Broadband Network Gateway evolution to 5G

Through Control and User Plane Separation and wireline-wireless broadband convergence

White paper

Wireline and fixed-wireless broadband networks are evolving, with a convergence path in 5G.

5G introduces a highly programmable and scalable cloud-native architecture that disaggregates and decouples user plane functions from control plane functions.

This paper discusses how Control and User Plane Separation (CUPS) in Nokia Broadband Network Gateway platforms improves operational efficiency and supports the integration of wireline and fixed-wireless broadband into converged 4G and 5G service architectures.

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Disaggregating the Broadband Network Gateway

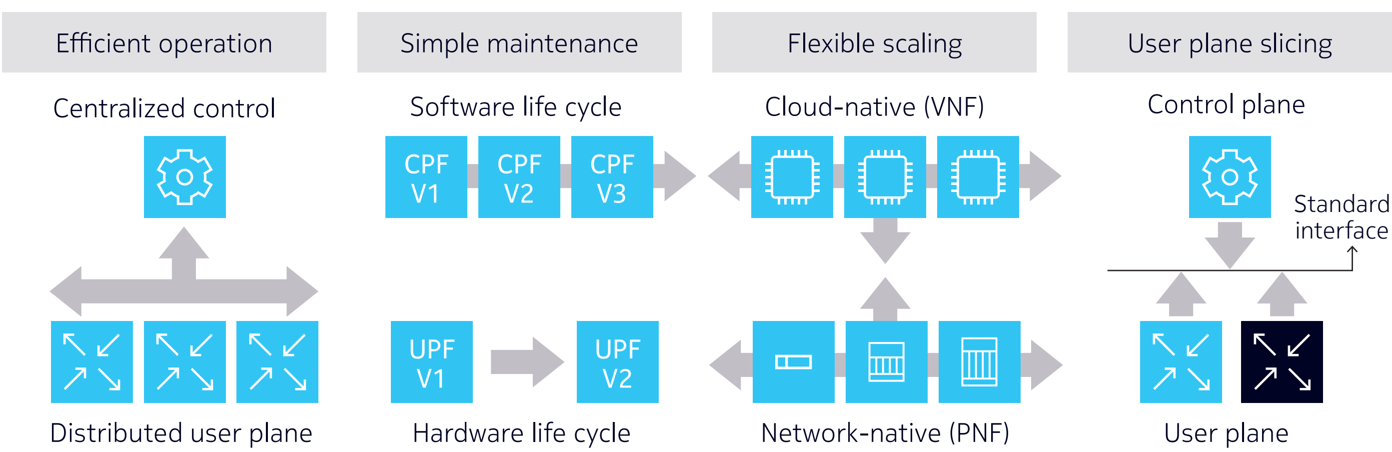
The Broadband Network Gateway (BNG) is an essential component in delivering broadband services that manages and controls network access policies for subscribers and connected user devices. Over the years the BNG evolved from broadband remote access servers used for dial-up internet access to a highly versatile and capable system for delivering broadband wholesale and retail services over a wide range of wireline and fixed-wireless access technologies.

Traditionally, the BNG is an integrated system that combines both user and control plane functions on a common network appliance that is deployed in centralized locations close to internet peering points.

Alternatively, distributed BNG deployment closer to users may offer better cost and performance in large networks with high subscriber densities, distributed internet peering, and local IPTV/video content insertion points. In this distributed deployment scenario, as the BNG footprint grows, the subscriber management control points also proliferate, increasing operational complexity.

Control and User Plane Separation (CUPS) addresses this problem by separating the subscriber management control plane and user plane for BNGs. This simplifies operations and also provides independent location, scaling and life cycle management for Control Plane Functions (CPFs) and User Plane Functions (UPFs). A single control plane running in a centralized virtualized network function (VNF) can control and manage multiple user plane instances, which may be distributed and separated from the control plane (see Figure 1).

