



IEEE Recommended Practice for Software-Defined Networking (SDN) Based Middleware for Control and Management of Wireless Networks

IEEE Communications Society

Developed by the
Virtualized and Software Defined Networks and Services Standards Committee

IEEE Std 1930.1™-2022

STANDARDS

IEEE Recommended Practice for Software-Defined Networking (SDN) Based Middleware for Control and Management of Wireless Networks

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Virtualized and Software Defined Networks and Services Standards Committee
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Abstract: A software-defined networking (SDN) middleware is outlined in this recommended practice to support unified control and management of multiple radio access technology (multi-RAT) wireless access networks for fifth generation (5G) and beyond. An SDN architecture is also defined, which facilitates radio access network (RAN) level interworking and unification of RATs.

Keywords: fifth generation (5G), IEEE 802.11™ WLAN, IEEE 802.22™ WRAN, IEEE 1930.1™, software-defined networking (SDN), network virtualization

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Introduction

This introduction is not part of IEEE Std 1930.1-2022, IEEE Recommended Practice for Software-Defined Networking (SDN) Based Middleware for Control and Management of Wireless Networks.

This recommended practice specifies a middleware to support unified control and management of multi-radio access technology (RAT) wireless networks in accordance with the software-defined networking (SDN) paradigm.

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1. Overview

1.1 Scope

This recommended practice provides an SDN-based architecture for multi-radio access technology (RAT) wireless access networks. It also specifies an SDN-based middleware to support unified and vendor independent control and management of the data plane functions belonging to different RATs, such as wireless local area networks (WLANs), wireless regional area networks (WRANs), and other terrestrial radio access systems [e.g., those defined by the 3rd Generation Partnership Project (3GPP) and International Telecommunication Union Radiocommunication Sector (ITU-R)]. This document also recommends a logically unified multi-RAT control plane function. The control plane function is responsible for control and management of the multi-RAT access network with the help of the proposed middleware.

1.2 Purpose

Today's wireless networks are multi-RAT networks comprising different RATs, such as IEEE 802.11™, IEEE 802.22™, 3GPP, and ITU-R cellular technologies.¹ These are also multivendor networks consisting of equipment from a diverse set of vendors. An SDN-based control and management framework can facilitate unified and vendor-independent control and management for these multi-RAT wireless access networks. Such a framework can also help improve the performance of the wireless networks.

The purpose of this recommended practice is to define an SDN middleware along with an SDN architecture, enabling unified control and management of multi-RAT radio access networks.

1.3 Word usage

The word *shall* indicate mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall equals is required to*).^{2,3}

¹Information on references can be found in [Clause 2](#).

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The word *should* indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* be used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

3GPP TS 23.501:2019, V16.1.0—System Architecture for the 5G System (5GS).⁴

3GPP TS 37.340:2020, V16.0.0—NR; Multi-connectivity; Overall Description; Stage 2.

3GPP TS 38.401:2020, V16.2.0—NG-RAN; Architecture Description.

IEEE Std 802.11™-2016, IEEE Standard for Information Technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements Part 11: Wireless LAN Medium-Access Control (MAC) and Physical Layer (PHY) Specifications.^{5,6}

IEEE Std 802.22™-2011, IEEE Standard for Information Technology—Telecommunication and information exchange between systems—Wireless Regional Area Networks (WRAN)—Specific requirements Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

IETF RFC 5415:2009, Internet Engineering Task Force, RFC 5415—Control and provisioning of wireless access points (CAPWAP) protocol specifications.⁷

IETF RFC 6241:2011, Internet Engineering Task Force, RFC 6241—Network Configuration Protocol (NETCONF).

ONF TS-025:2016, Open Networking Foundation, OpenFlow switch specification v1.5.1.⁸

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3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms *and definitions apply*. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁹

access point (AP): A term specifically used in the context of IEEE 802.11™ networks. Denotes “an entity that contains one station (STA) and provides access to the distribution services, via the wireless medium (WM) for associated STAs. An AP comprises a STA and a distribution system access function (DSAF).” (Adapted from IEEE Std 802.11-2016)

active scanning: A term specifically used in the context of IEEE 802.11™ networks. Active scanning “involves the generation of ‘Probe Request’ frames by the station (STA) and the subsequent processing of received ‘Probe Response’ frames. (Adapted from the general description provided in IEEE Std 802.11-2016 as no definition of the term is available in IEEE Std 802.11-2016)

adaptation function (AdpF): This function within the radio access network (RAN) helps to adapt the data flows for the underlying radio interface protocol layers [i.e., medium access control (MAC) layer and the physical (PHY) layer function over the radio interface]. It performs the adaptation function according to the service requirements of various data flows. It is a type of data plane function in RAN.

admission control: A network function to help ensure that admission of a new data flow or new user equipment into a network does not violate parameterized service commitments made by the network to already admitted data flows or user equipment. (Adapted from the following definition provided in IEEE Std 802.11™-2016: “An algorithm intended to prevent the violation of parameterized service commitments made by the network to admitted flows by controlling the admittance of a new flow into a resource constrained network”).

aggregation function (AgrF): This function within the radio access network (RAN) is responsible for aggregating (disaggregating) traffic received from (sent toward) multiple base stations (BSs) and for exchanging it with other RAN networking functions [e.g., interworking function or other external network nodes such as border network gateway (BNG)]. It is a type of data plane function in RAN.

association service: A term specifically used in the context of IEEE 802.11™ networks. Denotes “the service used to establish access point/station (AP/STA) mapping and enable STA invocation of the distribution system services (DSSs).” (Adapted from IEEE Std 802.11-2016)

base station (BS): A generalized equipment set in radio access networks (RANs) responsible for radio transmission/reception in an area to/from the user equipment (e.g., transmission/reception in a cell in case of IEEE Std 802.22™-2011). It contains a radio head function in addition to other functions as may be required. (Adapted from the following definition given in IEEE Std 802.22-2011: “Generalized equipment set providing connectivity, management and control of the customer premise equipment (CPE). The functionalities attributed to the BS, in the context of this standard, may be implemented by a device or a collection of devices”).

base station function (BSF): The entity that contains the physical layer functionality of transmission/reception over a wireless medium and its associated medium access control functionality. It may also contain the radio transmit/receive unit. It is a type of data plane function in RAN.

base station function—Fifth generation new radio (BSF-5G NR): A base station function (BSF) belonging to the Third Generation Partnership Project (3GPP) fifth generation new radio (5G NR) radio access technology (RAT) with the wireless physical (PHY) layer and medium access control (MAC) layer functionality.

