Broadband Network Gateway evolution with control and user plane separation

Application note

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Abstract

Wireline and fixed-wireless access networks are evolving, with a convergence path in 5G. 5G introduces a programmable and modular service architecture in which control and user plane functions are disaggregated and separated.

This application note discusses how a disaggregated Broadband Network Gateway (BNG) with Control User Plane Separation (CUPS) offers operators more flexibility to optimally scale wireline and fixed-wireless access deployments.

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Broadband Network Gateway evolution

The Broadband Network Gateway (BNG) is an essential network demarcation function that manages and controls broadband access policies for subscribers and connected user devices. Over the years the BNG evolved from a broadband remote access server for dial-up internet access to a highly versatile and capable system for delivering broadband services to residential and business users over wireline and fixed-wireless access technologies (FWA).

As the industry enters the digital era of 5G and cloud-based Information Technology, the disaggregated Broadband Network Gateway with control and user plane separation marks the next evolution milestone. As operators expand broadband capacity and coverage through fiber upgrades and the introduction of fixed-wireless access (FWA), the broadband edge must evolve to support more access technologies, users, and bandwidth capacity (Figure 1).

Figure 1. Broadband edge evolution for wireline and fixed-wireless access
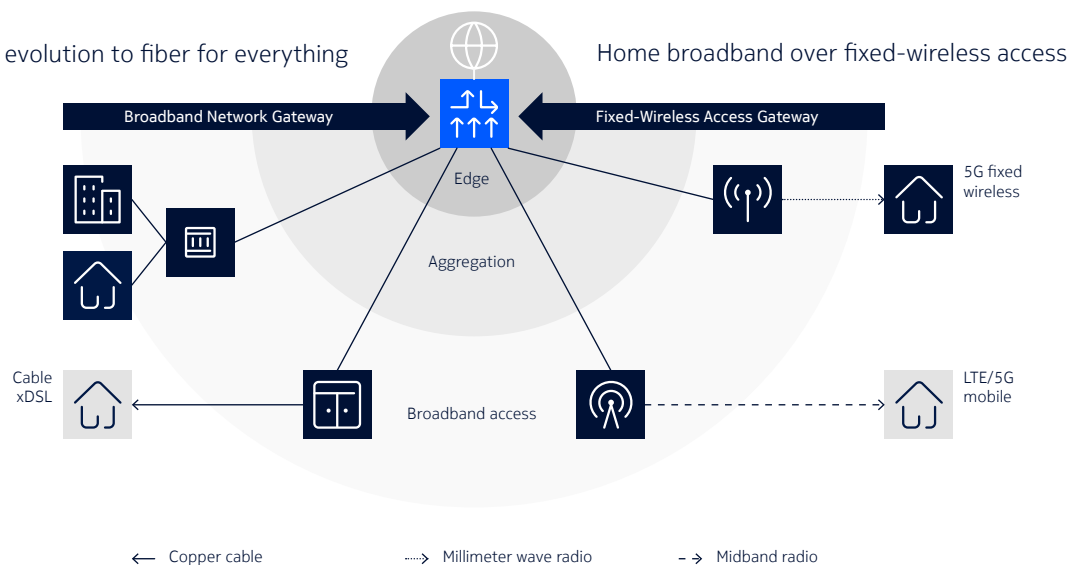
Why disaggregate BNG control and user plane functions?

BNGs are traditionally deployed in centralized locations close to internet peering points as an integrated system combining both user and control plane functions on a common routing appliance. While this deployment model remains valid, its limited flexibility has operational drawbacks for large deployments. Centralized BNGs are easy to manage but more challenging to scale for higher density deployments. Important considerations are the potential impact of BNG outages on subscriber traffic (the so-called "blast radius") and the cumulative cost and latency of data transport between access and edge.

Distributing BNGs closer to users offers better cost and performance in larger networks with higher subscriber densities, local internet peering, and IPTV/video content insertion points. But a larger BNG footprint also results in more touch points with management for control systems, which increases operational complexity.