Figure 1. Benefits of CUPS



The benefits of CUPS are:

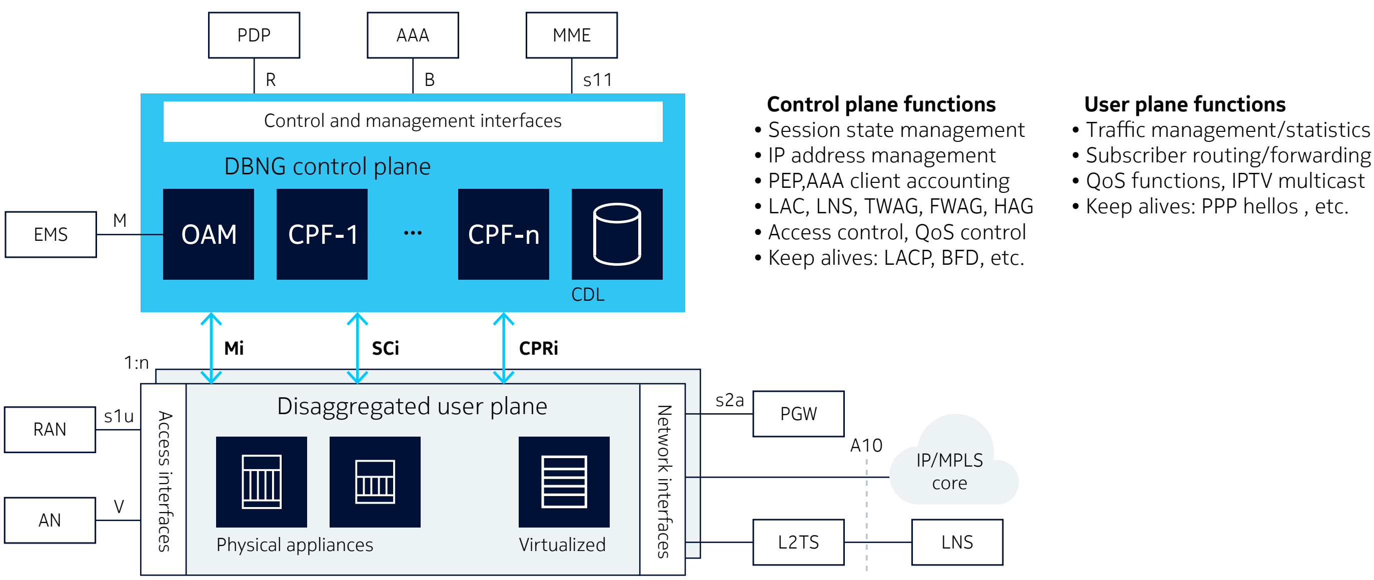
- Efficient operation by centralizing CPFs while distributing UPFs to optimize throughput, latency, and delivery cost
- Simple maintenance by decoupling CPFs and UPFs; this makes it easier to manage their different life cycles and minimize the impact of hardware and software upgrades
- Independently scale CPFs and UPFs on dedicated platforms that are most suitable (ie. CPF on generic x86 servers and high-throughput UPFs on custom NPU appliances).
- User plane slicing by operating a heterogeneous user plane that consolidates different platforms and/or access technologies under a common control plane.

Operators that are deploying an integrated BNG solution (e.g., based on the Nokia 7750 service routing portfolio) can easily migrate to the BNG CUPS deployment model by means of a software upgrade of the platform operating system (i.e., the Nokia SR OS) because the underlying UPFs remain the same.

Control and User Plane Separation on BNG

To achieve all the benefits of open interworking with minimal system integration costs, there must be a harmonized and standardized approach to dividing and interfacing the BNG CPFs and UPFs. Nokia has spearheaded this effort with the Broadband Forum technical recommendation TR-459 [3]. A general outline is shown in Figure 2.

