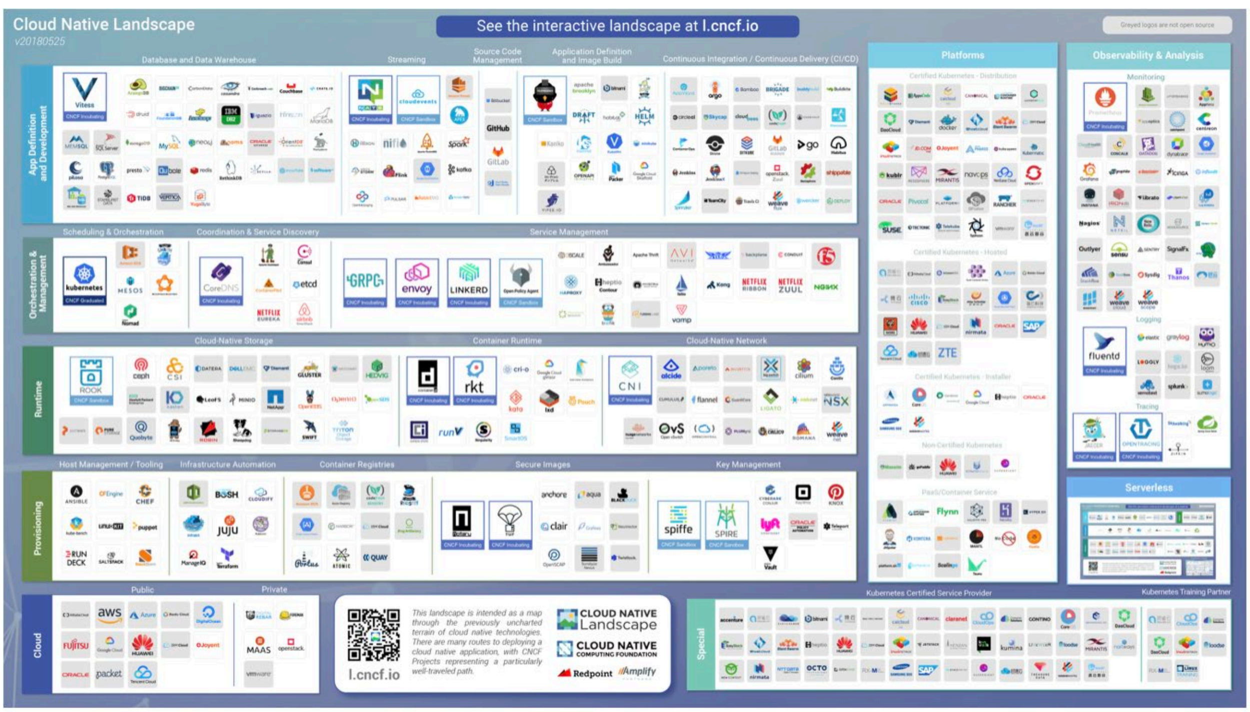

Figure 7 – Cloud Native Landscape

As can be seen from these diagrams there is a huge number of tools, from CI/CD tools to loggers, databases, buses and more. Functional components such as the packet core and the CMTS can be applications built on top of this infrastructure.

7.4.3 Example use case

- Mobile use tends to be high during the day. When subscribers are home fixed line usage goes up. With a common infrastructure compute resources can be moved by time of day
- Same devops process for SW upgrade for both mobile and cloud CMTS.

7.5 Unified Manageability

7.5.1 Benefits

Similar to the unified infrastructure case, the same set of tools can be used to manage both the mobile side and the cable side. For example, a stats collector polls managed objects and should not care if these managed objects are part of a mobile system or a wireless system.

7.5.2 Architecture

One option for unified management is ONAP (Open Network Automation Platform), see [17].