Figure 2. Broadband Network Gateway deployment options
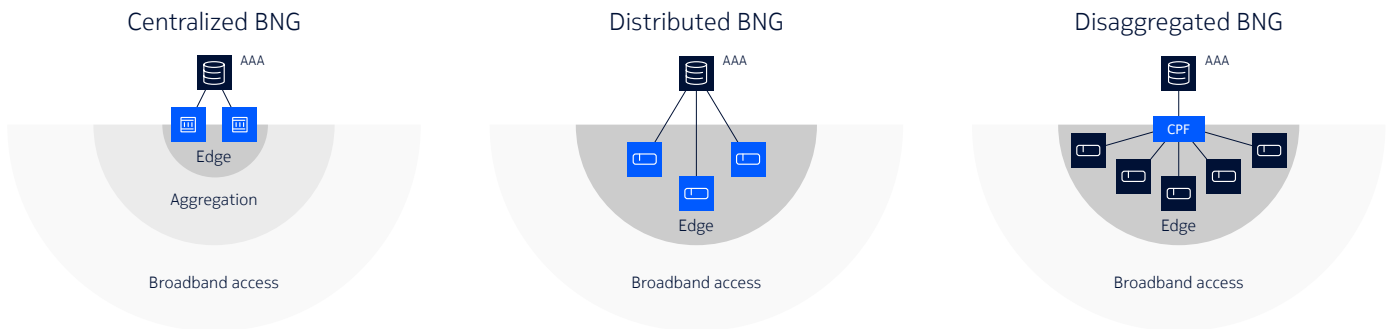
A disaggregated BNG with control and user plane separation (CUPS) gives the flexibility to place and scale control plane functions (CPFs) and user plane functions (UPFs) independently. It combines the operational simplicity of the centralized deployment model and the cost and performance of distributed deployment (Figure 2). The BNG CUPS deployment model scales well for larger networks because UPFs can be centralized or distributed, as needed, based on subscriber densities and demographics without impacting management and control operations:

• **Operational efficiency.** Centralizing CPFs while distributing UPFs optimizes throughput, latency, delivery cost of content, and reliability with N:1 redundancy.

• **Independent scaling.** Optimally scale CPFs and UPFs on most suitable platforms (i.e. CPFs on generic x86 servers and high-throughput UPFs on custom network processor unit (NPU) silicon).

• **Simpler maintenance.** Decoupling CPFs and UPFs makes it easier to manage their different lifecycles and minimize the impact of hardware and software upgrades.

Figure 3. Benefits of Control User Plane Separation on the BNG
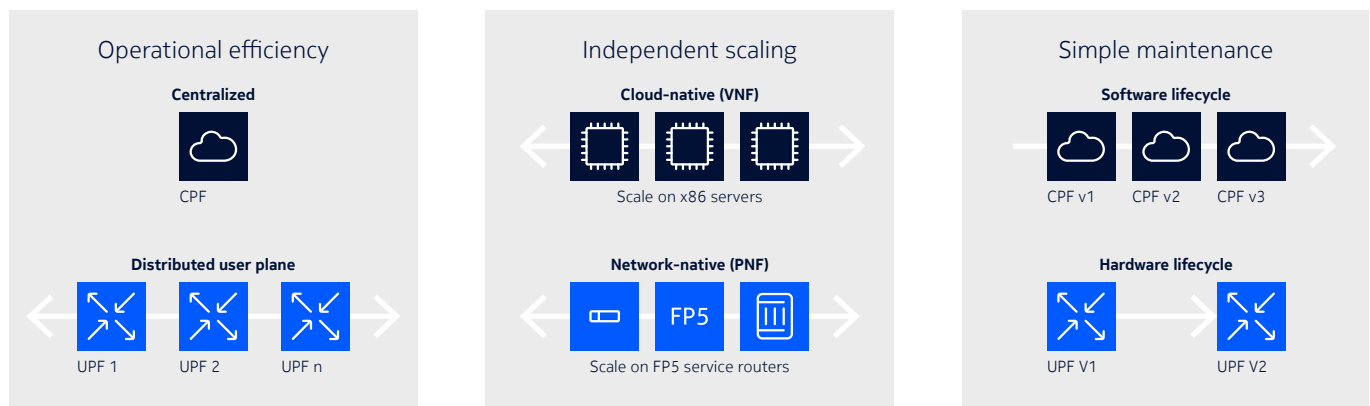
Operators deploying an integrated BNG solution based on Nokia 7750 service routers can easily transition to a CUPS deployment model by upgrading their SR OS operating system and deploying the Nokia Multi-Access Gateway controller (MAG-c).