Figure 2. Disaggregated BNG architecture with Control and User Plane Separation

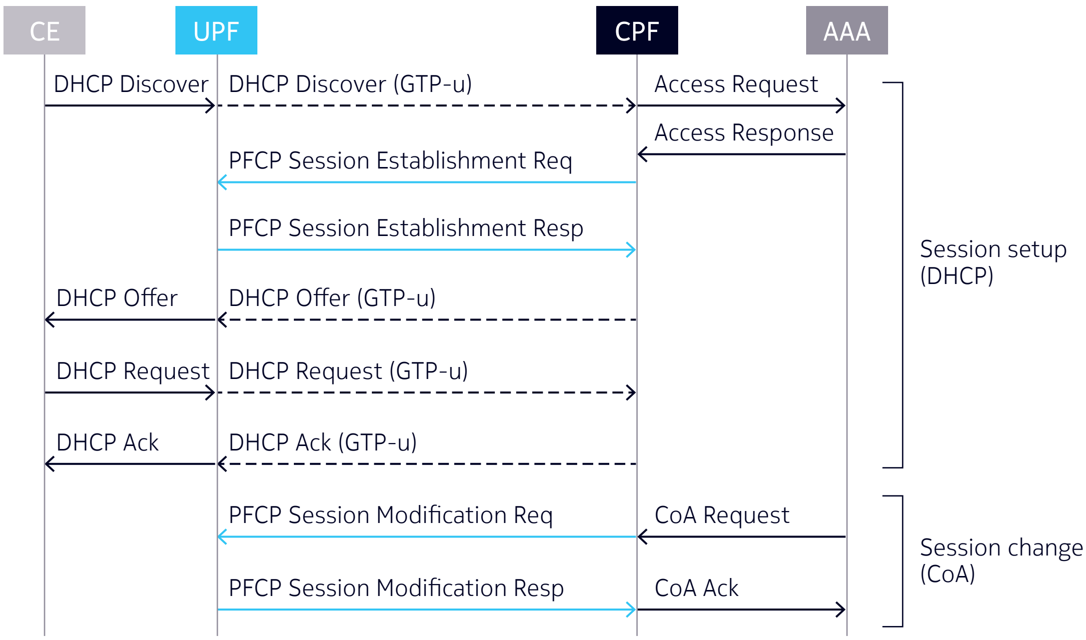


The Nokia BNG CUPS implementation also adopts key 3GPP 5G architecture principles such as using a common data layer (CDL) to decouple and independently scale storage and processing functions, and for implementing a state-efficient control plane that delivers resource efficiency and resiliency. The virtualized control plane appears as a single client towards external systems, e.g. a RADIUS server and presents a single management touch-point for a decoupled system based on model-driven management interfaces (Mi) using well-defined data models. The UPFs can be instantiated on any combination of physical or virtualized platforms together with a small set of essential user plane control functions to enable IP unicast and multicast routing, MPLS switching and Bidirectional Forwarding Detection (BFD) for connectivity verification.

The State Control Interface (SCi) leverages the Packet Forwarding Control Protocol (PFCP) used for the 3GPP Sx/N4 reference point to interface CPFs and UPFs (3GPP 5G Technical Specification 29.244 iso 129.244) [4] with extensions for fixed broadband access. The Control Packet Redirect interface (CPRi) applies GTP-u tunneling to enable the user plane to relay in-band control plane messages from attached customer equipment (CE) to the control plane.

Figure 3 shows an example scenario of how PFCP and GTP-u tunneling work together to establish a DHCP subscriber session and modify its parameters through a RADIUS change of authorization (CoA). The same principles can be applied for establishing PPPoE sessions.

Figure 3. Communication between control and user plane functions (DHCP session example)



