5G-OPERA Deliverable 3.2

Definition of the Reference Architecture

Document Properties	
Nom du projet :	5G-OPERA
Titre du document :	Definition of Reference Architecture
Donneur d'ordre :	Ministère de l'économie, des finances, et de la relance, Bundesministerium für Wirtschaft und Energie
Référence officielle :	5G-OPERA D3.2
Relecteur :	Florian Kaltenberger, Thomas Höschele
Résumé :	
Date de publication :	10/02/2023
Version :	1.0
Accès :	Public
Mots clés :	Open RAN, 5G Private Network, Reference Architecture

Executive Summary

This report describes the detail of the reference architecture for private 5G networks. More specifically, the overall architecture of open RAN and core network has been described by partners of 5G-OPERA project by taking account the standards in 3GPP and O-RAN Alliance. The report covers necessary functions and interfaces for private 5G networks. Each description has a short content and has been referenced to the related specification, since 5G-OPERA project takes standards into account. The report starts with section 1 giving a brief introduction.

Section 2 describes the reference architecture of the open RAN based on the split option 7.2. Particularly, the function of the open RAN and interfaces between functions have been described. For implementation of all components, standards of 3GPP or O-RAN Alliance will be taken into account in order to make RAN open.

Section 3 gives definition of the 5G core network function and interfaces. There are many function in the standards; however, network functions related to the 5G-OPERA project have been considered in this report.

Section 4 gives an overview of the role of Time Sensitive Networking (TSN) in 5G system. The section has an overview about end station, TSN bridge and TSN system. Addition to these, it also describes the device and network side TSN translators.

Section 5 starts with definition of O-Cloud platform and continues with the deployment scenarios of open RAN. O-RAN Alliance has introduced several deployment scenarios. It is agreed that 5G-OPERA project will take first scenario into account since it fits to the private 5G network. Moreover, this section also describes the configuration for fronthaul synchronization which will be applied in the project.

Finally, section 6 concludes the report.

Table of Contents

Abbreviations

HW	Hardware
RAN	Radio Access Network
gNB	New Generation Node B
CU	Centralized Unit
DU	Distributed Unit
RU	Radio Unit
5GC	Core Network
SBA	Service-Based Architecture
NFs	Network Functions
CP	Control-Plane
UP	User-Plane
TSN	Time Sensitive Networking
VNFs	Virtualized Network Functions
VMs	Virtual Machines
PNFs	Physical Network Function
SMO	Service Management and Orchestration
RIC	Radio Intelligent Controller
Non-RT RIC	Non-Real-Time RIC
Near-RT RIC	Near-Real-Time RIC
E2SMs	E2 Service Models
E2T	E2 Termination
SCTP	Stream Control Transmission Protocol
O-CU-C	O-CU-Control
O-CU-P	O-CU-User
RRC	Radio Resource Control
PDCP	Packet Data Convergence Protocol
3GPP	Third Generation Partnership Project

UPF	User Plane Function
LLS	Low Layer Split
AMF	Access and Mobility Management Function
SDAP	Service Data Adaptation Protocol
MIMO	Multi Input Multi Output
MAC	Medium Access Control
RLC	Radio Link Control
HARQ	Hybrid Automatic Repeat Request
SDU	Service Data Unit
AAL	Acceleration Abstraction Layer
SW	Software
IFFT	Inverse Fast Fourier Transform
SDR	Software Defined Radio
FTT	Fast Fourier Transform
eCPRI	Enhanced Common Public Radio Interface
ICs	Integrated Circuits
RF	Radio Frequency
PA	Power Amplifiers
SPI	Serial Peripheral Interface
LVDS	Low Voltage Differential Signaling
VGA	Variable Gain Amplifier
ML	Machine Learning
UE	User Equipment
O-eNB	Open Evolved NodeB
FCAPS	Fault, Configuration, Accounting, Performance Security
AI	Artificial Intelligence
MEs	Management Entities
CUS-Plane	User Synchronization Plane
UL	Uplink