BNG CUPS architecture and implementation standards

To support open system interworking there must be a common approach for dividing and interfacing CPFs and UPFs. Nokia spearheaded Broadband Forum technical recommendation TR-459 [3] which defines the reference architecture, deployment models, interfaces, and protocol specifications for a disaggregated BNG with CUPS.

The BNG CUPS specification adopts the architecture principles and protocols defined in 3GPP 5G Technical Specification 29.244 iso 129.244 [4] with extensions for fixed broadband access. CPFs include subscriber management via authentication, authorization, and accounting (AAA) servers; IP address assignment; and session state management. The user plane performs forwarding, traffic management, and policy enforcement of subscriber traffic.

The Nokia Multi-Access Gateway (MAG) product solution implements the TR-459 CUPS recommendations for disaggregated BNGs [4]. The MAG controller (MAG-c) implements the virtualized CPFs and can be hosted in regional data centers, while user plane functions are located on physical (7750 SR) or virtualized (VSR) service routers at the broadband edge (Figure 4).

Figure 4. Nokia Multi-Access Gateway for BNG CUPS deployments
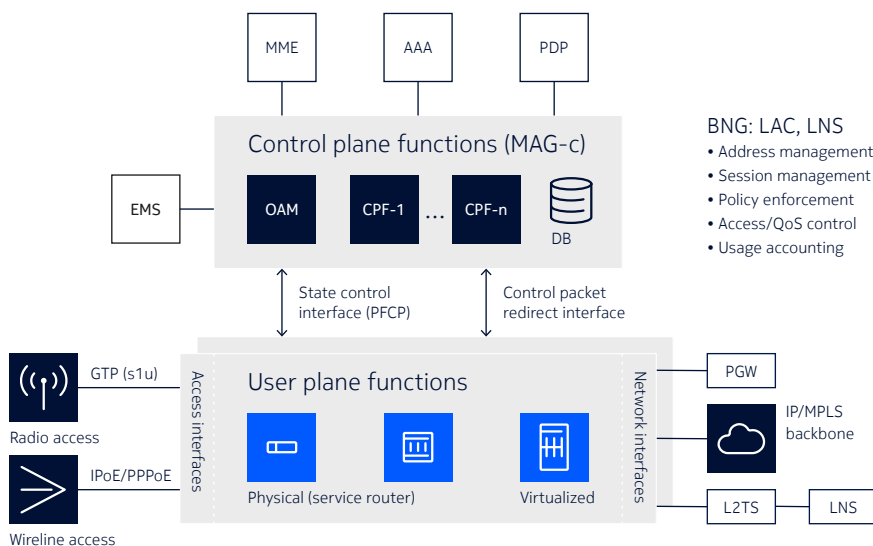
The virtualized control plane appears as a single client towards external systems such as AAA RADIUS servers and presents a single management touchpoint with operations support systems using well-defined data models (OAM interface to EMS).

The UPFs can be instantiated on any combination of physical or virtualized service routers with a small set of essential user plane control functions to enable IP unicast and multicast routing, MPLS switching, and session connectivity verification.

The State Control Interface (SCi) uses the Packet Forwarding Control Protocol (PFCP) defined for the 3GPP Sx/N4 reference point between CPFs and UPFs. The Control Packet Redirect interface (CPRi) applies GTP-u tunneling to enable the user plane to relay in-band control plane messages from customer equipment (CE) to the control plane.

Figure 5 shows an example scenario of how PFCP (solid blue arrows) and GTP-u tunneling (dashed black arrows) work together to establish a Dynamic Host Configuration Protocol (DHCP) subscriber session and modify its parameters through a RADIUS change of authorization (CoA). The same principles are applied for Point-to-Point Protocol over Ethernet (PPPoE) sessions.

