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The Road to Wireline-Wireless Convergence

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Executive Summary

Consumers are becoming increasingly dependent on Internet connectivity to go about their daily lives, expecting seamless and uninterrupted connectivity wherever they are. Service providers are offering bundles consisting of wireline and wireless network access to meet customers' needs. However, simply providing connectivity over multiple access network types is not sufficient to meet customers' expectations, and providers will not see operational efficiencies or cost savings by managing these as independent networks.

Wireline-wireless convergence (WWC), with a single converged core, will enable service providers to deliver a unified customer experience across multiple access networks while reducing expenses. This paper describes the following considerations.

- Benefits of deploying WWC with a single converged core

- Key capabilities offered by the converged core

- Phased approach to delivering WWC for current and future networks

- Gaps in current specifications and products

1. Overview of Wireline-Wireless Convergence

Broadband users expect seamless and uninterrupted connectivity in their daily lives. This ubiquitous connectivity should be available whether they are at home, on the go, in the office, or even at the coffee shop. The consumer's expectations do not change, regardless of their location or which access network technology is being used—they just want services to work seamlessly. MSOs can offer this next level of connectivity through a combination of wireline and wireless access networks. Cellular and Wi-Fi are the primary methods for untethered access to the broadband network with fiber, and DOCSIS networks provide the backhaul connectivity for most wireless networks.

Service providers offer bundled solutions for mobile and fixed broadband access. These mobile and fixed services are delivered using different access technologies, each using their independent network cores. Mergers and acquisitions of service providers can increase the number of core systems, further exasperating the heterogenous mixture of network cores that need to be managed.

The desire to improve the customer's experience when connecting to the broadband network via different access methods, coupled with a growing edge computing market, drives an even greater need to provide consistent, seamless, and low-latency network access. Operators and application providers need to deploy services with guaranteed service-level agreements (SLAs), regardless of the underlying access network technology.
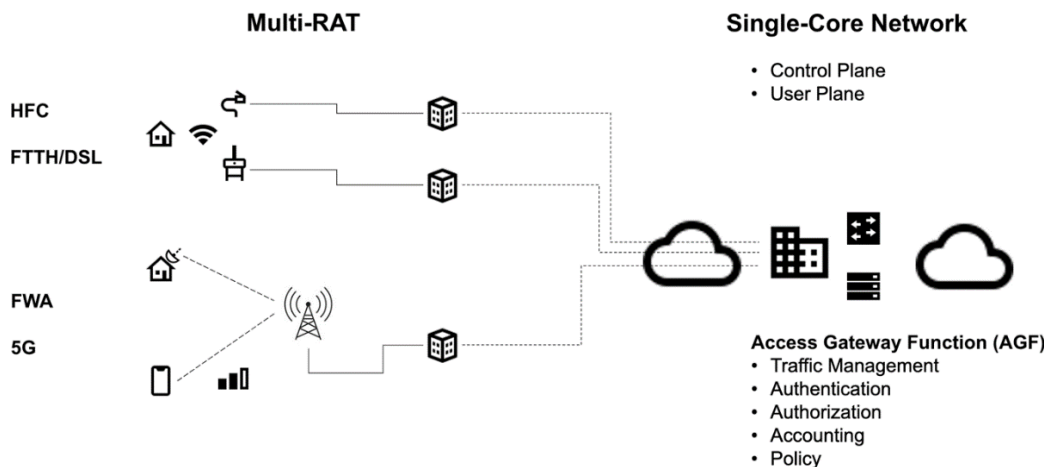

Figure 1. Converged Access Network Overview

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To meet these demands, CableLabs is working with members and the vendor community to consolidate these networks through a single converged core. WWC will leverage a single converged core based on existing mobile cores to enable seamless wireless access across Wi-Fi and cellular networks. Wireline networks were designed to be fixed and lack many of the features needed by mobile users; Wi-Fi users need these mobility features on wireline networks.

1.1. Drivers for Network Convergence

Migrating wireless and wireline access networks to a single converged core will benefit both the users and the service providers. Three key drivers that are motivating this access network transformation investment are listed below.

- Improve the customer experience and provide differentiated experiences in order to reduce churn, and become more competitive in the marketplace.

- Increase revenue by offering more value to the customer (home broadband plus mobile).

- Reduce CapEx and OpEx costs with more efficient networks and organizations.