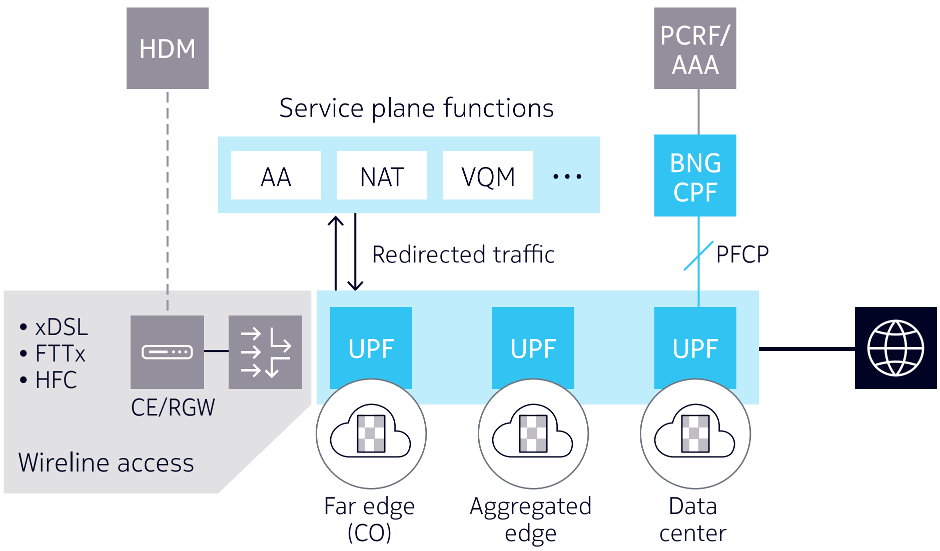
The following sections discuss the various BNG evolution scenarios that are enabled by CUPS.

BNG CUPS for wireline broadband evolution

Communications service providers (CSPs) that are operating wireline access technologies based on copper (xDSL), fiber (FTTx) and hybrid fiber coax (HFC) will value the enhanced flexibility that CUPS offers to scale and optimize service delivery. CUPS makes it easy to operate a combination of fixed access technologies with different distribution characteristics under a common control plane. The CUPS ability to decouple and distribute UPFs also optimizes capacity, performance and cost when offering multiple services such as triple play (internet, voice and TV) bundles by providing flexible traffic distribution, breakout and offload options (see Figure 4):

- Distributed UPFs in far edge locations enable breakout of wholesale, voice and internet traffic.
- Edge cloud UPFs enable caching of popular video content and processing of latency-sensitive compute functions in closer proximity to users. BNG Service Plane Functions (SPFs) such as Application Assurance (AA), Network Address Translation (NAT) or Video Quality Management (VQM) can also be placed closer to users.
- Centralized UPFs are typically breakout points for BNG control plane traffic and are collocated with authentication, authorization and accounting (AAA) and the Policy Charging Rules Function (PCRF).

Figure 4. BNG CUPS for fixed broadband evolution



The BNG user plane operates at Layer 2 and Layer 3 to aggregate subscriber traffic. Unlike generic IP interconnect routers, the BNG user plane requires a highly scalable Hierarchical QoS (HQoS) and access control list (ACL) implementation to support high subscriber and session density for a broad range of different service profiles. Scalable HQoS queuing and scheduling with line rate packet buffering are needed to ensure that thousands of subscribers on dozens of access nodes can fairly share the available broadband capacity. Granular shaping and policing of traffic flows ensures that each subscriber receives the committed and peak rate throughput according to their subscription policy. Scalable and granular ACL support is required for access security functions such as anti-spoofing and distributed denial of service (DDoS) protection.

The BNG service plane performs compute- and storage-intensive packet processing functions that go beyond the capabilities of typical Layer 2 and Layer 3 user plane capabilities such as AA, NAT or VQM. Service plane functions are best executed on a CPU architecture such as Intel x86, on either an integrated service adapter or integrated service module in the router (PNF), or as a virtualized UPF (VNF) on server platforms in the edge cloud (external service adapter). The BNG CPF will automatically steer/redirect select user plane traffic to an integrated or external service adapter when a BNG service plane function is required.

The compute and storage-intensive BNG control plane functions in a CUPS architecture are ideally deployed on generic x86 servers in a telco data center where they can scale independently of the BNG user plane functions. A decoupled and centralized CPF provides a single management and control touch-point for operations support systems, AAA servers (authentication, authorization and accounting), and policy servers with the potentially large set of distributed user plane instances and allows to efficiently manage commonly shared resources. For example, conventional integrated BNG deployments require operators to partition the address pool in dedicated subnets for each BNG network appliance, which leads to resource fragmentation and is cumbersome to manage efficiently. The disaggregated BNG CUPS deployment model addresses this issue by letting the centralized CPF dynamically allocate subnets from a shared IP address pool across all BNG user plane instances it controls. Finally, the BNG CUPS model also supports efficient N:1 redundancy and load-balancing of distributed UPF instances that connect to centralized CPFs deployed in geo-redundant data center locations.