Figure 5. Control and user plane interactions (DHCP session example)
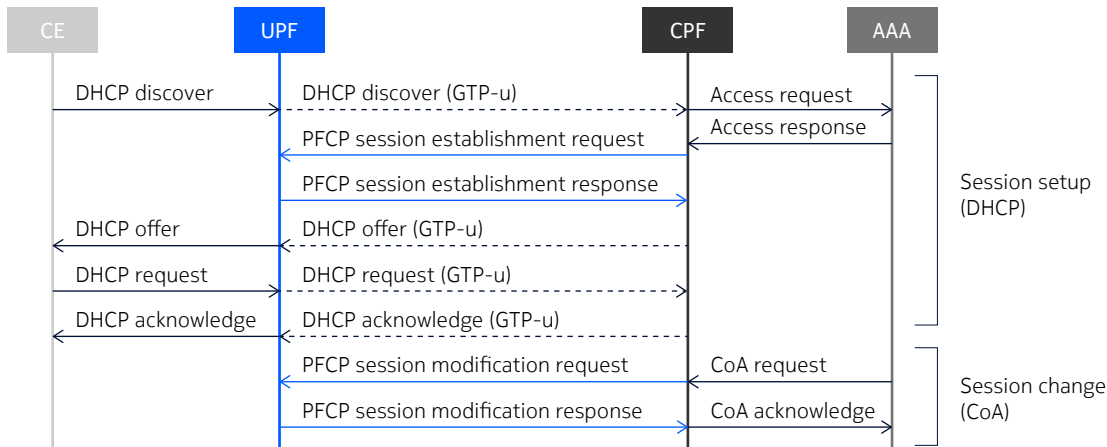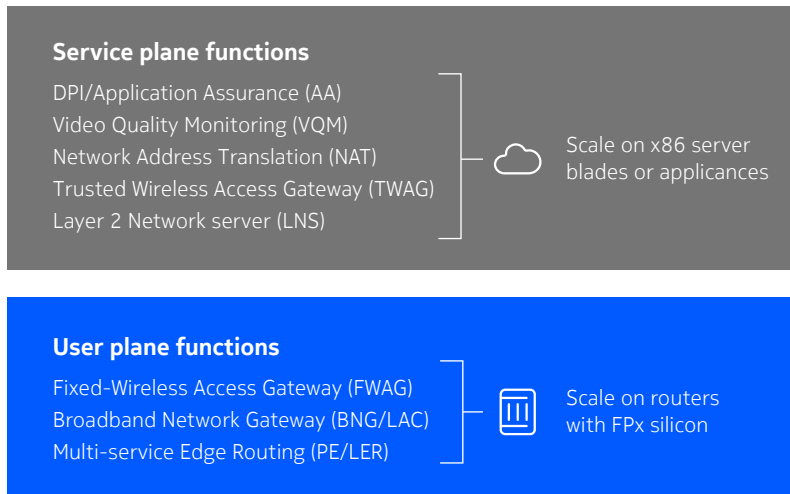

Scaling wireline broadband deployments with BNG CUPS

A decoupled and centralized BNG control plane provides a single touchpoint for network management systems, AAA, and policy servers with a potentially large set of distributed BNG user plane instances. The BNG CUPS deployment model also allows for more efficient IP address management by maintaining a common, centralized IP address pool across all BNG user plane instances.

Routing operating systems, such as Nokia SR OS, already leverage multi-core CPUs and symmetric multi-processing to scale management and control functions on the router so it's not a big leap to decouple, virtualize, and scale these functions on servers in a datacenter.

Besides disaggregating the BNG management and CPFs, the Nokia CUPS solution also allows independent scaling of service and user plane functions (Figure 6).

Figure 6. Independent scaling of service and user plane functions

Service plane functions

DPI/Application Assurance (AA)
Video Quality Monitoring (VQM)
Network Address Translation (NAT)
Trusted Wireless Access Gateway (TWAG)
Layer 2 Network server (LNS)

Scale on x86 server blades or applicances

User plane functions

Fixed-Wireless Access Gateway (FWAG)
Broadband Network Gateway (BNG/LAC)
Multi-service Edge Routing (PE/LER)

Scale on routers with FPx silicon

BNG user plane functions require high-throughput IP routing, forwarding, and traffic management functions that scale best on purpose-built packet processors such as Nokia FP routing silicon. CUPS allows efficient scaling of BNG UPFs on service routers with line rate packet buffering and deterministic performance under all traffic conditions. Distributing UPFs under a CUPS controller also enables dynamic traffic load-balancing and N+1 UPF redundancy schemes.

BNG service plane functions (SPF) such as application assurance and network address translation require compute- and storage-intensive L4 to 7 packet processing functions best executed on general purpose CPUs (i.e. Intel x86). Based on applicable subscriber and application policies, the BNG UPF will automatically steer/redirect select user plane traffic to these dedicated server appliances (i.e. a server blade in the router, external server appliances, or virtual servers residing in a regional data center). A flexible software licensing model allows operators to add service plane functions as needed.