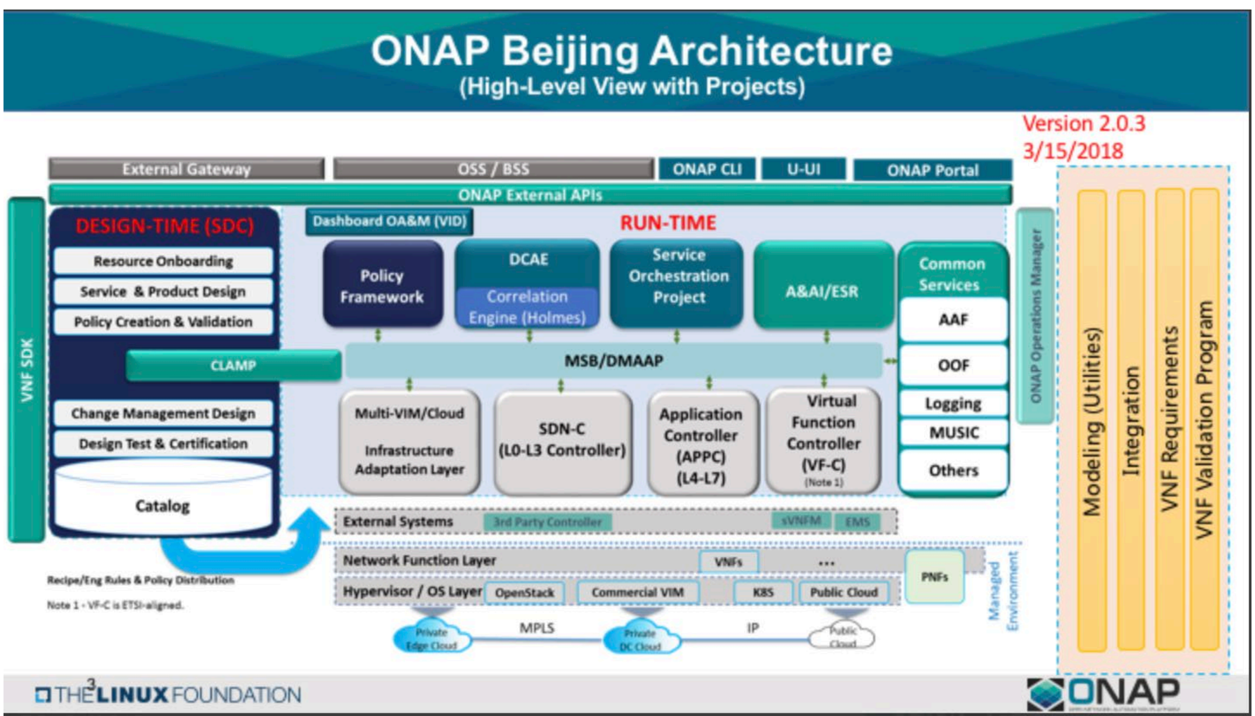

Figure 8 – ONAP Architecture [17]

Detailing ONAP is outside the scope of this paper. However, at a high level it's a full network management suite, currently optimized around virtual appliances but can apply to physical appliances as well. It can help the full automation life cycle that is depicted below:

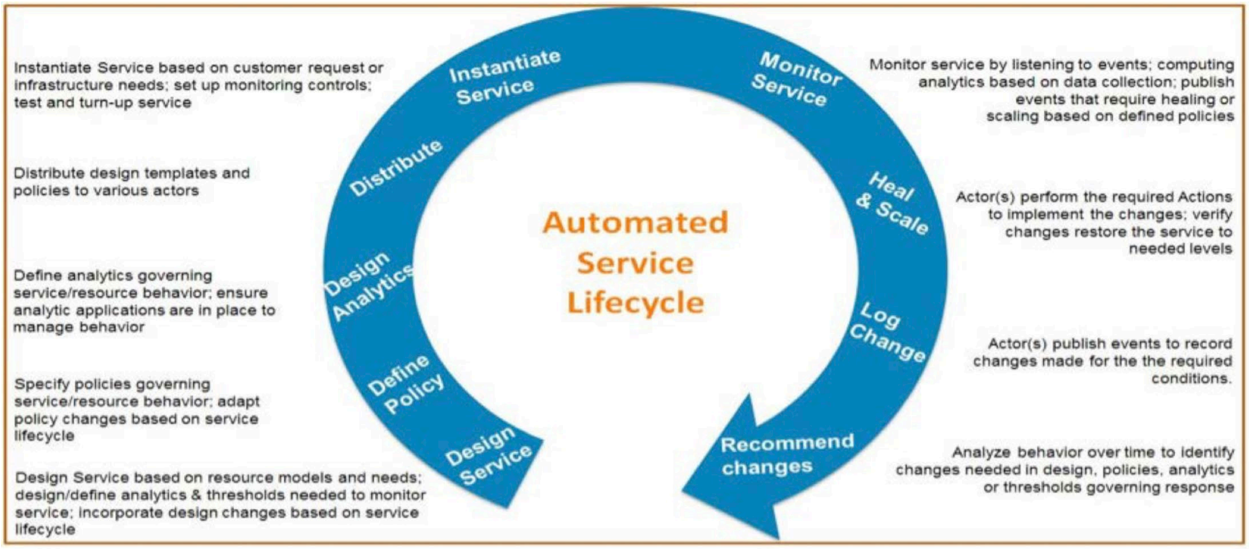

Figure 9 – ONAP Service Lifecycle [17]

Note that at this high level the underlying access technology can, and should, be abstracted. In the bigger picture the ability to build and support services is one of the more OPEX intensive tasks, and one where convergence can be achieved as it is all designed to work above the network layer.

7.5.3 Example Use Cases

An example use-case may be the definition of a VPN service that can work over mobile or wireless and eventually reaches the same firewall regardless of the access technology.

7.6 Business Level Convergence

It is possible to converge only at the business layer and leave all the technical layers below separate. With business level convergence, the customer receives a single bill for both the wireless and the mobile subscription, regardless of the technical implementation, e.g. converged, non-converged, an MVNO agreement with a mobile operator or a native wireless network. The one technical aspect this type of a convergence might have is on the provider icon displayed on the mobile, e.g., if cable company ABC sells a mobile service it will need to show ABC on the mobile phone. Cable company ABC will also need to issue its own SIM cards and have the ability to populate the customer database on the UDM.

8 Conclusion

This white paper presents a look ahead of emerging wireless-wireline convergence trends within the global ecosystem.

An access network is a multi-layered system as depicted in Figure 10. The layering itself is similar for both cable and mobile because the underlaying design is common to many communication systems. In this paper, we have provided a brief overview of convergence at the different layers, with our main focus and contribution at the network element layer. We are at a critical time where the 3GPP, the BBF, and the cable industries are innovating synergistically. This is a rare opportunity to converge at the network element layer.

Specifically, recent work to introduce service based architectures in mobile cores and wireline cores presents an opportunity to leverage core convergence in order to:

- Reduce OPEX
- Apply new 5G network services across mobile and wireline access networks

Can operators who own both mobile and HFC networks exploit these recent trends to provide improved subscriber services at lower costs? How deep into the network does convergence need to penetrate in order to produce savings and improved services? Solutions for light convergence and fully integrated convergence are now being identified. The 3GPP will standardize its view of core convergence by the end of 2019. Operators of mobile and HFC networks can work together with their technology suppliers to evaluate the convergence level solutions that best meets their needs. Now is the time to insert HFC operator requirements for convergence into the global ecosystem.