⁹IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

base station function—Fifth generation new radio (BSF-LTE): A base station function (BSF) belonging to the Third Generation Partnership Project (3GPP) long-term evolution (LTE) radio access technology (RAT) with the wireless physical (PHY) layer and medium access control (MAC) layer functionality.

base station function—IEEE Std 802.11™-2016 (BSF-802.11): In the context of IEEE 802.11 networks, a base station function (BSF) is the network entity that contains an IEEE 802.11-compliant physical layer functionality and the medium access control (MAC) layer to transmit and receive data over wireless medium to/from user equipment. Such an entity essentially supports a part of the functionality of an access point (AP) as specified by IEEE Std 802.11-2016. The entity also supports connectivity [typically the existing wired local area network (LAN) connectivity] to other network elements for transfer of data and control information [e.g., to software-defined networking (SDN) middleware for exchange of control information].

base station function—IEEE Std 802.22™-2011 (BSF-802.22): In the context of IEEE 802.22 networks, a base station function (BSF) is the network entity defined as a base station in IEEE Std 802.22-2011, that is, generalized equipment that provides connectivity, management, and control of the customer premise (or portable) equipment (CPE). The entity also supports connectivity [typically the existing wired local area network (LAN) connectivity] to other network elements for transfer of data and control information [e.g., to software-defined networking (SDN) middleware for exchange of control information].

base station function—Particular radio access technology (BSF-nRAT): A base station function (BSF) supporting the physical (PHY) and the medium access control (MAC) layer functionality to transmit/receive data over a wireless medium and provide radio connectivity to the mobile stations belonging to a particular RAT (n-RAT).

basic service area (BSA): A term specifically used in the context of IEEE 802.11™ networks. It denotes “the area containing the members of a basic service set (BSS). It might contain members of other BSSs.” (Adapted from IEEE Std 802.11-2016)

basic service set (BSS): A term specifically used in the context of IEEE 802.11™ networks. It denotes “A set of stations (STAs) that have successfully synchronized using the JOIN service primitives and one STA that has used the START primitive. Alternatively, a set of STAs that have used the START primitive specifying matching mesh profiles where the match of the mesh profiles has been verified via the scanning procedure. Membership in a BSS does not imply that wireless communication with all other members of the BSS is possible.” (Adapted from IEEE Std 802.11-2016)

basic service set (BSS) transition: A term specifically used in the context of IEEE 802.11™ networks. Denotes “change of association by a station (STA) from one BSS to another BSS in the same Extended Service Set (ESS).” (Adapted from IEEE Std 802.11-2016)

control and provisioning of wireless access points (CAPWAP): A protocol defined by the Internet Engineering Task Force (IETF) for control and provisioning of wireless access points as part of Request for Comments (RFCs) 4118, 5415, and 5416.

customer premise equipment (CPE): A term specifically used in the context of IEEE Std 802.22™-2011. A CPE is a generalized equipment set providing connectivity between a base station and a subscriber premise. (Adapted from IEEE Std 802.22-2011)

data flow: A set of data packets belonging to a specific data session for a user, for example, packets belonging to a Voice over Internet Protocol (VoIP) session or packets being exchanged for web browsing by a user.

data plane function [radio access network (RAN)]: A data (forwarding) plane function in the RAN capable of forwarding data traffic. It should also expose an abstract information model to the control plane [software-defined network (SDN) controller]. The forwarding plane functionality may also involve certain special processing on data packets, such as encryption/decryption or Internet Protocol (IP) header compression.

distribution system: A term specifically used in the context of IEEE 802.11™ networks. It denotes a system used to interconnect a set of basic service set (BSS) and integrated local area networks (LANs) to create an extended service set (ESS). (Adapted from IEEE Std 802.11-2016)

distribution system medium: A term specifically used in the context of IEEE 802.11™ networks. Denotes “the medium or set of media used by a Distribution System for communications between [access points] APs, mesh gates, and the portal of an [extended service set] ESS.” (Adapted from IEEE Std 802.11-2016)

distribution system service (DSS): A term used in the context of IEEE Std 802.11™-2016. Denotes “the set of services provided by the distribution system (DS) that enable the medium access control (MAC) to transport MAC service tuples between stations (STAs) that are not in direct communication with each other over a single instance of the wireless medium (WM).” (Adapted from IEEE Std 802.11-2016)

extended service set (ESS): A term specifically used in the context of IEEE 802.11™ networks. Denotes “a set of one or more interconnected basic service sets (BSSs) that appears as a single BSS to the logical link control (LLC) layer at any station (STA) associated with one of those BSSs.” (Adapted from IEEE Std 802.11-2016).

incumbents: A term specifically used in the context of IEEE 802.22™ networks. Denotes “licensed transmission systems operating in the television bands on a primary or secondary basis according to international and local regulatory rules.” (Adapted from IEEE Std 802.22-2011).

independent basic service set (BSS): In the context of IEEE Std 802.11™-2016, a BSS that forms a self-contained local area network (LAN), and in which no access to a distribution system is available. (Adapted from the general description provided in IEEE Std 802.11-2016 as no definition of the term is available in IEEE Std 802.11-2016)

infrastructure basic service set (BSS): A term specifically used in the context of IEEE 802.11™ networks. Denotes a set of stations (STAs) that have successfully synchronized using the procedure defined in IEEE Std 802.11-2016, that is, a set of STAs that have synchronized using the JOIN service primitives and a STA that has used the START primitive. For further details (e.g., definition of terms such as START and JOIN), refer to IEEE Std 802.11-2016. One STA in an infrastructure BSS is an access point (AP). The infrastructure BSS IEEE 802.11 wireless local area networks can be considered akin to a cellular network, wherein a BSS can be thought of as a cell under the control of an AP acting as the base station. (Adapted from the description provided in IEEE Std 802.11-2016 as no definition of the term is available in IEEE Std 802.11-2016)

interworking function (IWF): A data plane function responsible for interworking of a radio access network (RAN) with other networks such as fourth generation (4G) or fifth generation (5G) core networks or external data networks, like the Internet.

management information base (MIB): A collection of information organized hierarchically. An MIB is typically accessed using protocols like the Simple Network Management Protocol (SNMP). MIBs comprise managed objects identified by object identifiers.

medium access control (MAC) protocol data unit (PDU): The unit of data exchanged between two peer MAC entities using the services of the physical layer (PHY) (Adapted from IEEE Std 802.11™-2016 but also used in the context of other wireless networks).

medium access control (MAC) service data unit (MSDU): Information delivered as a unit between MAC service access points. (Adapted from IEEE Std 802.11™-2016 but also used in the context of other wireless networks)

middleware Northbound interface (m-NBI): The interface exposed by software-defined network (SDN) middleware toward the SDN controller.

middleware Southbound interface (m-SBI): The interface provided by software-defined network (SDN) middleware toward the underlying physical infrastructure.

mobile station (MS): A type of station (STA) that uses network communications while in motion. (Adapted from IEEE Std 802.11™-2016 but also used in the context of other wireless networks)