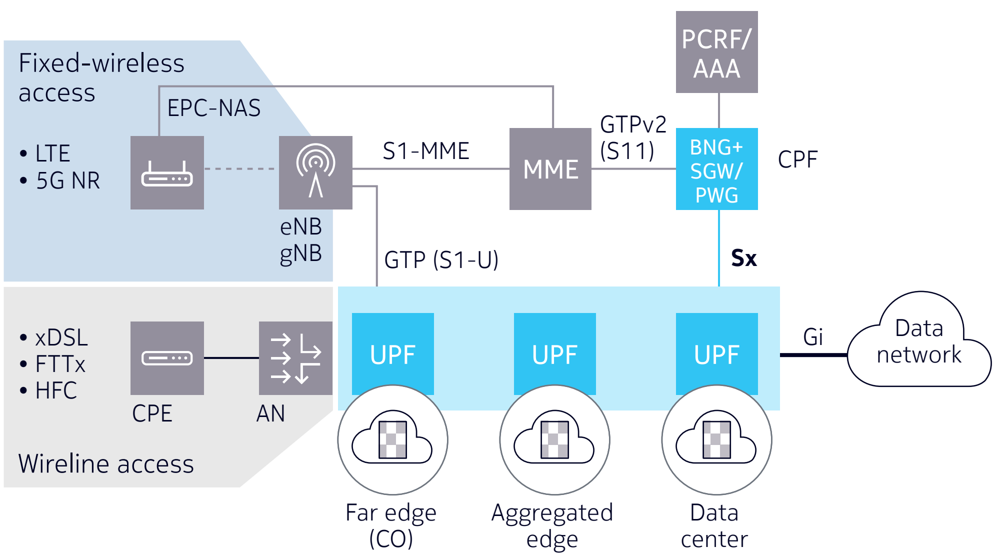
Fixed-wireless broadband integration with 4G

Service evolution and regulatory requirements put CSPs under continuous pressure to expand broadband capacity and coverage. However, limitations in the existing wireline access plant can make it progressively more costly or cumbersome to achieve this goal in brownfield areas. In addition, there may not always be a compelling business case for deploying fiber-to-the-home in greenfield areas. These types of broadband capacity and coverage challenges can often be addressed by complementing wireline broadband access with fixed-wireless broadband, in particular 4G/LTE and 5G radio technology.

This can be achieved by enhancing the BNG (CPF + UPF) with a subset of 3GPP Serving Gateway (SGW) and Packet Data Network Gateway (PGW) capabilities relevant for fixed-wireless access. The fixed-wireless broadband access solution shown in Figure 5 supports both LTE access (eNB) and the integration of 5G NR access (gNB) in Non-Stand alone (NSA) Option 3, 3A and 3X with existing 4G Evolved Packet Cores (EPCs).

Although not shown here, the BNG CPF can optionally be enhanced further to operate as a Trusted Wireless Access Gateway to support carrier Wi-Fi® access with open or closed service set identifiers (SSIDs) on home spots and public hot spots.

Figure 5. Wireline and fixed-wireless broadband access integration



The SGW/PGW CPF interfaces with the Mobility Management Entity (MME) through the S11 reference point to control subscriber access and steer LTE and 5G NR residential fixed-wireless user traffic into the common UPFs shared with the wireline access network. Note that with customer premises equipment (CPE) the SGW/PGW is only required to support “limited mobility”, only requiring handover between adjacent base stations (X2 handover).The CPF combines BNG and SGW/PGW control plane functions, and uses PFCP (with proposed extensions for BNG) to control the UPFs over the Sx interface. The UPFs can terminate both wireline and fixed-wireless subscribers, or handle them separately and the converged CPF can control both a BNG UPF with wireline and fixed-wireless subscribers. A common Gx interface to PCRF/AAA enables seamless subscriber management across fixed wireline and fixed-wireless access.

