Fixed-wireless convergence on a multi-access edge

Technical Paper prepared for SCTE by

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1. Introduction

Broadband access is an essential utility to connect with each other and the cloud, from the convenience of our homes. Ultimately broadband evolution is about delivering a reliable and affordable user experience at gigabit speeds, but no single access technology can cover all use cases equally well. To connect everyone with the digital world we live in, requires a multi-access broadband strategy that combines an expanding range of wireline and wireless access technologies.

The paper discusses how cable operators may effectively leverage 5G fixed-wireless access (FWA) to complement and enhance their existing wireline broadband offer and deliver a converged multi-access broadband experience everywhere.

2. The case for fixed-wireless broadband access

Cable operators have done a remarkable job extending the life and utility of the existing coaxial access plant to bring the Internet to nearly every home. By pushing fiber ever closer to the home, they were able to speed up data transfer rates from kilobits to megabits per second and do so without breaking the bank. But demand for faster access continues unabated while the cost of extending fiber further to the home is increasingly steep. Fiber-to-the-home is typically the preferred and future safe way to go, but deployment can be costly and time consuming, even for new housing projects. Gradually and inevitably, a faster broadband experience may literally become out of reach for more and more consumers.

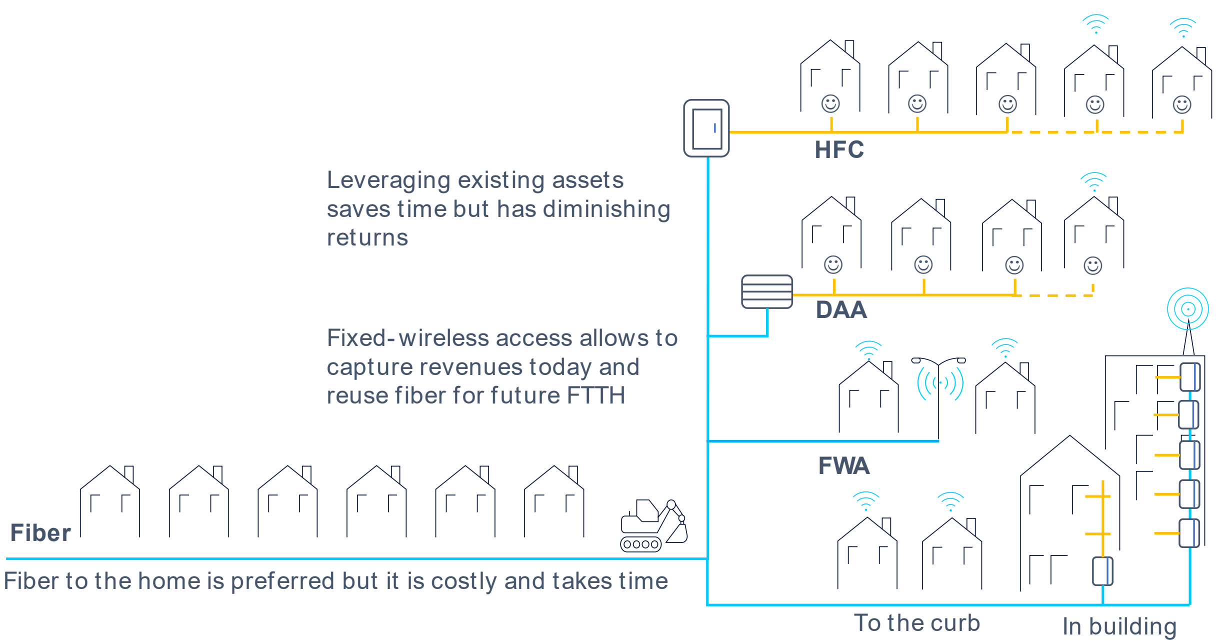

Figure 1. The case for fixed-wireless broadband access

Fixed-wireless access can address these last-mile broadband wireline coverage issues (

Figure 1). LTE/5G radio deployed in the sub 6 GHz frequency bands can rapidly cover large areas with access speeds that can sustain high definition video streaming. Small cells operating at mmWave frequencies (24 to 39 GHz) can even deliver fiber-grade Gigabit broadband services. Besides licensed spectrum, many regulators have actively engaged to make shared and unlicensed spectrum available in various frequency bands. For example, the US Federal Communications Commission designated spectrum in the 3.5 GHz band for shared use (the "innovation band" of the Citizen's Broadband Radio Service or CBRS).