Northbound interface (NBI): The interface exposed by a network element toward higher level control and management functions; for example, the interface exposed by software-defined network (SDN) middleware toward the SDN controller is part of the NBI of the SDN middleware [middleware-NBI (m-NBI)].

optimization function (OptF): This function in the radio access network (RAN) is responsible for performing different types of optimizations on data traffic. The example optimizations may include quality-of-service (QoS) support, header compression, dropping of packets, and address translation. It is a type of data plane function in RAN.

particular radio access technology (nRAT): A term used to represent RATs other than the IEEE 802.11™, IEEE 802.22™, and Third Generation Partnership Project (3GPP) RATs. It may typically be used to represent non-3GPP RATs.

portal: A term specifically used in the context of IEEE 802.11™ networks. A portal is the logical point at which the integration service is provided. All data from or to non-IEEE 802.11 local area networks enter or leave the IEEE 802.11 architecture via a portal. (Adapted from IEEE Std 802.11-2016)

radio access technology (RAT): Type of wireless access technology used for radio access, for example, IEEE 802.11™, IEEE 802.22™, and Third Generation Partnership Project (3GPP) long-term evolution (LTE).

radio head: The physical or network entity that contains a radio frequency antenna.

security function (SF): The network function responsible for ciphering and integrity protection of user data and control messages being sent over the wireless medium. It is a type of data plane function in a radio access network (RAN).

software-defined network (SDN) controller: A logical network entity comprising the control and the management plane functionalities and having an exclusive control over the forwarding plane resources. An SDN controller is responsible for the control and the management of base stations (BSs) and the SDN middleware to support an efficient and optimized radio access network (RAN). The SDN controller along with the SDN middleware and the BSs should be responsible for the realization of the services as specified by a specific radio access technology (RAT) standard. For example, the services as required to be supported by access points (APs) and the distribution system of IEEE Std 802.11™-2016 should be realized with the help of the SDN controller, the SDN middleware, and the BSs.

software-defined network (SDN) middleware: SDN middleware is a logical network entity with well-defined functionality and interfaces. It exposes an abstract information model of the underlying RAN (especially the IEEE 802.11™ and IEEE 802.22™ RANs) to an SDN controller.

Southbound interface (SBI): The interface used by a network element for the control and the management of a lower level network element/device; for example, the interface used by the software-defined network (SDN) middleware toward a base station (BS) is part of the SBI of the SDN middleware [middleware-SBI (m-SBI)].

station (STA): A logical entity that is a singly addressable instance of a medium access control (MAC) and physical layer (PHY) interface to the wireless medium. (Adapted from IEEE Std 802.11™-2016 but used in the context of other wireless networks: “Some STAs may be mobile stations, i.e., a station that uses network communication while in motion”)

station (STA) services: The set of services that support transport of medium access control (MAC) service data units (MSDUs) between STAs within a basic service set. (Adapted from IEEE Std 802.11™-2016)

user equipment (UE): Generalized equipment used directly by an end user or a subscriber to communicate over a radio access network via a base station.

user equipment—IEEE 802.11™-2016 (UE-802.11): A possible mobile station (MS). It should contain the functionality of a station as specified in IEEE Std 802.11-2016 in addition to other functions of a generic device.

user equipment—IEEE 802.22™-2011 (UE-802.22): In addition to having generic user equipment functions, it should also contain the functionality of customer premise equipment, a generalized equipment set providing connectivity between a base station and a subscriber premise over the radio interface.

user equipment—Particular radio access technology (UE-nRAT): A network function that contains the functionality of a generic user equipment device, as well as any other functions mandated by the particular RAT's specifications.

user equipment—Third Generation Partnership Project (3GPP) fifth generation new radio (UE-5G NR): A network function that contains the functionality of user equipment as specified in the 3GPP 5G standard.

virtual adaptation function (vAdpF): A virtual instance of the AdpF.

virtual aggregation function (vAgrF): A virtual instance of the AgrF.

virtual base station (vBSF): A software implementation (a virtual instance) of a physical base station. It should not contain those hardware functions of a base station that cannot be implemented in software, such as a radio transmit/receive unit.

virtual interworking function (vIWF): A virtual instance of the IWF.

virtual optimization function (vOptF): A virtual instance of the OptF.

wireless local area network (WLAN) system: A term specifically used in the context of IEEE 802.11™ networks, that is, a system that includes the distribution system, access points (APs), and portal entities. It is also the logical location of distribution and integration service functions of an extended service set (ESS). A WLAN system contains one or more APs and zero or more portals in addition to the distribution system. The functionality of the APs and the services that need to be supported by a WLAN should be realized by a set of network elements/devices, such as base stations, a software-defined network (SDN) middleware, and an SDN controller. (Adapted from the general description provided in IEEE Std 802.11-2016 as no definition of the term is available in IEEE Std 802.11-2016)

wireless medium: The medium used to implement the transfer of protocol data units (PDUs) between peer physical layer (PHY) entities of a wireless local area network (WLAN). (Adapted from IEEE Std 802.11™-2016 but also used in the context of other wireless networks)

3.2 Acronyms and abbreviations

3GPP	Third Generation Partnership Project
4G	fourth generation
5G	fifth generation
AAA	authentication, authorization and accounting
AC	access controller
ACL	access control list
AdpF	adaptation function
AgrF	aggregation function
AMF	access and mobility management function
AP	access point
AR	augmented reality
ARQ	automatic repeat request
AUSF	authentication server function
BBU	baseband unit
BNG	broadband network gateway
BS	base station
BSA	basic service area
BSF	base station function
BSF-5G NR	base station function—Fifth generation new radio
BSF-802.11	base station function—IEEE Std 802.11–2016
BSF-802.22	base station function—IEEE Std 802.22–2011
BSF-LTE	base station function—Long-term evolution
BSF-nRAT	base station function—nRAT
BSS	basic service set
CAPWAP	control and provisioning of wireless access points
CBC	CPE basic capability
CN	core network
CPE	customer premise equipment
CPF	control plane function
C-RAN	centralized/cloud radio access network
DB	database
DCD	downstream channel descriptor
DHCP	Dynamic Host Configuration Protocol
DNS	domain name server
DPF	data plane function

DRB	data radio bearer
DSA	dynamic service addition
DS-MAP	downstream MAP
DTLS	datagram transport layer security
E1AP	E1 Application Protocol
EAP	Extensible Authentication Protocol
EAP-TLS	EAP—Transport layer security
EAP-TTLS	EAP—Tunneled transport layer security
EIRP	equivalent isotropically radiated power
EMS	element management system
eNB	evolved NodeB
EPC	evolved packet core
ePDG	evolved packet data gateway
ESP	encapsulating security payload
ESS	extended service set
E-UTRAN	evolved universal terrestrial radio access network
eV2X	enhanced vehicle to everything
F1AP	F1 Application Protocol
FFS	for future specification
FT	fast BSS transition
gNB	gNodeB
gNB-CU	gNB—Centralized unit
gNB-CU-CP	gNB-CU—Control plane
gNB-CU-UP	gNB-CU—User plane
gNB-DU	gNB—Distributed unit
GRE	generic routing encapsulation
GTP	General Packet Radio Service Tunneling Protocol
GTP-U	GTP user plane
ID	identification
IE	information element
IETF	Internet Engineering Task Force
IKEv2	Internet Key Exchange version 2
IMT	International Mobile Telecommunications
IP	Internet Protocol
IPsec	Internet Protocol Security
IWF	interworking function