Integrating fixed and wireless broadband access supports the following deployment options:

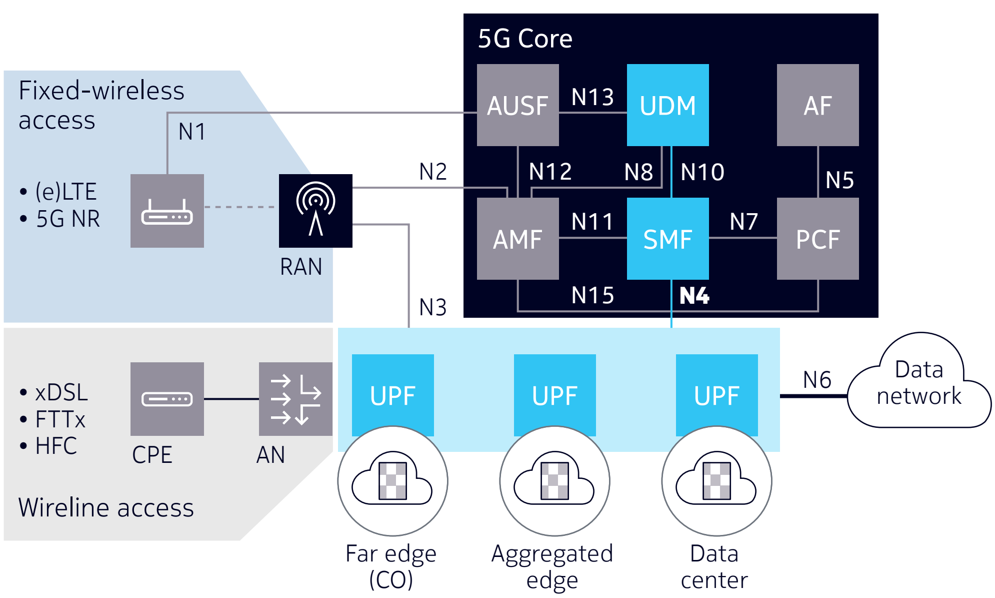
- Fixed-wireless access only, for coverage in greenfield areas without wireline broadband access
- Fixed-wireless access to supplement wireline access in brownfield areas with wireline coverage issues

As fixed-wireless and wireline broadband access support the same customer base and service mix, their gateway user plane functions share similar requirements. Both must support a dozen or more stationary user devices such as TVs, personal computers, game consoles, laptops and tablets that generate high traffic volumes over sustained time periods. Aggregating fixed-wireless broadband traffic on a physical network appliance will yield the same cost and performance as for wireline BNGs and result in significantly lower cost-per-bit compared to virtualized user plane functions on generic x86 server appliances.

Evolution to a multi-access edge and converged 5G core

Converged wireline and fixed-wireless broadband access on a disaggregated BNG is a key enabler for the 5G multi-access edge and core evolution. 5G Core interworking is enabled by deploying a common Session Management Function (SMF) for both wireline and fixed-wireless broadband access. Network operators can leverage the CUPS architecture to optimally dimension and distribute BNG user plane functions for wireline and fixed-wireless access slices, and leverage a converged control plane to dynamically select the proper UPF based on Access Point Name or Data Network Name (see Figure 6). Dynamic UPF selection allows network operators to optimally dimension and distribute BNG user plane functions for wireline and fixed-wireless access slices under a common control plane.

Figure 6. Wireline and fixed-wireless access interworking with a 5G Core



Consolidating wireline and fixed-wireless broadband on a common 5G Core enables operators to expand broadband connectivity and coverage to deliver any service over any access while benefitting from the superior programmability of a cloud-native 5G service architecture.