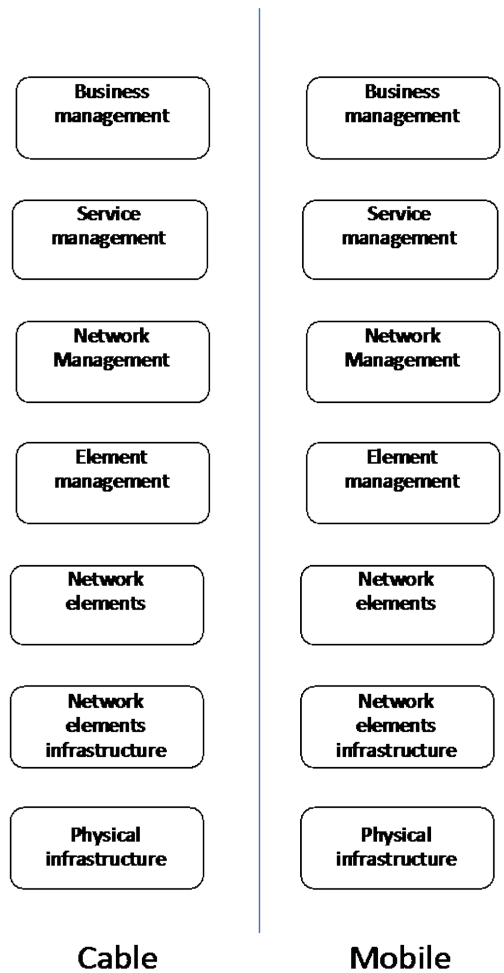

Figure 10 – Layers where mobile and cable can converge

9 Abbreviations

3GPP	Third Generation Partnership Project
5GC	5G Core
5GS	5G System
AF	application function
AMF	access management function
AN	access network
BBF	Broadband Forum
EPC	evolved packet core
FEC	forward error correction
FMC	fixed mobile convergence
HFC	hybrid fiber-coax
HD	high definition
Hz	hertz
ISBE	International Society of Broadband Experts
KPI	key performance indicator
NEF	network exposure function
NG RAN	next generation RAN
NR	new radio
NRF	network repository function
N3IWF	non-3GPP interworking function
PCF	policy control function
RAN	radio access network
SA2	System Architecture working group 2
SCTE	Society of Cable Telecommunications Engineers
SMF	session management function
UDM	unified data function
UPF	user plane function
URLLC	ultra-reliable low latency communications
W-5GCAN	wireline 5G cable access network

10 Bibliography & References

[1] Kyung Mun, "Spectrum – Will its intrinsic value decrease in a small cell world?" October, 2016. https://www.fiercewireless.com/wireless/mun-spectrum-will-its-intrinsic-value-decrease-a-small-cell-world

[2] "Synchronization Techniques for DOCSIS Technology Specification," D-01 Draft 2018-07-30. CableLabs.

[3] John T. Chapman and Jennifer Andreoli-Fang, "Mobile Backhaul over DOCSIS," Proceedings of SCTE Fall Technical Forum, October, 2017. https://www.nctatechnicalpapers.com/Paper/2017/2017-mobile-backhaul-over-docsis

[4] "Creating an ecosystem for supporting non-ideal fronthaul," Telecom Infra Project white paper, February, 2018. https://telecominfraproject.com/wp-content/uploads/VRAN_WP_final.pdf

[5] Cloud native toolkit.Cloud native toolkit. https://github.com/cncf/landscape

[6] PacketCable Multimedia Specification (PCMM). I-07, 2018-11-11. CableLabs. https://apps.cablelabs.com/specification/packetcable-multimedia-specification

[7] 3GPP TS 23.501, "System Architecture for the 5G System", https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3144

[8] 3GPP TS 23.502, "Procedures for the 5G System", https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3145

[9] 3GPP 24.244, "Wireless LAN control plane protocol for trusted WLAN access to EPC", https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=1062

[10] 3GPP Document 23.716

[11] 3GPP TS 38.413, "NG Application Protocol (NGAP)" www.3gpp.org/DynaReport/38413.htm

[12] 3GPP TS 29.281, "General Packet Radio System (GPRS) Tunnelling Protocol User Plane (GTPv1-U)" www.3gpp.org/dynareport/29281.htm

[13] 3GPP TS 38.415, "PDU Session User Plane Protocol" www.3gpp.org/dynareport/38415.htm

[14] 3GPP TS 24.501, "Non-Access-Stratum (NAS) protocol for 5G System (5GS)" www.3gpp.org/dynareport/24501.htm

[15] 3GPP TS 24.502, "Access to the 3GPP 5G Core Network (5GCN) via Non-3GPP Access Networks (N3AN)" www.3gpp.org/dynareport/24502.htm

[16] 3GPP TS 29.244, "Interface between the Control Plane and the User Plane nodes", www.3gpp.org/dynareport/29244.htm

[17] ONAP, Open Networking Architecture Platform: https://www.onap.org