Wireline and fixed-wireless access convergence

Wireline, mobile and converged operators may choose to deploy 5G FWA at mmWave frequencies for delivering home broadband services with fiber-grade data speeds. As FWA users have the same bandwidth needs as wireline users and require no mobility, both the user and control plane requirements of 5G FWA gateways are similar to BNGs.

The Nokia Multi-Access Gateway (MAG) uses these similarities to efficiently scale FWA and BNG user plane functions on common edge routing platforms that are purpose-built for broadband service delivery [5].

Operators can deploy 5G fixed-wireless access in non-standalone or standalone mode for out of-region coverage and in greenfield areas without wireline broadband access. Alternatively, they can use 5G fixed-wireless access to supplement wireline access in brownfield areas in a converged solution.

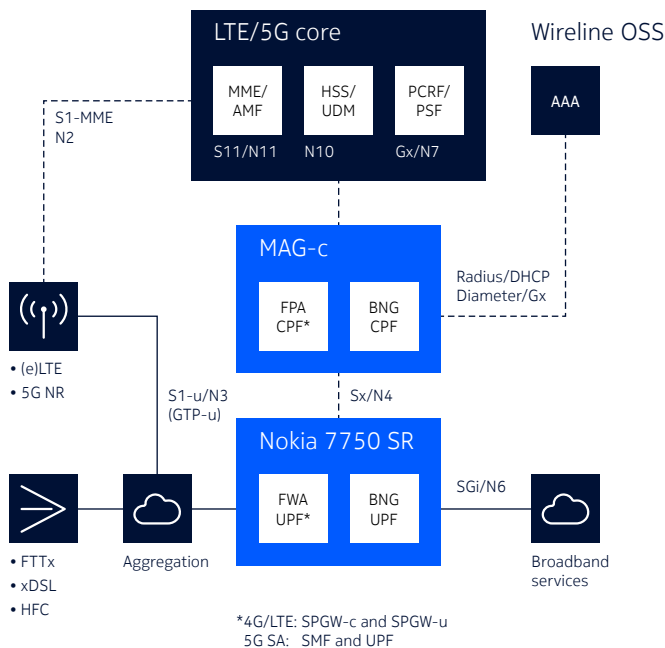Figure 7 Wireline and fixed-wireless access convergence

Figure 7 shows a FWA broadband deployment with MAG-c and 7750 SR routers providing combined 4G/LTE and 5G control plane and user plane functions respectively. A combined core with 4G and 5G interworking provides a seamless service experience for subscribers.

FWA operation in 5G Non-standalone mode

Many operators initially deploy 5G radio equipment with an 4G/LTE Evolved Packet Core (EPC) in Non-Standalone Option 3, 3A and 3X. Operators can opt to terminate FWA user sessions on separate service routers for more flexibility or to host FWA and BNG UPFs on common routers for better cost synergies.

A CUPS control plane is optional for 4G/5G NSA. Operators may either deploy an integrated FWA gateway solution with the Serving Gateway and Packet Data Network Gateway (SPGW) control plane functions for FWA (LTE eNB or 5G NR gNB) on the service routers or deploy the CUPS solution with the MAG-c shown in Figure 7.

The SPGW 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.

For residential broadband services, the SPGW is only required to support handover between adjacent base stations (X2 handover). The SPGW control plane functions in the MAG-c interface with FWA UPFs on the service routers over the Sx interface (Packet Forwarding Control Protocol).

Wireline and fixed-wireless convergence with a 5G Core

Converged and mobile operators are gradually transitioning to a 5G core to leverage the programmability and scalability of its service-based architecture. To support this evolution, the MAG-c provides the Session Management Function (SMF) to operate 5G FWA in standalone mode with a 5G core while the UPFs run on service routers.

5G FWA broadband services can operate in a separate 5G core slice with dynamical UPF selection based on a local policy, Access Point Name (EPC), or Data Network Name (5GC). Scaling 5G FWA UPFs on service routers with FP network processors will optimize data throughput, performance, and efficiency for residential broadband services.

Operators can opt to terminate FWA user plane sessions on separate service routers for more flexibility or to cohost them with BNG UPFs on the same routers for better cost synergies. Because FWA traffic can quickly exceed mobile broadband traffic but is only a fraction of wireline broadband traffic, converged operators can easily accommodate it on their existing wireline network footprint to optimize economies of scale (Figure 8).