DL	Downlink
DSS	Dynamic Spectrum Sharing
PTP	Precision Time Protocol
PDU	Protocol Data Unit
E-UTRAN	Evolved Universal Terrestrial Radio Access
GTP-U	GPRS Tunnelling Protocol
DRB	Data Radio Bearer
UPF	User Plane Function
NGAP	NG Application Protocol
NAS	Non-Access Stratum
Open-nFAPI	Open network Functional Application Platform Interface
SCP	Service Communication Proxy
NRF	NF Repository Function
DN	Data Network
SMF	Session Management Function
PCF	Policy Control Function
PCC	Policy and Charging Control
SDF	Service Data Flow
QoS	Quality of Service
UDM	Unified Data Management
I-UPF	Intermediate UPF
PFCP	Packet Forwarding Control Packet
UDR	Unified Data Repository
SUPI	Subscriber Permanent Identifier
SUCI	Subscriber Concealed Identifier
5GS	5G System
LMF	Location Management Function
NSSF	Network Slice Selection Function
UCMF	UE radio Capacity Management Function

PLMN	Public Land Mobile Network
NAS	Non-Access Stratum
LCS	LoCation Services
NGAP	NG Application Protocol
AF	Application Function
NEF	Network Exposure Function
CNC	Centralized Network Controller
CUC	Centralized User Configuration
DS-TT	Device-side TSN Translator
NW-TT	Network-side TSN Translator
TSN-AF	TSN Application Function
CPE	Customer Premises Equipment
PDP	Packet Data Protocol
PoC	Proof of Concept

Table of Figures

1 Introduction

The goal of the **5G-OPERA** project is to build a Franco-German ecosystem for private 5G networks under the joint leadership of TU Dresden and EURECOM (Sophia Antipolis). The project focuses on the idea of open hardware (HW), software and interfaces so that multiple providers can participate in the technical equipment of private 5G networks and user needs can be flexibly realized. The overall goal of the project is to ensure that the HW and software of all project partners can work together technically, independently of the respective manufacturer. In addition to setting up reference test environments and demonstrators in Industry 4.0 environments of both countries, **5G-OPERA** is supporting the trials in the three demonstration projects and will advise all additional projects joining the program

This deliverable is the second of the 5G-OPERA project and defines the reference architecture. As already noted in D3.1 - 'Private 5G: State of the Art and Gap Analysis based on country specific conditions -' the 5G-OPERA project is committed to follow the specifications of 3GPP as well as O-RAN. Figure 1 depicts the overall architecture of a 5G system. The Radio Access Network (RAN) subsystem consists of one or multiple gNBs, which could potentially be split into Centralized Unit (CU), Distributed Unit (DU) and Radio Unit (RU). The figure also shows the near-real-time RAN intelligent controller and the non-real-time

The core network (5GC) follows a service-based architecture (SBA) in which the system functionality is achieved by a set of Network Functions (NFs), providing services to other authorized NFs to access their services [1]. Also, the control-plane (CP) functions are separated from the user-plane (UP) in order to make them scale independently allowing operators to use these components for dimensioning, deploying and adapting the network to their needs easily.

The figure also includes reference to time sensitive networking (TSN), which is an important element for Industry 4.0 applications. Here, the 5G network serves as a bridge for a TSN network, which is defined by a set of standards from IEEE.