FWA perfectly complements wireline broadband deployments in the last mile:

- In brownfield it can be used in overlay to address capacity and coverage issues of underserved wireline broadband users.
- In greenfield, FWA can be an effective tactic to get quick service coverage and revenues and potentially support a phased fiber-to-the-home rollout.

The question is how to integrate FWA in a combined multi-access broadband infrastructure to create better cost synergies reduce operational complexity?

3. Multi-access broadband and edge convergence

Convergence in general aims to achieve operational simplification and better economies of scale by consolidating network requirements and pooling resources. The operational goal of fixed and wireless broadband convergence is a seamless and simplified multi-service user experience that is access agnostic. Although broadband consumers typically use only one wireline or wireless access method at a time, another objective is to leverage a common operational infrastructure to manage subscriber access and service policies. Converged operators that also offer mobile broadband services are keen to consolidate all their services on a more agile, cloud-native 5G Core (5GC), and reap the cost and performance synergies of fixed and mobile convergence (FMC).

The ultimate goal is to build an agile and cost optimized network that can deliver a ubiquitous and seamless service experience over any broadband access medium. Figure 2 summarizes the requirements in a multi-access broadband target infrastructure.

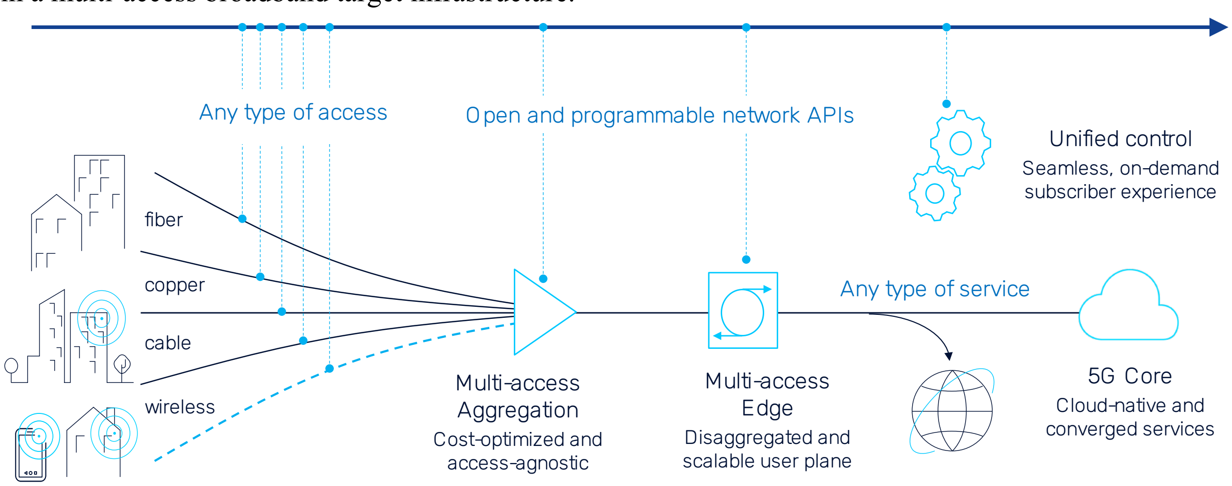

Figure 2. Multi-access broadband target architecture

Because all service traffic has converged on IP, all wireline and wireless broadband traffic can potentially be aggregated over a common multi-access backhaul network. However, current broadband access and aggregation networks may present an obstacle that hinders a smooth transition to this multi-access broadband architecture. While most operators are moving towards access-agnostic IP/ethernet aggregation layer in the metro and regional network, they often maintain dedicated platforms that accommodate for different access network requirements. The inherent duplication of functions in a heterogenous aggregation network reduces becomes increasingly costly and complex as more access technologies are introduced and evolve in parallel.