LAN	local area network
LLC	logical link control
LTE	long-term evolution
LWA	LTE WLAN aggregation
LWAAP	LTE WLAN Aggregation Application Protocol
LWIP	LTE WLAN integration with IP Security (IPsec) tunnel
MAC	medium access control
MIB	management information base
MIoT	massive Internet of Things
MME	mobility management entity
MN	master node
m-NBI	middleware Northbound interface
m-SBI	middleware Southbound interface
MSDU	MAC service data unit
MS	mobile station
N3IWF	non-3GPP interworking function
NAS	non-access stratum
NBI	Northbound interface
NCMS	network control and management system
NETCONF	Network Configuration Protocol
NFV	network function virtualization
NGAP	Next Generation Application Protocol
NG-RAN	next generation radio access network
NMEA	National Marine Electronics Association
NMS	network management system
NR	new radio
NTP	Network Time Protocol
ONF	Open Networking Foundation
OptF	optimization function
PDCCP	Packet Data Convergence Protocol
PDU	protocol data unit
P-GW	packet-gateway
PHY	physical layer
PRB	physical resource block
QoS	quality of service
RADIUS	remote authentication dial-in user service

RAN	radio access network
RAT	radio access technology
RE	resource element
REST	representational state transfer
RFC	request for comments
RLC	radio link control
RPC	remote procedure call
RRC	radio resource control
RRH	remote radio head
RRM	radio resources management
SAE	simultaneous authentication of equals
SAP	service access point
SBI	Southbound interface
SCH	superframe control header
SDAP	Service Data Adaptation Protocol
SDN	software-defined networking
SDO	standards development organization
SNMP	Simple Network Management Protocol
SF	security function
SFF	service function forwarder
S-GW	serving gateway
SIB	system information broadcast
SM	spectrum manager
SMF	session management function
SN	secondary node
SNMP	Simple Network Management Protocol
SRB	signaling radio bearer
SSA	spectrum sensing automation
SSF	spectrum sensing function
SSID	service set identifier
SSL	secure socket layer
STA	station
TCP	Transmission Control Protocol
TFTP	Trivial File Transfer Protocol
TLS	Transport Layer Security
TNGF	trusted non-3GPP gateway function

TR-069	Technical Report-069
TV	television
TWAG	trusted wireless access gateway
UAV	unmanned aerial vehicle
UCD	upstream channel descriptor
UDP	User Datagram Protocol
UE	user equipment
UE-5G NR	user equipment—Fifth generation new radio
UE-802.11	user equipment—IEEE Std 802.11–2016
UE-802.22	user equipment—IEEE Std 802.22–2011
UE-LTE	user equipment—Long-term evolution
UE-nRAT	user equipment—nRAT
UPF	user plane function
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
US-MAP	upstream map
vAdpF	virtual adaptation function
vAgrF	virtual aggregation function
vBSF	virtual base station
vIWF	virtual interworking function
VoIP	Voice over Internet Protocol
vOptF	virtual optimization function
VRB	virtual resource block
vSF	virtual security function
Wi-Fi	wireless fidelity
WLAN	wireless local area network
WRAN	wireless regional area network
WTP	wireless termination point
XML	Extensible Markup Language
YANG	yet another next generation

4. Notations used in this recommended practice

The notations used in this recommended practice for illustrating system diagrams and call flows are provided in [Table 1](#). Note that we have chosen to represent diagrams referenced from other standards/specifications as illustrated in the original document. Some notations used here are inspired by Object Management Group's (OMG's) Unified Modeling Language (UML).

Table 1—Notations used in this recommended practice

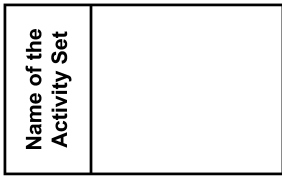
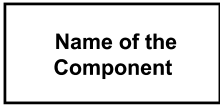
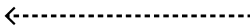
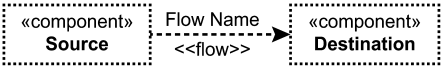
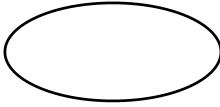
Name of the notation	Symbol	Meaning
Activity set		An activity set is a group of related activities that perform a specific function.
Asynchronous message		The sender is not blocked when an asynchronous message is triggered by it and can proceed to perform further operations.
Component		A component is a modular unit of a network function with well-defined interfaces and behavior. It can be replaced with another realization with the same interface and behavior.
Interface		An interface defines the type of protocol/information exchanged between two interacting entities (components/network functions).
Manifestation		A manifestation is the concrete physical rendering (or realization) of one or more architectural elements.
Parallel execution		Used to indicate operations that can be executed in parallel without any regard to the order of execution.
Response		This notation indicates the given message is sent as a response to some previous message.
Synchronous message		When a synchronous message is triggered, the sender is blocked and cannot perform further operations until it receives a response.
Data flow		This notation has only been used in data flow diagrams to indicate the direction and type of information transferred from source to destination.
IEEE 802.11 CAPWAP messages	“Message Name” or Message Name [Remark] (Protocol)	Typically used in call flows. May be followed by an optional remark including details of other messages carried within, actions performed by the message, etc.

Table continues

Table 1—Notations used in this recommended practice (continued)

Name of the notation	Symbol	Meaning
IEEE 802.22 OpenFlow messages	“MSG_NAME”	Denotes an IEEE 802.22 OpenFlow message. However, in a sequence diagram, an optional remark may also follow. The remark may include details of other messages carried within, actions performed by message, etc.
NETCONF RPC message	“rpc_call_name()”	Indicates an RPC call.
Geographical region		Indicates a geographical region.

5. General description

Wireless networks are an integral part of our current lives. Different types of wireless and cellular technologies play important roles in providing connectivity to people (and now machines) worldwide. The usage of wireless networks is expected to increase further with the deployment of the 5G mobile communication networks in the near future.