1.2. Mobile Network Models

Service providers offer mobile access through two different business models: The traditional mobile network operator (MNO) model and the mobile virtual network operator (MVNO) model. The MNO model requires the provider to deploy and manage the entire mobile network, whereas with the MVNO model, the service provider resells access to the MNO's network. There are different flavors of MVNO models, ranging from reselling the MNO services all the way to hybrid MVNOs (H-MVNO) where the MVNO runs a full mobile core with some wireless assets of their own in conjunction with leveraging the MNO infrastructure. See Figure 2 for more information on the different MVNO levels.
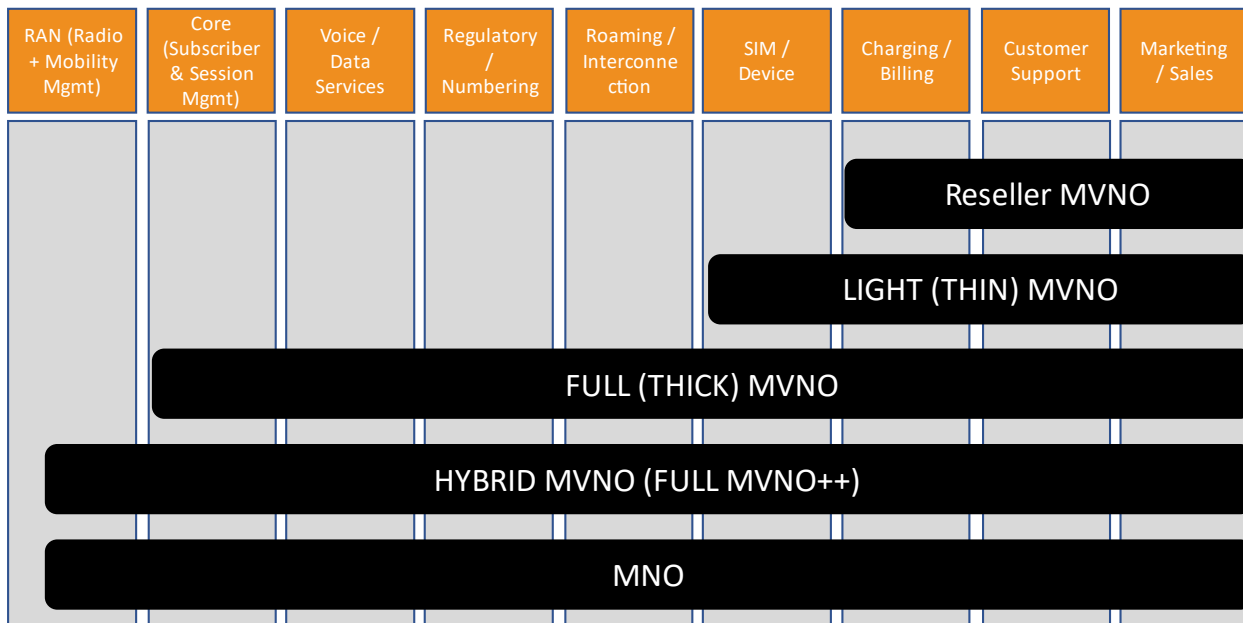
RAN (Radio + Mobility Mgmt)	Core (Subscriber & Session Mgmt)	Voice / Data Services	Regulatory / Numbering	Roaming / Interconnection	SIM / Device	Charging / Billing	Customer Support	Marketing / Sales
						Reseller MVNO		
					LIGHT (THIN) MVNO			
	FULL (THICK) MVNO							
HYBRID MVNO (FULL MVNO++)								
MNO								

Figure 2 MVNO Models

To build a converged network experience, service providers will need to have a mobile core deployed on their networks. MVNOs that do not have their own mobile core, such as reseller, light/thin, and service providers, will need to add one to their networks. MNO-based, full MVNO-based, or H-MVNO-based operators will already have a mobile core deployed in their network, which can be used as a foundation for their converged core. The converged core will help service providers realize the potential across multiple types of access networks and Wi-Fi.

1.3. Vision of the Converged Network

The vision for a converged network consists of access networks based multiple radio access technologies (multi-RAT) managed by a single core and supported by a single back-end infrastructure. The broadband network that is used to deliver services to the end user, whether it is a mobile network, DOCSIS network, fiber network, or Wi-Fi network, is transparent to the end user/device and the application/ service provider.