Fortunately, the new generation of disaggregated wireline and 5G wireless access solutions enable access-agnostic IP/Ethernet transport aggregation on a converged interconnect network (CIN) by virtualizing technology-specific access network functions and moving them into the distributed edge cloud under a programmable software defined network (SDN) controller. Examples are virtualized converged cable access platform (vCCAP) for distributed access architectures, virtualized optical line terminal (vOLT) for XGS-PON, and virtualized baseband units (vBBU) for the 5G radio access networks.

The second obstacle is a broadband service edge that typically deploys dedicated edge gateways for each access network technology: A CCAP/CMTS for cable access, a Broadband Network Gateway (BNG) for fiber-to-the-home (FTTH) access and a Serving and Packet Data Network gateway (SPGW) for 4G/LTE mobile services. While such divide and conquer edge strategy separates concerns, it also reduces cost synergies while increasing complexity, both at the service edge and in operational back-end systems.

The broadband service edge is a critical network junction where subscribers and service policies are enforced. The inclusion of fixed-wireless access should at least add no further complications, and this is the main subject the rest of the paper will focus on.

4. Fixed-wireless access gateway requirements

A converged fixed-wireless edge can play an important role in delivering affordable, high-performance broadband services to every home. However, wireline and wireless access technologies come from very different worlds, so where does fixed-wireless access fit in? Wireline or wireless?
To answer this question, we must compare their service characteristics (Table 1).

Table 1. Comparing wireless and wireline service characteristics

Requirement	Mobile user	Wireline user
User devices	1 (typically)	>10 per home
Service type	Nomadic	Stationary
Session type	Dynamic	Always-on
Subscription type	Usage based	Unlimited (flat rate)
Monthly data usage	3-5 GB	100s of GB
Average speed	~10 Kilobit/s	~1 Megabit/s
Gateway location	Centralized	Distributed
Gateway functions	Virtualized (x86)	Physical (NPU)

To complement (or compete with!) wireline broadband, fixed-wireless access gateways must support the same residential broadband applications. There are no roaming requirements because all user devices are tethered to a single, stationary home gateway that serves up to a dozen user devices such as TVs, PCs, tablets and gaming consoles. Home broadband services are always on and must sustain high bandwidth usage for multi-cast IPTV and streaming ultra-high definition broadcast TV, binge-watching Netflix, Zoom video conferencing, and downloading software for PCs and game consoles. Sophisticated quality-of-service (QoS) techniques are needed for the delivery of multiple services over the same bearer.

Monthly data usage per home averages several hundreds of Gigabytes that are charged at a monthly flat rate, without usage caps for the highest service tiers.

In contrast, wireless broadband users typically connect a single device (smartphone) with short-lived dynamic user sessions. Although mobile devices can generate significantly more control plane traffic, mobile data volumes are orders of magnitude lower and charged by the Gigabyte. Mobile data rates are comparably high. One month of broadband usage charged at mobile data rates would easily cost a homeowner more than a one year wireline broadband subscription.

As a result of their different usage characteristics, mobile-wireless gateways are polar opposites of the wireline gateways used for residential broadband:

- Wireless gateways are optimized for dynamic, mobile user applications that yield a high revenue per bit. They are typically centralized and virtualized on x86 servers, which allows operators to cost-efficiently pool resources for roaming users and leverage cloud-native compute and storage to support dynamic user sessions with elastic scaling needs. They are not designed nor dimensioned to cost-efficiently support bandwidth-intensive internet or IPTV applications over extended periods of time.
- Wireline gateways are cost-optimized for delivering always-on Gigabit broadband services to homes and businesses. They are typically purpose-built network appliances that leverage custom routing silicon for granular bandwidth management and hierarchical QoS to ensure that available network resources are fairly and optimally shared among subscribers and user devices. Default residential broadband service features such as Internet access and IPTV multicast replication are far more economical to deploy and scale on wireline gateway platforms, compared to Internet offload (LIPA-SIPTO) and IP multicast (eMBMS) on mobile gateways.