5.1 Key architectural enhancements in 5G

The 3GPP 5G system, which has been standardized recently, is a significant departure from the previous generations of mobile and cellular communication systems. It has introduced many novel concepts as part of its architecture. A few of those concepts are highlighted in the following:

- **Heterogeneous multi-RAT Network:** The 5G (and beyond) communication networks are expected to be heterogeneous multi-RAT networks wherein the deployment would typically comprise a diverse set of RAN nodes belonging to different RATs and of varying coverage areas to provide a variety of services to users. Some key access technologies expected to be present in the 5G network are the 5G NR, 3GPP LTE, and IEEE 802.11 WLANs in addition to a host of other RATs as specified in 3GPP TS 23.501-2019. The 5G system may also incorporate IEEE 802.22 WRANs, especially to provide connectivity to users in sparsely populated (rural) areas and developing economies. The 5G system also envisages the integration of a fixed access network within a single architectural framework (3GPP TS 23.501-2019).
- **Increased Network Softwarization:** Technologies like SDN and NFV are expected to be a cornerstone of the wireless systems in 5G and beyond.
- **Control Plane—Data Plane Separation:** Following the SDN paradigm, the CPF will likely separate from the DPFs (or UPFs, as called in 3GPP specifications) in wireless networks. This separation will probably allow for independent scalability and evolution of the two planes and bring flexibility to network deployments. For example, to separate the control plane and the data plane in the 3GPP 5G system, control interfaces/protocols such as the F1/E1 interface and F1AP/E1AP have been standardized for 5G-NR access technology (3GPP TS 38.401-2020).

- **Disaggregated Network Architecture:** The functionality, which was defined as a single unit (or box) in an earlier generation of cellular technology, has been separated into multiple smaller units and defined as a set of disaggregated functions. A key example herein is that of a BS, which was defined as a single unit, that is, eNB in 4G LTE. In the 3GPP 5G specifications, a 5G-NR BS (or gNB) has been designed as a set of multiple disaggregated functions, that is, as gNB distributed unit (gNB-DU), gNB centralized unit control plane (gNB-CU-CP), and gNB centralized unit user plane (gNB-CU-UP) with the scope for further disaggregation.
- **Integration of RATs:** The 3GPP 5G system architecture defines a converged and unified core network (5GC) for managing multiple access technologies in an integrated manner. 3GPP access technologies, such as 5G NR and LTE, and non-3GPP access technologies, such as WLAN, can be integrated with the 5GC.

Although the 3GPP 5G system has brought out many architectural innovations and enhancements in wireless networks especially in the control and management aspects, some issues/aspects, more specifically pertaining to the access networks, still need to be addressed to achieve an efficient, flexible, and integrated multi-RAT access network for 5G and beyond. The next subclause summarizes some of these issues.

NOTE—A more detailed description of the architecture, high-level capabilities, and some key issues with the existing wireless access networks is available in [Annex D](#). Readers are encouraged to refer to the relevant sections in the annex to obtain a more detailed understanding of the working of these RATs, as well as some of the issues faced by them.¹⁰

5.2 Issues with existing wireless access networks including 5G

Many different wireless access technologies are in use today. IEEE 802.11 WLAN is one of the most popular wireless broadband access technologies worldwide. As far as the IEEE 802.11 WLAN is concerned, centralized architectures, for example, based on CAPWAP (IETF RFC 5415:2009) and the variant protocols, are commonly used to control and manage them. Such centralized architectures, typically comprise a large number of wireless AP devices (similar to base stations) and a few centralized controllers commonly called “ACs.” APs provide radio connectivity to mobile devices, and ACs are responsible for control and management of these APs. APs and ACs together support the required access functionality specified in IEEE 802.11 standards. Such centralized architectures offer better manageability and control of the WLANs. For example, the public Wi-Fi networks described in [D.4.1](#) typically follow such an architecture. However, despite their large-scale usage and many advantages, such centralized WLANs suffer from a few handicaps too, such as follows:

- A clear separation may not exist between the control plane and the data plane entities in existing centralized WLAN architectures; that is, ACs and APs in such networks can possess control plane, as well as the data plane, functionality. The AC, typically responsible for control and management of WLAN APs, can also play the role of an aggregation point for the data traffic. Therefore, such WLAN architectures do not follow the SDN paradigm and do not possess the advantages thereof.
- No universally acceptable (or at least acceptable to most the equipment manufacturers/vendors) standard interface exists between the AC and the APs along with a standard mandated separation of functionality between the two network functions. Thus, interoperability issues may occur between equipment from different vendors. For example, the AC from vendor “X” may not be able to work with the AP from vendor “Y”. Therefore, such WLANs are mostly being managed and controlled through proprietary management and control architecture/protocols. As a result, any number of different protocols may need to be used to manage devices (APs) in multivendor networks. This scenario results either in vendor lock-ins or in an increased complexity of network control and management due to the need to support multiple protocols in a multivendor network. In some cases, the pace of network deployment, network upgrades, and introduction of new services may slow.

¹⁰Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

- Such AC and AP centralized architectures are also RAT specific and are typically catering to IEEE 802.11 networks only and therefore cannot be used for the unified control and management of a multi-RAT access network. Even though CAPWAP, which is a commonly used protocol in centralized architectures for IEEE 802.11 WLAN, has the option of supporting such an architecture for other RATs like IEEE 802.22 WRANs through a new protocol binding, such bindings for other access technologies like IEEE 802.22 WRAN were never defined.

The 3GPP Evolved UMTS Terrestrial Radio Access Network (E-UTRAN)/4G LTE is the most popular broadband cellular technology globally. However, it also suffers from certain handicaps, especially those related to control and management aspects of the access network:

- The 3GPP E-UTRAN has been designed such that the control and data plane functionalities are integrated into every node (LTE eNB) within the radio access network. Multiple LTE eNBs are deployed in the access network with each eNB possessing control and data plane functionality.
- LTE eNBs also suffer from the problem of tight coupling of the control and data plane functions; that is, no standardized interface exists between these functions of an eNB, leading to every eNB vendor implementing its own proprietary interface between the two.

As mentioned in 5.1, the issue of tight coupling of control and data plane functionality in RAN is being addressed in 5G technology. 3GPP 5G NR RAN follows an SDN architecture with the control plane of the RAN node (gNB-CU-CP) separated from its data plane functions (gNB-DU and gNB-CU-UP) through standardized interfaces. However, these protocols are not usable for IEEE 802.11 WLANs even when WLANs are integrated with the 5G networks.

Although the 3GPP 5G system has defined a converged CN for diverse RATs leading to a simplified architecture and bringing certain efficiencies, it does not enable integrated control and management of different RATs at the RAN level. The 3GPP 5G system still deals with a fragmented multi-RAT RAN. The logical centralization of the control function in RAN, as discussed, is applicable to 5G-NR RAT only, and no proposal exists to bring different RATs under a unified multi-RAT RAN architecture as part of the 5G standards. If control plane functionality is logically centralized, a global view of the available network resources across RATs could be obtained, which would enable unified control of the underlying network and facilitate deployment of better resource management and optimization algorithms. A fragmented RAN has architectural limitations too. For example, no unified and common interworking mechanism is available for services such as concurrent multiple access in existing multi-RAT RANs, and implementation of such services (requiring interworking of multiple RATs) makes the system complex and interactions cumbersome. As discussed in 6.1, lack of RAN level unification and integration thwarts certain simplicity and flexibility too, which might have been possible otherwise.