Figure 8. Optimizing cost synergies with wireline and FWA convergence
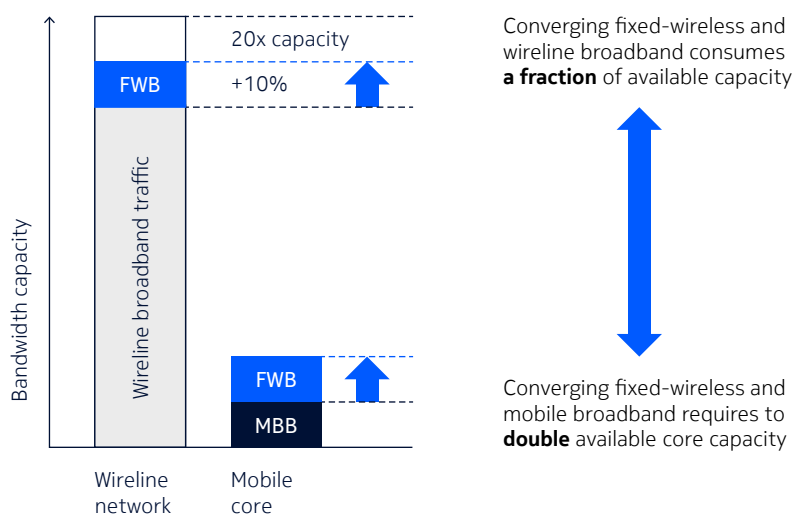
For a demonstration of the capabilities and performance of the Nokia Multi-Access Gateway solution for wireline BNG and 5G FWA, please refer to the demo video [6].

Executive summary

Control user plane separation offers several benefits for wireline BNG deployments:

- Efficient operation by centralizing CPFs while distributing UPFs to optimize throughput, latency, reliability and cost.

- Simpler maintenance by decoupling CPFs and UPFs, making 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 (i.e. CPF on generic x86 servers, and high-throughput UPFs on custom NPU appliances).

Nokia is a leading supplier of broadband infrastructure, with over 300 BNG deployments. We led the BNG CUPS standardization efforts in Broadband Forum TR-459 and are the first vendor with large-scale commercial deployments. Operators using Nokia service routers as an integrated BNG can easily transition to a disaggregated CUPS deployment model with the Nokia Multi-Access Gateway controller (MAG-c).

The MAG-c [7] also offers a convergence path for wireline and fixed-wireless access on a common multi-access edge, with a cloud-native CUPS management and control plane:

- Optimally scale FWA UPFs on service routers with CUPS Control Plane interworking for 5G non-standalone options 3, 3A, 3X, and/or 5G standalone.

- Seamlessly integrate FWA to expand broadband coverage in wireline brownfield areas and manage the cost and lead times of new fiber deployments in greenfield areas.

For more information about Nokia's Multi-Access Gateway and BNG CUPS solutions, visit https://www.nokia.com/networks/ip-networks/multi-access-gateway/ or contact your Nokia sales representative.

Table of figures

References and resources

1. Nokia Multi-Access Gateway. Data sheet.
2. Control User Plane Separation for a disaggregated BNG. Broadband Forum TR-459.
3. LTE; Interface between Control Plane and User Plane nodes. ETSI Technical specification.
4. Nokia Broadband Network Gateway. Solution brochure.
5. Nokia Fixed-wireless access Gateway. Solution brochure.
6. Multi-Access Gateway demonstration. Video.
7. Multi-Access Gateway controller. User documentation.

Abbreviations

5G NR	5G New Radio
AA	Application Assurance
AAA	authentication, authorization, accounting
ACL	access control list
AMF	Access and Mobility management Function
BNG	Broadband Network Gateway
CDL	common data layer
CE	customer equipment
CoA	change of authorization
CO	central office
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
HQoS	Hierarchical Quality of Service
IPoE	IP over Ethernet
L2TP	Layer 2 Tunneling Protocol
LAC	L2TP Access Concentrator

LNS	Layer 2 Tunneling Protocol Network Server
LTE	long term evolution
MME	Mobility Management Entity
MPLS	Multiprotocol Label Switching
NAS	Non-Access Stratum
NAT	Network Address Translation
NFV	network functions virtualization
OAM	operations, administration, and maintenance
PCF	Policy Control Function
PCRF	Policy Charging Rules Function
PDP	Policy Decision Point
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

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