In conclusion, the service requirements of fixed-wireless access are very similar to wireline broadband access. Because fixed-wireless access gateways and broadband wireline gateways share most requirements, there are potentially significant operational cost and performance synergies when leveraging the same type of edge platform for both.

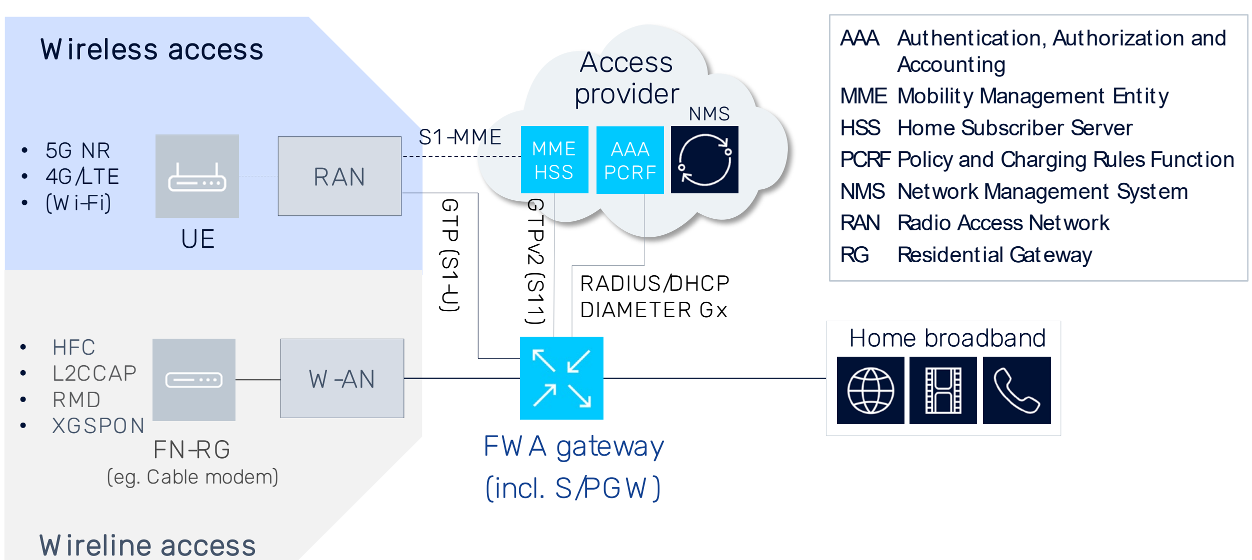

Figure 3. Fixed-wireless broadband access gateway

The addition of a Serving and PDN Gateway (S/PGW) function allows wireline operators to deploy FWA stand-alone or in conjunction with wireline access (see Figure 3). Broadband access providers deploying FWA will chiefly consider using shared, unlicensed or mmWave spectrum because licenses are more affordable. Because user devices are tethered to a stationary home gateway there is no need to provide blanket service coverage from multiple angles to support user roaming and only a subset of the MME and HSS mobility functions are needed to enable X2 handovers between adjacent base stations (eNB, gNB) within the tracking area. This significantly reduces the operational complexity of integrating FWA in a home broadband offer and enables access providers to essentially leverage the same operational backend as used for their existing wireline broadband service.