Additionally, even though SDN has been introduced within the 3GPP 5G NR RAN separating the control and data plane functionality within the network, a few other drawbacks still exist. In particular, the control plane functionality within 5G NR RAN broadly comprises two categories of tasks. First, the RAN control plane performs tasks that involve interfacing with UE and handling signaling exchanges with it (the UE), for example, through RRC messages. The second category of tasks is similar to that in wired SDNs and pertains to the control and management of data plane functions (i.e., gNB-DU and gNB-CU-UP) within the RAN through F1/E1 interfaces. The existing 5G specifications do not distinguish between these two types of tasks and treat the combined functionality as the RAN control plane. However, to achieve uniform control of a multi-RAT RAN, it should be important to introduce a logical separation between these two types of tasks and provide a well-defined interface between them.

Also, even though the workings of various access networks (belonging to different RATs) differ from one another, certain functions, such as packet forwarding, encryption/decryption of data, interworking with other networks such as core network, are present in most RATs. Redefining the RAN in terms of smaller modular network functions and reorganizing it in terms of these common functions may achieve a simpler multi-RAT

RAN architecture. Such an architecture can also enable an improved disaggregated architecture for RAN and introduce flexibility into the network. We will also see that such a disaggregated RAN architecture facilitates an improved unification of RATS at the RAN level. Procedures that involve coordination across RATs, such as multiaccess support, can be supported in an easier manner within such an architecture. However, no such proposal to disaggregate RAN functions is being considered currently under any standard development organization. As mentioned, the 5G standard has developed a disaggregated RAN architecture, but it has limited scope and does not try to apply the concept to multi-RAT RAN as has been discussed here.

5.3 SDN multi-RAT RAN architecture

One way of resolving the highlighted issues is the reorganization of the RAN using an SDN paradigm with a unified multi-RAT control plane function responsible for control and management of data plane functions belonging to different RATs. This recommended practice sets out to define the key components of such an architecture to support better manageability and control of multi-RAT RAN. The important contributions made by this recommended practice have been listed in [Annex F](#).

SDN, as defined in IETF RFC 7426 [B3],¹¹ is a networking concept that enables a logical separation between the data (forwarding) plane functionality and the control plane functionality within the network. Data plane functions perform one or more network operations related to packet manipulation and forwarding. Control plane functions control the data plane. They instruct the data plane functions on how to process and forward the packets.

An example network architecture resulting from the use of SDN is illustrated in [Figure 1](#). The application of SDN results in logical centralization of the control plane functionality within the network. However, the nature of the data plane functionality remains distributed with multiple data plane entities distributed in the network. Other functions within the network may also exist, such as management plane functions. These functions monitor, configure, and maintain the data plane and are also typically centralized. As illustrated in the figure, the control plane and management plane together may constitute a logical entity known as the

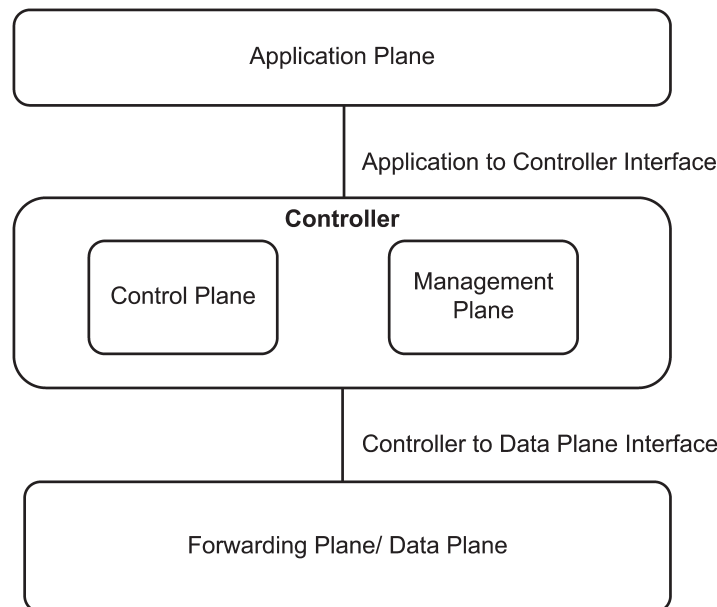


Figure 1—SDN network architecture

¹¹The numbers in brackets correspond to those of the bibliography in [Annex A](#).

“SDN controller.” Note that the management plane may also be a part of a separate system (known as the NMS) and not necessarily a part of the SDN controller. Another set of functions known as the application plane may be used to provide network services by defining a service-aware behavior of network resources in a programmatic manner (ITU-T Y3300-2014 [B4]).

It can be observed that the SDN controller has two sets of interfaces, one toward the application plane and another toward the data plane. These interfaces are open and programmable. The application plane programs the network behavior by providing policies. The controller uses the policies provided by the application plane and translates them into control and management of the data plane and together support the desired behavior.

The usage of SDN enables the creation of open standardized interfaces between the control plane and the forwarding plane, and thus, it allows vendor-neutral control and management of networks. In addition, SDN provides the flexibility of applying network-wide policies over the network through the use of applications over the controller. The policies are then translated by the controller (to vendor/device-specific routing rules) to configure and manage the network. Therefore, a unified control and management framework enabled by SDN would not only simplify network control and management, but also it would allow easier deployment of newer services and applications.

Figure 1 illustrates a generic SDN network architecture.¹² However, it does not support the multi-RAT RAN and therefore cannot address the issues mentioned above. A modified SDN multi-RAT RAN architecture is thus proposed as part of this recommended practice. Figure 2 depicts a high-level view of the proposed architecture. The proposed architecture has been developed to address the issues mentioned in 5.2.

As shown in Figure 2, an additional layer called “SDN middleware” has been introduced in between the control plane and the data plane. The SDN middleware is a key component of the proposed architecture. It facilitates a unified control and management of data plane elements within a multi-RAT RAN. The middleware virtualizes the underlying data plane resources and exposes a unified abstract information model (of the RAN data plane) to the controller. As a result, the SDN controller can manipulate and manage the network resources in a unified and integrated manner. The middleware also facilitates a vendor-agnostic control plane functionality and brings simplicity and flexibility to the multi-RAT RAN architecture.