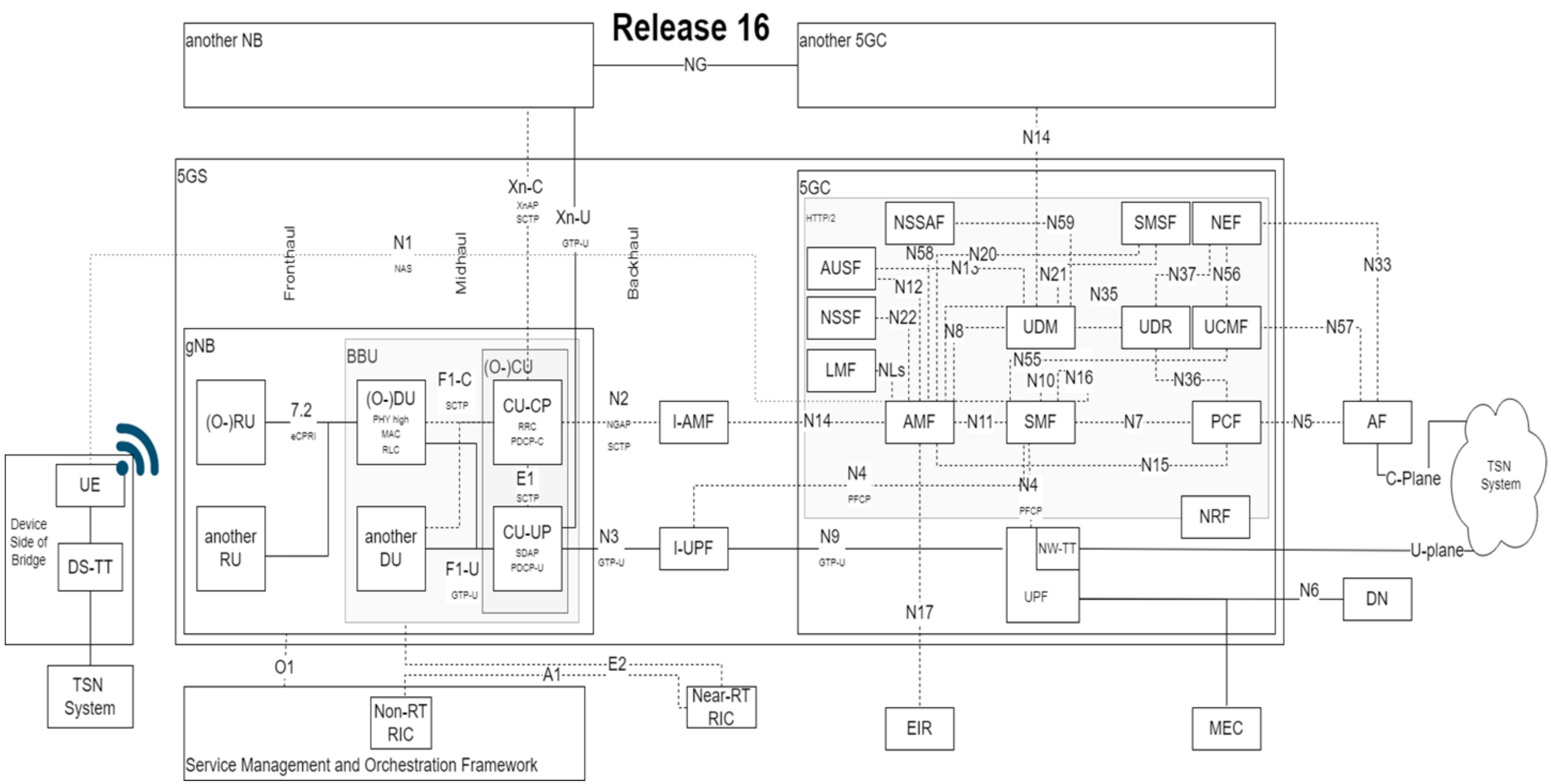

Figure 1: 5GS and TSN

2 Overall Architecture of Open RAN

Figure 2 provides a high-level view of the O-RAN Logical Architecture with the key interfaces. Open RAN network functions can be VNFs (Virtualized Network Function), i.e., VMs or Containers, sitting above the O-Cloud and/or PNFs (Physical Network Function) utilizing customized HW. All Open RAN network functions are expected to support the O1 interface when interfacing the SMO (Service Management and Orchestration) framework.