5. Disaggregated multi-access edge gateway

Converged operators may wish to interwork their wireline and fixed-wireless access services with their 5G packet core to enable fixed-mobile convergence. Most user traffic that is converging on the multi-access edge will originate from wireline broadband users (including 5G mobile users connected to Wi-Fi), followed by fixed-wireless access, and mobile roaming services. IPTV (live and on-demand) and Internet are the largest broadband consumers by far, and this traffic should be offloaded at the multi-access edge to distributed edge caches and peering points. The remaining (mobile) traffic is forwarded to an Evolved Packet Core (LTE and 5G non-standalone) or a 5G core and mainly consists of metered traffic from mobile voice, IMS and roaming data applications.

From an scaling perspective, a multi-access edge gateway needs to make a gymnastic split to combine the need for a distributed, high-performance user plane capable of processing massive data volumes, with the goal of operating a centralized, cloud-native management and control plane that can seamlessly integrate with a 5G Core. Control and User Plane Separation (CUPS) achieves this feat and is the key enabler for the wireline broadband evolution to fixed-wireless and fixed-mobile convergence.

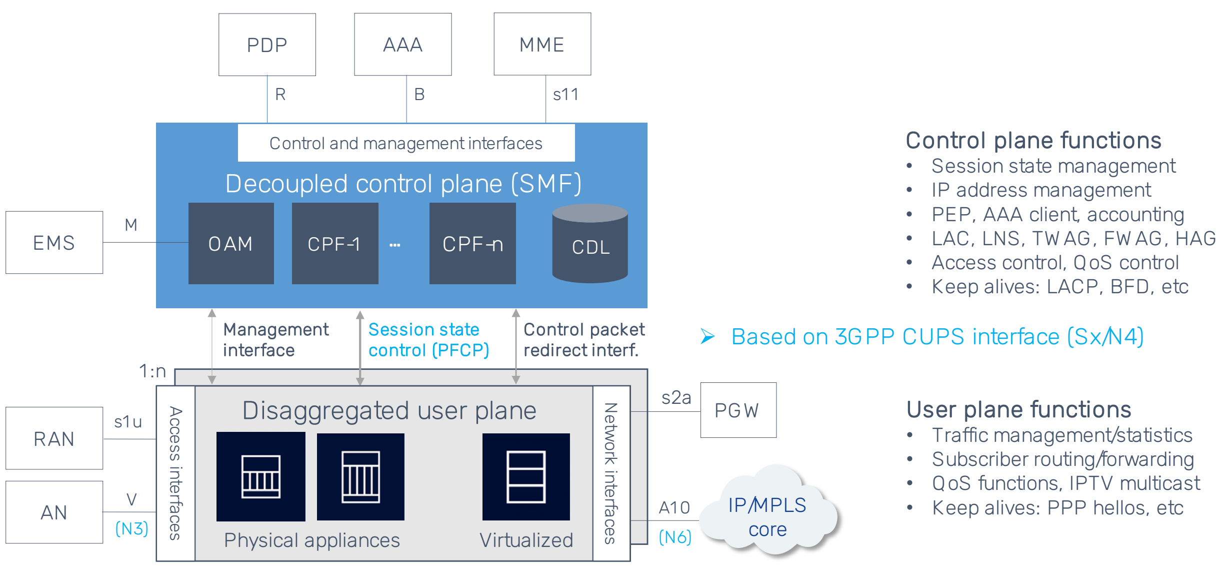

Figure 4. Disaggregated multi-access edge gateway with CUPS

A broad industry cooperation between the 3GPP, Broadband Forum and Cable Labs helped define the necessary standards (e.g., BBF TR-459) for a disaggregated multi-access edge gateway that can fully integrate with the 5G ecosystem (Figure 4). The standards specify the functional separation of control and user plane functions and the interface protocols to be used for their subsequent interworking. The interworking protocols between the control and user plane are derived from the 3GPP CUPS standards with extensions for use in wireline access networks. They encompass the following:

- Model-driven management APIs allow for centralized management of multiple, distributed user plane functions as a single management entity.
- The Packet Forwarding Control Protocol (PFCP) is used by the control plane to manage subscriber session state. It leverages the 3GPP CUPS specification with wireline extensions.
- The Control Packet Redirect interface enables the User Plane to forward subscriber authentication messages from the CE to the centralized control plane over GTP tunnels.