A single converged core will manage a wide variety of wireline and wireless access networks and end-user devices, providing a single source and reference for all subscriber data across all access technologies. A shim or proxy layer is introduced to converge some of the currently deployed wireline networks. As new generations of wireline networks are developed and then deployed, these shim layers will be retired in favor of a much tighter integration.

An architecture based on a single core supported by common back-end infrastructure will ensure the best possible end-user experience, regardless of which broadband network they are connected through; for example, the same firewall rules, speed tiers, DDoS mitigation, and authentication will work across all networks. New revenue opportunities will arise by leveraging bundles and being able to deploy and manage new services across all access networks with a single deployment. Operator expenses will be reduced through the elimination of redundant systems across each access network type by leveraging centralized cloud native functions and increasing scale.

1.4. Phases Toward a Fully Converged Network

Service providers have extensive wireline and wireless assets in place that cannot be easily replaced overnight but, rather, need to be gradually migrated toward a converged network architecture. Additionally, the latest access networking products available today do not provide sufficient capabilities to manage wireline and wireless networks with the same converged core.

The three primary phases for WWC are described below.

- Phase 1: BNG enablement—Enables a broadband network gateway (BNG) to provide some support to unify the control and user plane across wireline access networks with limited connectivity to a 5G core.

- Phase 2: AGF enablement—The Access Gateway Function (AGF) replaces the BNG and provides a tighter integration with the core and extends access into the customer premises using a 5G residential gateway (5G-RG).

- Phase 3: next-gen wireline technologies—With future wireline access networks, the AGF will be eliminated, and the wireline network will connect directly to the converged core.
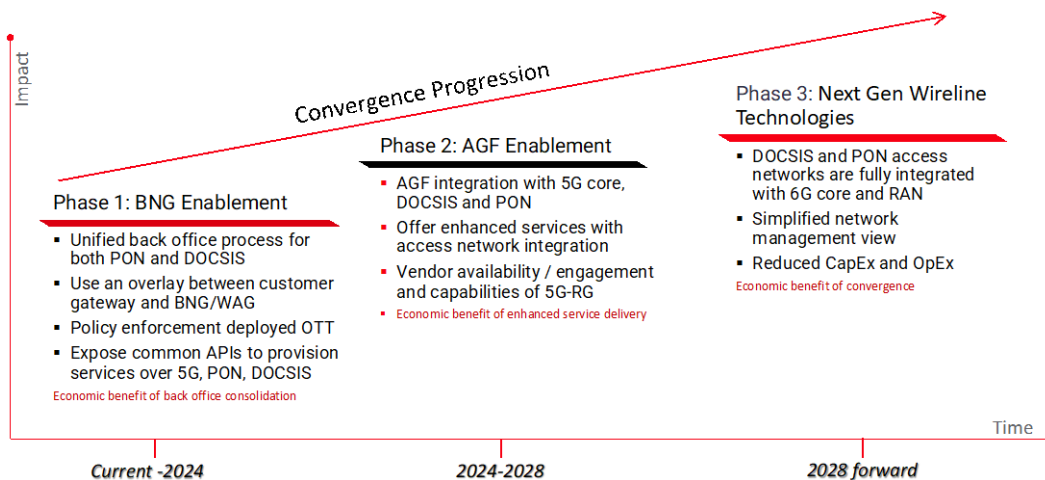