The two names Non-Real-time RIC (RAN Intelligent Controller) and a Near Real-Time RIC get their names from their response times. The Non-Real-Time RIC (Non-RT RIC) takes one second or more to execute its functions and the Near-Real-Time RIC (Near-RT RIC) executes functions between ten milliseconds and one second. Because of the discrepancy, the two controllers are responsible for different types of functions.

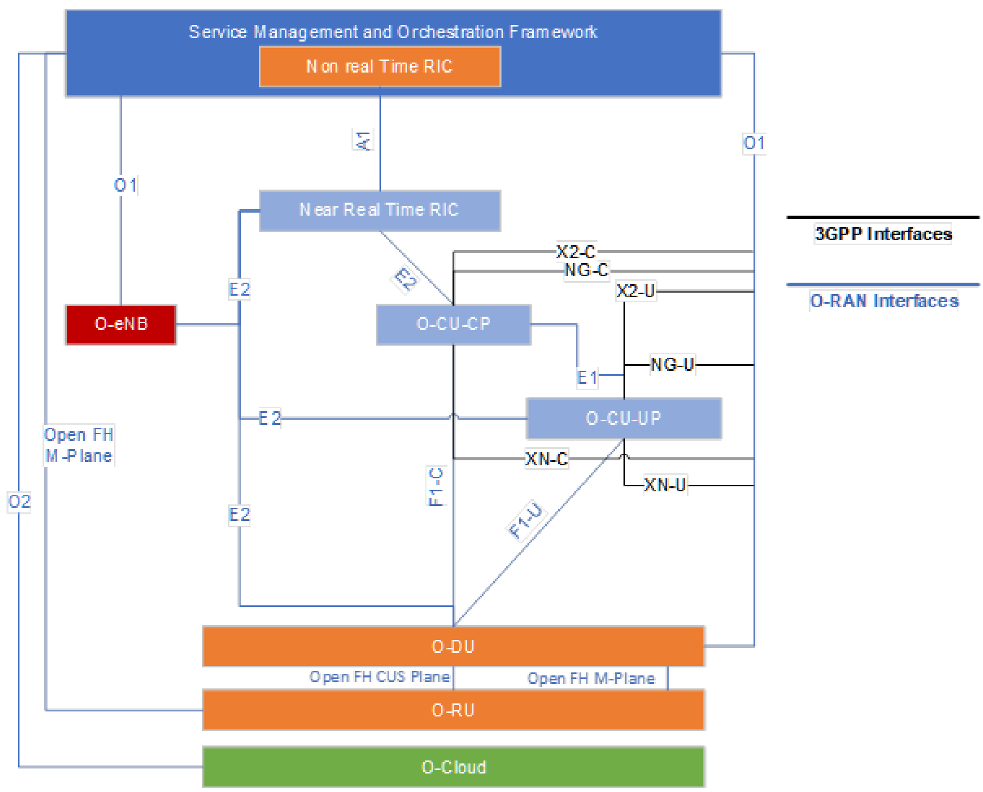

Figure 2: Open RAN Architecture

2.1 Definition of Open RAN Functions

2.1.1 Service Management and Orchestration (SMO)

2.1.1.1 Non-Real Time RIC

The Non-RT RIC and the Near-RT RIC are two RICs that the O-RAN architecture uses to facilitate RAN entities. These programmable components have an abstract and centralized point of view of the whole network and can therefore run optimization routines with closed-loop control and orchestrate the RAN entities. The Non-RT RIC is a component of the SMO framework and enables non-real-time control activities and procedures for RAN elements. Non-RT RIC performance management and control occurs at a time scale greater than one second. It can control all SMO-connected O-RAN architectural elements directly. As a result, it has the ability to decide on and implement policies that affect O-RAN components. Additionally, rApps ***(rApps are specialized microservices operating on the non-RT RIC*)** are hosted on Non-RT RICs to enhance its capabilities for policy direction, configuration management, and data management.