The control plane (SMF) is typically cloud-native and deployed in a data center. Ideally, it uses a stateless compute model with a Common Data Layer to manage control plane state information. This model allows to easily scale out and load-balance control plane capacity, and quickly recover from failure situations that trigger a reboot of any virtualized control functions.

Control and User Plane Separation (CUPS) offers several operational benefits:

- Efficient operation, through a centralized control plane that can scale out in the cloud, while distributing physical user plane to optimize delivery cost and performance.
- Simplified maintenance, as decoupling control and user plane functions makes it easier to manage their different life cycles and minimizes the impact of hardware and software upgrades.
- Flexible scaling, by allowing control and user plane functions to be deployed on either physical or virtualized platforms and to scale their capacity independently.
- Fixed-mobile convergence and wireline broadband integration with a 5G Core by interfacing the UP via the Sx/N4 interface with a common 3GPP Session Management Function (SMF).

The last two bullets are essential for the evolution to a cost-optimized multi-access edge that seamlessly integrates wireline and wireless access with a 5G core.

6. Wireline and wireless convergence on a 5G Core

Let's now examine the evolution to a multi-access edge that interworks both wireline and fixed-wireless access networks with a 5G core. Although 5G is strongly oriented to new radio technology and mobile service evolution, wireline access networks can be integrated by supporting a set of well-defined 3GPP reference interfaces:

- **N1** between User Equipment (UE) and Access and Mobility Management Function (AMF) to exchange NAS (Non-Access Stratum) messages.
- **N2** between Wireline Access Nodes (W-AN) and AMF based on NGAP (Next Generation Application Part).
- **N3** between W-AN and multi-access User Plane Function (UPF) based on GTP-U (GPRS Tunneling Protocol User Plane).
- **N4** between Session Management Function (SMF) and multi-access UPF to manage data sessions at the user plane based on the Packet Forwarding Control Protocol (PFCP).
- **N6** between multi-access UPF and packet data networks to transport IP and Ethernet packets.

A 5G Access Gateway Function (W-5G-AGF) can be introduced to interwork legacy wireline access platforms that do not natively support the required N1, N2 and N3 reference interfaces (see Cable Labs specification WR-TR-5WWC-ARCH). Through the W-5G-AGF, both the wireless and wireline access network can then be controlled by the 5G AMF.

The objective of delivering multi-access broadband access with 5G Core interworking is enabled by leveraging a common control plane (SMF) across both wireline and wireless user planes. The unified SMF operates on the same 3GPP N4/Sx CUPS interface and dynamically selects the proper UPF for fixed wireline/wireless or mobile access based on Access Point or Data Network Name, IP address range, subscriber profile, traffic load or configured resources and services. This allows efficient off-loading of broadband internet and video traffic from the 5G Core and allows independent scaling (and placing) of fixed/-wireless and mobile gateway functions (Figure 5).