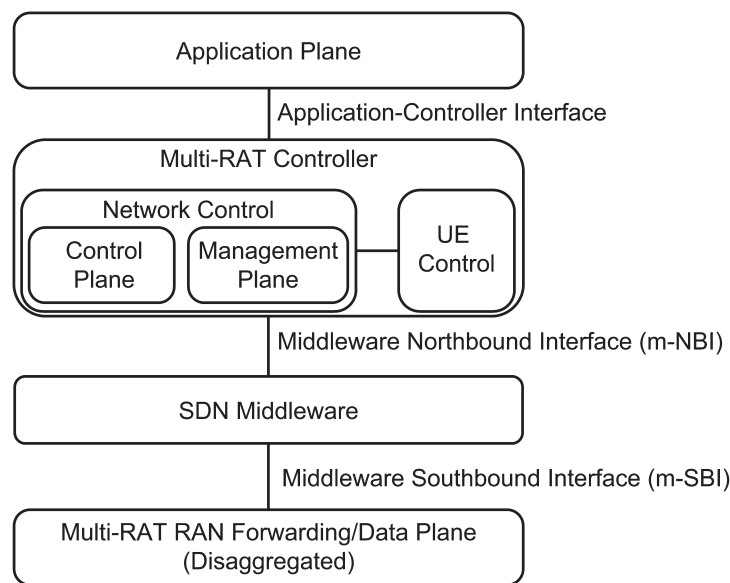


Figure 2—Proposed architecture for multi-RAT RAN

¹²The management plane may be responsible for the management (monitoring, configuration, etc.) of the control plane, as well as of application plane functions too. However, because this standard is focussed on the control and management of the data plane, those interfaces have not been shown or discussed here.

6. SDN multi-RAT RAN architecture

6.1 Design principles

The SDN multi-RAT framework defined by this recommended practice aims to resolve many of the issues highlighted in [Clause 5](#). Design principles have been proposed in an architectural framework for multi-RAT RAN. The architectural framework as devised by this recommended practice is developed on the basis of these design principles. The list of design principles is provided as follows:

- a) **Separation of control and data plane in RAN:** The framework should separate the control and data plane functionality in the RAN.
- b) **Centralizing access network control within a RAN controller:** The framework separates out the control plane functionality from RAN nodes and places it into a logically centralized SDN controller.
- c) **Unification of multi-RAT control:** The control functionality across RATs would be unified, and wherever possible a logically centralized controller across RATs would be used to control and manage the data plane.
- d) **Decomposition of control functionality:** Control functionality should be decomposed into UE and network control as described in [6.3.4.1](#). However, UE control may not necessarily be a part of the SDN controller and can be placed in a different network function.
- e) **Support for abstract information model on the data plane through an SDN middleware:** The data plane should provide an abstract information model that allows for easy manipulation by the controller. This abstract information model over the data plane is manifested through an SDN middleware, a layer present between the data plane and the control plane. The abstract information model allows virtualization of network resources and facilitates the creation of multiple logical/virtual networks over a shared physical infrastructure. A logically separate orchestrator shall be included. The orchestrator is responsible for creation of the abstract information model over the data plane.

The presence of an SDN middleware between the control plane and the data plane also facilitates unification of control functionality across RATs. The presence of SDN middleware also helps in the separation of the control plane from the data plane functionality in certain scenarios, which will be clarified in [6.3.3](#).

- f) **Usage of a single set of protocols for network configuration and control by the controller:** To simplify network control, the controller uses a single set of protocols for network control and management as far as possible. To control existing deployments using protocols different from those supported by the controller, a middleware would be used to enable interworking between the two. The middleware shall enable the translation of protocols supported by the existing network control entity to those supported by the SDN controller.
- g) **Building the RAN with modular, reusable network functions:** Although various RANs appear to be different from each other, on closer examination, they perform a lot of similar functions such as transmitting/receiving user data, interworking with other functions such as the core network, protecting user data through ciphering and integrity protection, optimizing the data for transmission over the air interface such as IP header compression for VoIP, and so on. This framework organizes the multi-RAT RAN data plane into smaller, modular virtualized network functions in terms of the above-mentioned common functions. These functions are logically chained together through a policy provided by the controller. For example, every data flow passes through a chain of functions, arranged using policy rules provided by the controller. The selection of functions for chaining is based on the requirements of the flow. The implementation of these constituent functions may vary across RATs. Further details on the possible implementation of these functions in various RATs are presented in [6.4](#) and [6.5](#).

- h) **Network control protocol to be used only for configuration of data plane network functions:** Wireless networks use separate sets of protocols for configuring UEs referred to here as “UE control protocols” and for configuring RAN data plane functions (other than UEs) referred to here as “network control protocols.” The separation of UE control also provides advantages with certain network deployments such as in fixed network or with public Wi-Fi networks where UE control functionality is not required. With a few other network types, such as in mobile networks, protocols such as RRC are used to configure UEs. However, these protocols are piggybacked on other network control protocols (such as F1AP). This recommended practice discourages such practices and chooses to transmit UE control protocol messages separately without aggregating them with (i.e., piggybacking them onto) network control protocol messages. This principle facilitates the separation of UE and network control, which simplifies the controller functionality and provides increased flexibility for placement of network functions.
- i) **Unification of interworking toward other networks:** The interworking functions with other networks such as cellular core networks shall be unified across RATs. Wherever possible, single interworking function shall exist toward other networks irrespective of the RAT type being used. As a result, RAT-specific interfacing functions would not be required. Note that it may also be possible to have multiple instances of the interworking functions for load balancing purposes. The the SDN controller could use network resources in a multi-RAT RAN in a more efficient manner.

6.2 SDN multi-RAT framework

The SDN multi-RAT framework introduced in this recommended practice re-architects the multi-RAT RAN in terms of data plane functions common for most RATs. These functions should provide an abstract information model to the SDN controller.

The list of proposed data plane functions are as follows: BSF, AdpF, OptF, AgrF, SF, and IWF. The control plane functions defined in the context of this framework include the SDN controller and orchestrator. These functions represent some of the most commonly used functionality in today’s RANs. At the same time, this list is not an exhaustive one of network functions in every RAN and does not include the entire set of RAN functionalities. However, the idea is to propose a disaggregated architectural framework for RAN, which can be used to unify different access technologies at the RAN level. Such a disaggregated framework enables different access technologies to come together under a simple and unified SDN architecture for multi-RAT RAN. The functions will be described later in this clause. As specified, it may also be the case that not all functions are required for a particular RAN deployment and only a subset of them is used. The SDN controller is responsible for the overall control plane function in the multi-RAT RAN. The other functions proposed here, for example, BSF, OptF, or SF, are primarily data plane functions. Some of these other functions might also have some control functionality; for example, real-time control functions like “scheduling” or “power control and management” are present on the BSF. However, such control functions also work under the guidance of the policy configuration provided by the SDN controller.

The BSF in the context of this recommended practice is used to refer to a RAN node of a particular RAT that typically possesses the physical layer and the MAC layer functionality. It may also have the radio transmission/reception functionality even though it is mostly devoid of control and management plane functionality.