Conclusion

CUPS on the BNG offers immediate deployment benefits for existing wireline access deployments:

- Efficient operation by centralizing CPFs while distributing UPFs to optimize throughput, latency and cost
- Simpler maintenance by decoupling CPFs and UPFs; this makes it easier to manage their different life cycles and minimize the impact of hardware and software upgrades
- Independently scale CPFs and UPFs on dedicated platforms that are most suitable (ie. CPF on generic x86 servers and high-throughput UPFs on custom NPU appliances).
- Open interworking by separating the control plane and user plane by a standardized interface; this enables operating a heterogeneous or multivendor user plane under a common control plane.

In addition, CUPS enables the BNG to evolve to support both wireline and fixed-wireless broadband access through a common control plane on a multi-access user plane, to:

- Deliver broadband service in underserved areas, either as an overbuild in brownfield areas with poor wireline coverage or as an intermediate step in greenfield wireline deployments
- Enhance broadband capacity and reliability by bonding wireline and fixed-wireless access to support very high-bandwidth services such as 4K video and to connect business subscribers
- Deliver a ubiquitous and seamless broadband experience across fixed wireline, 4G/LTE and 5G NR access in Non-Standalone options 3, 3A and 3X.

Finally, CUPS is an essential feature to support the evolution to a digital service infrastructure by:

- Converging and consolidating wireline and fixed-wireless broadband on a multi-access edge that integrates into a common 5G Core
- Leveraging the superior programmability of a cloud-native 5G service architecture to deliver an agile, dynamic and personalized broadband service experience.

Nokia is providing a complete 5G solution that includes high-capacity 5G New Radio, SDN-controlled "Anyhaul" transport, a converged multi-access edge, and a cloud-native 5G core.

Nokia is a leading supplier of residential broadband solutions for physical and virtual implementations in a variety of centralized and decentralized deployment models around the world. For more information about Nokia's multi-access Broadband Network Gateway offering, refer to [1] and visit http://www.nokia.com/solutions/multi-access-broadband-network-gateway.

References and resources

1. Nokia Broadband Network Gateway. Datasheet.
2. Nokia Virtualized Broadband Network Gateway. Data sheet.
3. Control and User Plane Separation for a disaggregated BNG. Broadband Forum TR-459.
4. LTE; Interface between the Control Plane and the User Plane nodes. 3GPP TS 29.244 v16.5.0

Abbreviations

5G NR	5G New Radio
AA	Application Assurance
AAA	authentication, authorization and accounting
ACL	access control list
AF	Application Function
AMF	Access and Mobility management Function
AUSF	Authentication Server Function
BFD	Bidirectional Forwarding Detection
BNG	Broadband Network Gateway
CDL	common data layer
CE	customer equipment
CoA	change of authorization
CO	central office
CPC	Cloud Packet Core
CPE	customer premises equipment
CPF	Control Plane Function
CPU	central processing unit
CUPS	Control and User Plane Separation
EPC	Evolved Packet Core
FTTx	fiber to the anything
GRE	Generic Routing Encapsulation
GTP	General Packet Radio Service (GPRS) Tunneling Protocol
HDM	home device management
HQoS	Hierarchical Quality of Service
HFC	hybrid fiber coax
IPsec	IP security
L2TP	Layer 2 Tunneling Protocol
LAC	L2TP Access Concentrator
LAN	local area network
LNS	Layer 2 Tunneling Protocol Network Server
LTE	long term evolution
MME	Mobility Management Entity
MPLS	Multiprotocol Label Switching
MP-TCP	Multipath TCP
NAS	Non-Access Stratum
NAT	Network Address Translation
NERG	Network Enhanced Residential Gateway
NETCONF	Network Configuration Protocol
NFV	network functions virtualization
OAM	operations, administration and maintenance
PCF	Policy Control Function
PCRF	Policy Charging Rules Function
PFCP	Packet Forwarding Control Protocol
PGW	Packet Data Network Gateway
PNF	physical network function
PPPoE	Point-to-Point Protocol over Ethernet
RADIUS	Remote Authentication Dial-In User Service
RGW	Residential Gateway
SDN	software defined network
SMF	Session Management Function
SGW	Serving Gateway
TCP	Transmission Control Protocol
UPF	User Plane Function
VNF	virtualized network function
xDSL	any DSL
YANG	Yet Another Next Generation

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