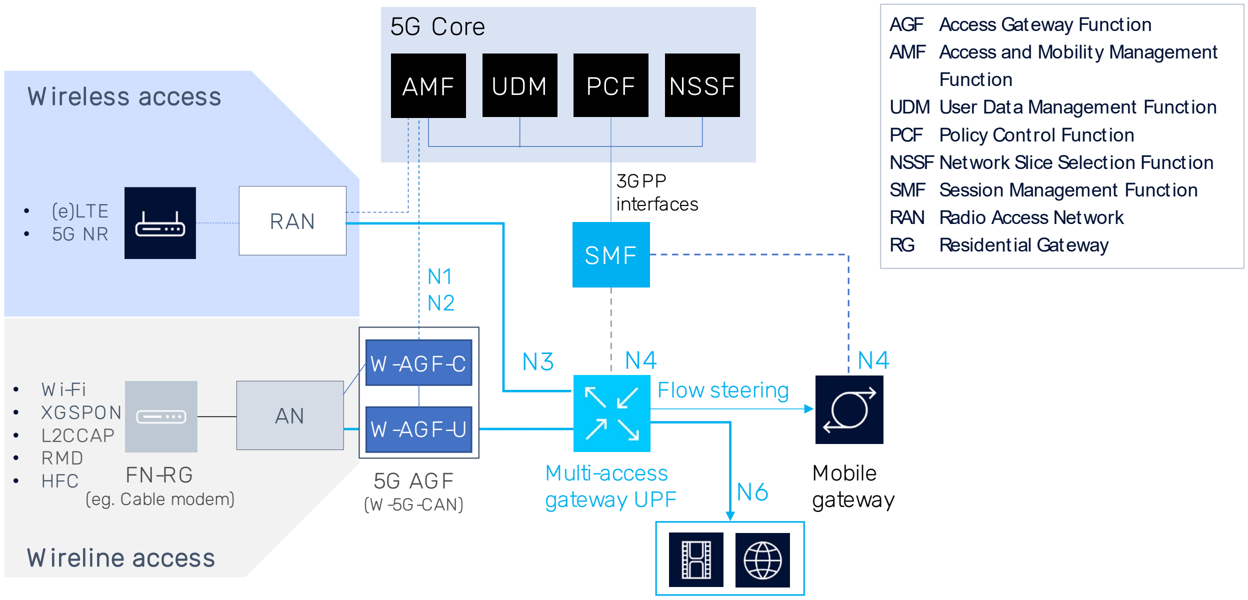

Figure 5. Wireline and wireless convergence on a 5G core

The multi-access edge gateway (UPF) handles all wireline and wireless broadband traffic. It offloads internet and video traffic to the IP/MPLS data network via the N6 interface and steers the remaining 5G user traffic to the more centralized cloud mobile gateway that control access to 5G Core services and applications.

To cost-efficiently manage high-volume/low-revenue broadband applications, the multi-access UPF is best performed by purpose-built edge router appliances that can be distributed in proximity of end users. The following requirements are typically supported by custom network processors and routing silicon:

- Highly scalable hierarchical QoS (HQoS) to enable thousands of subscribers on dozens of access nodes to fairly share the available broadband network capacity
- Granular shaping and policing of traffic flows to ensure that each subscriber receives the committed – and peak data bitrates according to their subscription policy
- Scalable and granular Access Control Lists (ACLs) to enforce security functions such as anti-spoofing to prevent service theft and denial of service (DDoS) attacks.
- IP multicast replication and IGMP snooping to facilitate premium broadcast TV streaming
- Streaming flow telemetry of subscriber flows to account for data usage and monitor quality of experience, and identify security threats,
- Flow mirroring to support lawful intercept and analyze potentially malicious traffic flows

The SMF provides a single access point for managing all distributed UPF instances and presents a common interface to the other 3GPP system functions (e.g., AMF, UDM, PCF, NSSF, etcetera).

7. Conclusion

5G fixed-wireless access is a new and promising technology that can be cost-effectively leveraged to expand the coverage and capacity for underserved broadband homes in wireline brownfield deployments, and to facilitate and accelerate the rollout of fiber-to-the-home in greenfield and out-of-region areas.

The introduction of a multi-access edge gateway with control user plane separation, enables converged service operators to combine wireline and wireless access in a seamless broadband experience, and to enable fixed-mobile convergence on a unified 5G Core.

Abbreviations

AGF	Access gateway function
AMF	Access and Mobility Management Function
CCAP	Converged cable access platform
CIN	Converged interconnect network
CPF	Control plane function
CUPS	Control user plane separation
DDA	Distributed access architecture
FWA	Fixed-wireless access
NSSF	Network slice selection function
PCF	Policy control function
SMF	Session management function
SPGW	Serving and Packet Data Network Gateway
UDM	User data management function
UPF	User plane function
XGS-PON	10 Gigabit/s symmetric passive optical network

Bibliography & References

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