As part of the proposed RAN architecture, an additional logical network entity, that is, “SDN middleware,” has also been introduced. The SDN middleware, which is placed in between the SDN controller and other data plane functions, such as BSF and IWF, exposes a unified abstract information model of the underlying RAN functions to the controller through an NBI and is the key component of the proposed architectural framework. This abstract information model exposed by the middleware allows the SDN controller to manage and control the underlying multi-RAT network in a unified manner. The SDN middleware also performs the adaptation of the existing control/management interfaces toward the “underlying RAN nodes” to “an abstract interface toward the controller” when underlying data plane is made up of existing network entities, such as, IEEE 802.11 WLAN AP, IEEE 802.22 WRAN BS, LTE eNB, 5G gNB-DU, or 5G gNB-CU-UP. The SDN

middleware enables the SDN controller to visualize and manage the underlying data plane in terms of abstract functions, BSF, SF, OptF, IWF, and so on, even when the underlying data plane is constituted of existing network entities, such as IEEE 802.11 WLAN AP, IEEE 802.22 WRAN BS, LTE eNB, 5G gNB-DU, and 5G gNB-CU-UP.

As part of the proposed architecture in this recommended practice, every RAN entity (other than the SDN controller and the SDN middleware), such as IEEE 802.11 WLAN AP and IEEE 802.22 WRAN BS, contains only the data plane function wherever possible. The RAN control plane functionality as defined in the IEEE 802.11, IEEE 802.22, and 3GPP LTE standards is moved to the SDN controller. Therefore, the existing RAN entities may need to be modified in some cases to be aligned with this architecture.

The SDN middleware facilitates the separation of the data plane from the control plane. As described in [D.1](#), ACs in some public Wi-Fi network deployments concentrate the data plane and control plane functionality. Replacing the AC with an SDN controller and middleware helps in separating the control plane from the data plane without changing other entities in the network.

6.3 SDN RAN architecture

The proposed multi-RAT RAN architecture comprises the following network functions/entities: UE (or mobile stations), BSFs for different RATs, AdpF, AgrF, OptF, SF, IWF, SDN middleware, and the SDN controller. These network functions/entities are together used to support all the functionality performed by a multi-RAT RAN. Such a RAN is based on IEEE 802.11, IEEE 802.22, or other RATs, such as 3GPP LTE and 5G NR. These entities/functions are described as follows.

6.3.1 UE

UE or a mobile station is generalized equipment used directly by an end user or a subscriber to communicate with a mobile network via RAN (i.e., via a BSF). There may be different types of UEs in use depending on the RAT being used, for example, UE for IEEE 802.11 wireless access network or UE for IEEE 802.22 wireless access network or an LTE/5G UE.

6.3.2 RAN data plane functions

The following functions BSF, AdpF, AgrF, SF, OptF, and IWF are defined as a set of abstract data plane functions in RAN. Using the resources available in RAN, these abstract functions can be instantiated as concrete functions and they can use the network resources to process and forward the user data through the RAN. As will be seen in [6.4](#), this division of the RAN data plane into a set of abstract data plane functions helps in organizing the multi-RAT RAN under a unified SDN architectural framework. As noted in [6.2](#), this list is not exhaustive of all data plane functions in every possible RAN. Instead, they encapsulate some of the most commonly used data plane functionality in different RANs. As indicated, one or more of these functions can be implemented as part of the existing RAN entities, for example, IEEE 802.11 WLAN AP, IEEE 802.22 WRAN BS, LTE eNB, 5G gNB-DU, 5G gNB-CU-UP, and 5G N3IWF. In such a case, the SDN middleware represents these existing RAN entities in terms of the abstract functions to the SDN controller through virtualization. This virtualization of existing entities in terms of the proposed abstract functions simplifies the control process at the controller as it has a uniform view of the data plane through these abstract functions irrespective of how they are implemented physically. A brief description of these abstract data plane functions has been provided in [6.3.2.1](#) through [6.3.2.6](#).

6.3.2.1 Base station function

A function representing a generalized equipment set in RAN, responsible for radio transmission/reception in an area to/from the user equipment (e.g., transmission/reception in a BSA in the case of IEEE 802.11 RANs). It contains radio transmission/reception functionality, the physical layer functionality, and the MAC layer functionality. Although the radio transmission/reception function can also be physically separate from the

BSF, we treat it logically as part of the BSF. The radio transmission/reception function is responsible for sending and receiving data to/from the UE over the radio interface, performing error control and coding, and so on. It can also support some control functionality, such as packet scheduling, link adaptation, and power control.

6.3.2.2 Adaptation function

The AdpF within RAN helps to adapt the data flows for the underlying radio interface protocol layers, that is, the MAC and physical layer functions over the radio interface, which are supported by the BSF. It performs the adaptation function (essentially link layer adaptation and control functionality) according to the service requirements of the various data flows. It should be responsible for functionality such as handling of packet loss and retransmission (ARQ), duplicate detection, packet reordering, and in-sequence delivery to other higher layer data plane functions.

6.3.2.3 Aggregation function

AgrF is responsible for aggregating (disaggregating) data traffic received from (sent toward) multiple base stations and exchanging it either with internal entities like IWF or with external entities like BNG in public Wi-Fi networks or UPF in the 5G core network.

6.3.2.4 Optimization function

OptF is responsible for performing optimizations on data traffic. The example optimizations include IP header compression/decompression, flow classification/identification and mapping, metering and dropping packets, address translation, and so on.

6.3.2.5 Security function

SF is responsible for ciphering and integrity protection of user data and UE-specific control messages being sent over the wireless medium.

6.3.2.6 Interworking function

IWF is responsible for interworking of RAN with other networks such as 4G or 5G core network or external data networks, like the Internet.

All or a subset of the above-mentioned data plane functions can likely be instantiated as part of a single network entity in the RAN. An example of such an instantiation is LTE RAN, where many data plane functions, for example, BSF, SF, and IWF, are instantiated as part of the LTE eNB. Further details and examples of disaggregation of various RAN nodes in terms of the proposed network functions are provided in 6.5. The architecture, as defined here, can be used with present-day RATs with a few modifications to the RAN nodes.

6.3.3 SDN middleware

SDN middleware is a network entity placed in between the SDN controller and other RAN functions, such as the BSF, AdpF, OptF, and IWF, or existing RAN entities, for example, IEEE 802.11 WLAN AP, 5G gNB-DU, and LTE eNB (Figure 3). It virtualizes the underlying RAN functions (essentially the network resources) or existing RAN entities in terms of the abstract data plane functions and exposes a unified abstract information model of RAN data plane functions/entities (along with their resources) to the controller. As a result, the SDN controller can manipulate and manage the network resources in RAN in a unified and RAT-independent manner, wherever possible.

Note that the SDN middleware is referred to as a “network entity” and not as a “network function” because a network function, as defined in ETSI GS NFV 003-2018 [B2], is typically viewed as a functional block with well-defined functional behavior and external interfaces. However, the behavior of the SDN middleware can