Figure 3 Convergence Deployment Roadmap

2. Architectural Details

This section describes the target architecture for delivering connectivity services with a converged core, along with a summary of the capabilities provided by the core. In this architecture, the wireline and wireless access networks are managed by the converged core, with the access networks being connected either directly to the converged core over a dedicated link or through a series of other access networks.
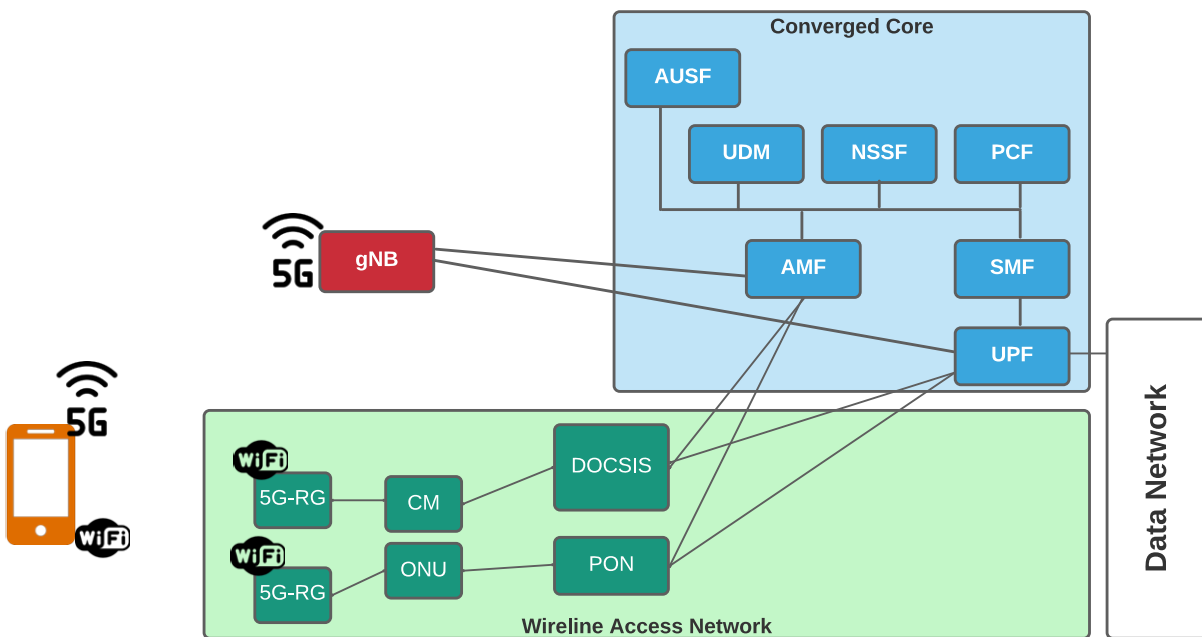

Figure 4 Phase 3 Architecture

2.1. Converged Core Responsibilities and Capabilities

When a converged core is deployed, many of the common capabilities that are currently provided by each access network are centralized into the converged core. This section identifies five classes of capabilities that are common across all access networks and can be moved to the converged core. These five of capabilities are listed below.

- User and device management

- Policy enforcement and QoS

- Traffic management

- Usage data

- Security and authentication

2.1.1. User and Device Management

This is a single unified platform for managing all subscribers and their devices. It can include different end-user devices for the different access networks: user equipment (UE) for 5G NR, client stations for Wi-Fi, cable modems for DOCSIS network, and optical network units (ONUs) for fiber networks and other gateway devices.

2.1.2. Policy Enforcement and QoS

A single network's function will manage all policy enforcement and QoS. This includes managing throughput and data caps, along with enabling users to manage their traffic. The core includes the control, monitoring, and elements of the user data. Some of these policies will be implemented by each access network. Downstream speeds can be managed and enforced by the converged core. Upstream speeds and QoS requirements are enforced by the access networks based on the policies from the converged core.

2.1.3. Traffic Management

Traffic management includes steering, splitting, and switching the traffic, along with session management. Current wireline networks do not implement steering, splitting, or switching for user devices and gateways because the network path is fixed. Smart phones, tablet computers, and other devices can seamlessly transition between 5G and Wi-Fi access points. When these devices are connected over Wi-Fi, the fixed wireline networks providing the backhaul for their traffic will need the advanced traffic and session management that is only available on wireless cores today. This will also enable 5G wireless and fixed wireline gateways to effectively manage traffic over both 5G and wireline network connections based on the customer's needs and the current network status.

2.1.4. Usage Data

Current wireline and wireless systems use different formats and provide different levels of detail around user and access network usage. The converged core will normalize this data and provide a single view across all subscribers and all access networks. When tied to a converged subscriber management system, it allows for subscriber level data to correlate disparate data to subscribers across multiple data sources. This will allow for efficient storage and analytics of the usage data.

2.1.5. Security and Authentication

Converging security and authentication capabilities across all access networks is critical. One of these capabilities is mutual authentication for operators to ensure that they know who is connecting to the network. This also allows the subscribers to know that they are connecting to the correct network. This means that keys on user devices and the operator's core will need to be managed across all wireless and wireline access networks.

Another aspect of security and authentication is ensuring data privacy in the network. This means encrypting the user data and the control data across the access network. Encryption algorithms and keys will be standardized for this to work seamlessly. Different access networks support different encryption algorithms and key management systems. The core and devices that it manages will need to interoperate across one or more cryptography stacks.

Additional security services, such as firewall and DDoS mitigation, will also be applied across the converged network for all users.

2.2. Wi-Fi Integration with Convergence

The capabilities described in the previous section will be applied to Wi-Fi connections. Wi-Fi has been treated as a local area network (LAN) and not a part of the access network. Wi-Fi is also the most widely used method for the last hop for end-user device connectivity, providing new ubiquitous connectivity that is delivered at a very low cost per bit. Connecting via Wi-Fi is often preferred by the service provider and the consumer over 5G and other cellular technologies.

Integrating Wi-Fi provides both unique challenges and opportunities to improve customer experience. The Wi-Fi convergence can be managed at the user device, especially for maintaining session and other capabilities as the device transitions between Wi-Fi and 5G coverage. Wi-Fi access points and gateways can also provide additional levels of support for convergence when they are managed by the service provider.

3.   Road to Convergence

As mentioned in Section 1.4, convergence will be delivered in a phased approach over the next several years. This section will dig deeper into what each of these phases will look like and will provide additional granularity within these phases. These phases progress toward more complete integration with the converged core and additional capabilities on residential gateways (RGs) running on the customer premises.

These phases are predicated on a 5G core being deployed to manage the operator's mobile network.

3.1. Phase 1—BNG Enabled WWC

The initial phase of WWC will be based on leveraging the BNG to integrate the wireline network into the mobile core. The BNG is not directly integrated with a 5G core, though it can proxy requests to a 5G core from a UE or connect to a 5G core through another application. In this phase, there are three architectural options being highlighted for deploying this initial integration, each with advantages and disadvantages. These three options for phase 1 are network overlay with access network agnostic capabilities, BNG access network integration, and Fixed Mobile Interworking Function (FMIF) integration.

With the addition of a BNG to the converged network, service providers can provide mobile offload over Wi-Fi, consolidate subscriber data onto a single converged core, and begin rolling out services independent of the access network. Once an operator has both wireline and wireless networks, it can begin its journey toward a converged network.
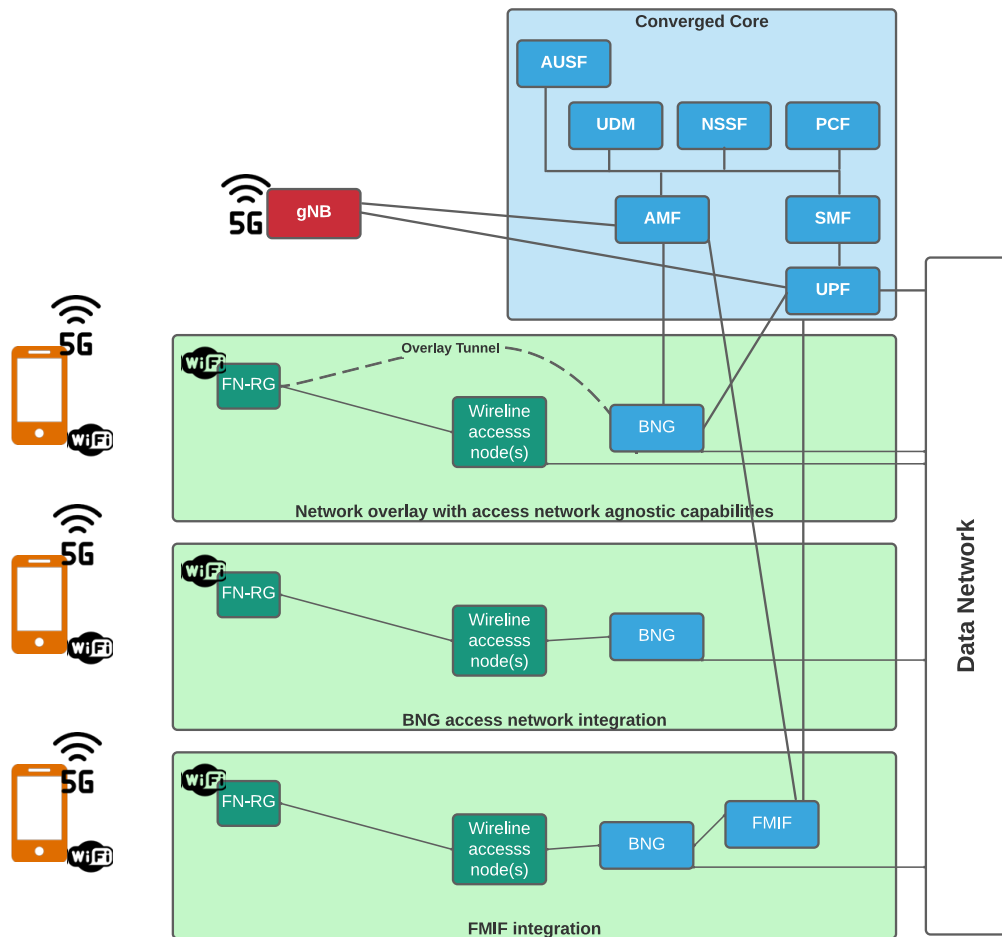

Figure 5 Phase 1 Architecture

3.1.1. Network Overlay with Access Network Agnostic Capabilities

The residential gateway RG and BNG are connected over a Layer 3 network tunnel, such as a GRE or L2TPv3 tunnel. These tunnels are agnostic to the underlying access network and leverage only the L3/IP networking capabilities. This means that this integration can be deployed without modifying the current wireline access network and will work across both DOCSIS and PON networks. This phase supports fixed network RGs (FN-RGs) that are currently deployed and have not been updated to natively support 5G control. Many gateways and access points deployed today have existing support for these tunnels and can be configured with current over-the-top device management tools. Once this overlay tunnel is deployed, the devices that connect to the gateway will use the BNG to provide authentication and authorization with other network management tools. The BNG can proxy authentication and access for Wi-Fi devices to a 5G core for mobile offload.

3.1.2. BNG Access Network Integration

The BNG can also provide centralized management and data plane for PON networks. This will provide services such as user and device authentication, IP management, policy enforcement, usage data, and routing.

DOCSIS network integration is not a part of the current BNG specifications and integration beyond a network overlay, and L3 routing would require vendor-specific modifications.

3.1.3. FMIF Integration

With the addition of an FMIF, the BNG can deliver a more complete convergence experience for PON networks through adding integration with a 5G core. The FMIF is still being specified as of the publishing of this paper. The FMIF will implement the 3GPP W-AGF specification. The FMIF further defines the interface between the 5G core and the BNG. When the FMIF is combined with a 5G residential gateway (5G-RG), additional WWC capabilities, such as network slicing and traffic steering, are enabled over the wireline access network.

Because of the close timing of the FMIF specification and the more complete AGF specification, it is possible that adoption of the FMIF outside of the AGF will be limited.

3.2. Phase 2—AGF Enabled WWC

With phase 2, service providers will fully integrate their existing wireline access networks with the converged core. The AGF provides a platform to connect the wireline networks and RGs to the 5G core. These 5G-RGs are enhanced to support the 5G control plane and communicate directly with the 5G core over any access network. AGF will replace BNG; a subset of necessary functionalities of BNG (e.g., gateway functionalities) would be retained in AGF.

This evolution of the BNG and FMIF will provide a much more complete integration with both control plane and user plane functions in the converged core. The AGF allows the 5G core to converge the five capabilities of convergence identified earlier (user and device management, policy enforcement and QoS, traffic management, usage data, and security and authentication).

Figure 6 shows a WWC network using the AGF control plane (CP) and user plane (UP), along with the 5G-RG integrating directly with the converged core.
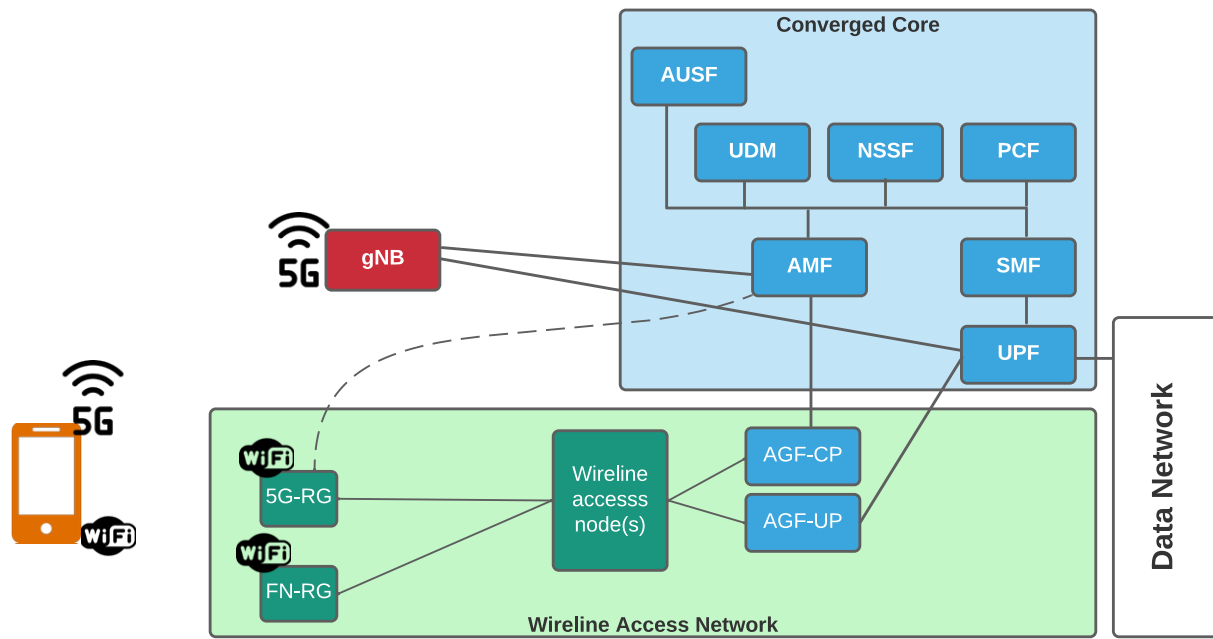
Figure 6 Phase 2 Architecture

3.3. Phase 3—WWC with Next-Gen Wireline Technologies

With next generation wireline networks and a 6G converged core, the need for an AGF- or BNG-type shim layer to proxy requests between the wireline access networks and the core will be eliminated. The wireline networks will be able to integrate with the converged core using the same interfaces as 5G/6G RAN. This new generation of wireline networks will also interface with the RAN Intelligent Controller (RIC) and other O-RAN functions.

This will provide a truly single core and will finally eliminate the need for wireline network provisioning systems and other proxies. All gateways will natively support 5G/6G-RG.

4. Gaps in Current Standards and Implementations

The WWC architecture and roadmap are largely based on existing specifications and product. Some of these specifications are mature and others are still in a draft phase. Through this analysis and proofs of concept, several gaps in both vendor implementations and specifications have been identified. Until these gaps have been closed, some WWC capabilities will not be available. The specifications and products being deployed in phase 1 are mature and may not be resolved prior to advancing to phase 2. Work is underway to prioritize and close these high-priority gaps.

4.1. Phase 1 Gaps

Phase 1 is based on existing standards and specifications.

4.1.1. Incomplete Interface Specifications

There are no current interface specifications between DOCSIS and the BNG or W-AGF. Vendors have demonstrated products using W-AGF with interfaces of their choosing to the DOCSIS system.

There is no interface defined between the BNG and the 5G core.

4.1.2. Optimizing All Access Networks from a Converged Core

With an overlay tunnel, there is no awareness of the underlying access network and its capabilities. This means that capabilities such as Low Latency DOCSIS are not utilized with this specification. All traffic on the underlying access network will need to be prioritized by the FN-RG and the BNG.

4.1.3. Vendor-Specific Solutions

Due to missing interface definitions, vendors have defined proprietary interfaces to support some of these integrations. These proprietary interfaces could pose challenges when migrating to the AGF in phase 2.

4.1.4. Optional Features and No BNG Certification

Many of the features needed in the BNG are optional and are not implemented by many vendors. For example, the WLAN-AG and TWAF to support Wi-Fi offloading and overlay tunnels are not implemented by all vendors.

Additionally, there is no certification for the BNG, and each must be tested for compliance.

4.2. Phase 2 Gaps

Phase 2 specifications are currently under development and are nearing completion. The gaps outlined for phase 2 will be resolved in the initial releases or through revised specifications.

4.2.1. Lack of DOCSIS Network Integration to the AGF

The current AGF draft specifications do not include DOCSIS networks. These need to be added to either the BBF AGF specification and/or a CableLabs AGF/DOCSIS interface specification.

4.2.2. 5G-RG Availability

There is a lack of 5G-RG availability, and vendor engagement is needed to develop 5G-RGs. Changes and additions to the 5G-RG specifications may also be required to support this development.

4.3. Phase 3 Gaps

Updates to the access networks will be required to support the same core side interfaces (N1, N2, and N3) as the AGF. The N1, N2, and N3 interfaces defined by 3GPP define the control and user data protocols between the core and the access network. These interfaces have been extended to support wireline networks, with several contributions being included in release 18 of the 3GPP specification. Additional changes to the N1, N2, and N3 interfaces may be required to support next generation wireline access networks as these next generation access technologies are not yet available, and support for N1, N2, and N3 interfaces can be added early in their release lifecycles.

4.3.1. N1 Interface

The N1 interface defines the control plane interface between the UE and the core. This will need to support Wi-Fi authentication, managing 5G/6G-RGs, and control of other devices in the customer premises network.

4.3.2. N2 Interface

N2 is the control plane interface between the core and the access network. The N2 interface and parameters supporting wireline networks have different speeds, protocols, and other capabilities from what is supported with the 5G RAN. Configuration options for these wireline networks have been added to the N2 interface and data models. Further development, integration, and testing will be needed on this interface to natively support next-generation wireline networks.

4.3.3. N3 Interface

N3 is the user plane interface that terminates the GTP-U tunnels between the RAN and the UPF. It carries QoS flows from UEs to the UPF. To support GTP-U tunnels, the next-generation wireline access networks will need to add them. Optionally, the UPF will need to add support for additional tunnel types; e.g., the UPF could terminate traffic from IPoE or PPPoE tunnels defined between the access networks and the BNG/AGF.

5. Conclusion

Enabled by current technologies, wireline-wireless convergence is now being delivered. Additional capabilities will be available with the deployment of AGFs and 5G-RGs. Before these can be developed by vendors and deployed, more specification work is needed to address DOCSIS capabilities. Many of these new services can be delivered now via vendor-specific and/or over-the-top components. To increase competition and keep costs down, standards-based solutions are needed. Though some standards exist, those standards will need to evolve or be supplemented by additional work to deliver a standards-based convergence solution.

Phase 1 WWC, based on BNGs, will enable features such as Wi-Fi offloading for mobile networks, common security features, unified billing, and usage billing for wireless networks. Newer services can come to market, along with additional bundling opportunities. Increasing the number of shared services between access networks will reduce operational cost and capital expenses. Traffic management will be centralized in the BNG and converged core.

Phase 2 WWC, based on AGFs and 5G-RGs, will provide an even tighter integration and additional capabilities over the BNG. This will enable further consolidation between the converged core and wireline networks. Policy and QoS enforcement will be managed by the core for both wireline and wireless networks. Additional access network management components will be replaced with shared services in the converged core.

Phase 3 WWC, based on next generation access networks, will realize a fully converged access network across a wide variety of access technologies. The AGF can be eliminated, with its functionality moved to the core and access networks. The access networks will support unified and standardized control and user plane protocols that are no longer specific to the access network. Real-time and near real-time controllers can be deployed in all access networks to ensure optimal operation with more predictive fault and capacity management.

The gaps in converging DOCSIS, PON, and Wi-Fi with 5G networks outlined in this paper will be resolved through CableLabs' member and vendor collaboration. This will result in updating and extending existing CableLabs and other industry specifications. New specifications for next-generation access networks will also be developed.

This phased approach toward convergence allows for a gradual migration and, at the same time, delivers additional system capabilities in every phase. The roadmap evolves toward a complete integration of wireline and wireless networks.

6. Abbreviations and Acronyms

3GPP	3rd Generation Partnership Project
5G	fifth generation
5G-RG	5G residential gateway
5GC	5G core
AGF	Access Gateway Function
AMF	Access and Mobility Management Function
BBF	Broadband Forum
BNG	broadband network gateway
CapEx	capital expense
CM	cable modem
CPE	customer premises equipment
DOCSIS	Data-Over-Cable Service Interface Specifications
FN-RG	fixed network residential gateway
GRE	generic routing encapsulation
IP	Internet Protocol
IPoE	IP over Ethernet
L2	Layer 2 (from OSI model)
L2TPv3	Layer 2 Tunnel Protocol version 3
L3	Layer 3 (from OSI model)
NSSF	Network Slice Selection Function
OpEx	operational expense
PCF	Policy Control Function
PON	Passive Optical Network
PPPoE	Point-to-Point Protocol over Ethernet
QoS	Quality of Service
RG	residential gateway
SMF	Session Management Function
UDM	unified data management
UE	user equipment
W-AGF	Wireline Access Gateway Function

7. Acknowledgements

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