2.1.2 Near-RT RIC

The near-RT RIC is another RIC included in the O-RAN architecture that performs management and control of the network at the time scale of near-real-time (10 ms to 1 s). The main components of the Near-RT RIC are the xApps. xApps can perform data collection from RAN elements and impose actions or setting configurations to/in the RAN elements through the E2 interface. These xApps leverage standard compliant E2 Service Models (E2SMs) to communicate with the RAN entities. The key components of the near-RT-RIC platform that enables modular, open, and efficient services for the xApps include the E2Manager (E2M) that controls E2 connection establishment and provides REST APIs to manage these connections, the E2 Termination (E2T) to establish the Stream Control Transmission Protocol (SCTP) connection as requested by E2M, the Routing Manager for generating and distributing routing policies to xApps, and the Subscription Manager to manage the subscription of the E2Node.

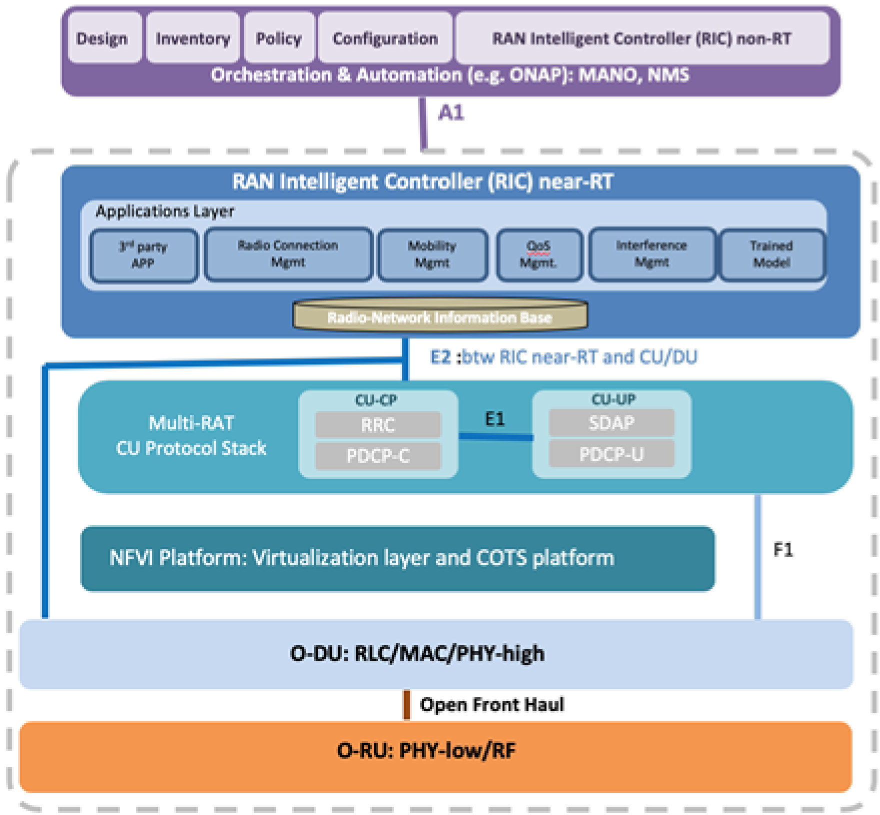

Figure 3: O-RAN architecture [2]

2.1.3 O-CU

2.1.3.1 O-CU-C

The O-CU-C (O-CU-Control) implements the Radio Resource Control (RRC) and the Packet Data Convergence Protocol-Control (PDCP-C) of the 3GPP protocol stack. It is connected to the DU via the F1-C interface and to the Access and Mobility Management Function (AMF) via the NG-C interface. Further it is connected to the O-CU-U via the E1 interface and to the Near-RT RIC via the E2 interface.

2.1.3.2 O-CU-U

The O-CU-U (O-CU-User) implements the Service Data Adaptation Protocol (SDAP) and PDCP-U layers of the 3GPP protocol stack. It is connected to the DU via the F1-U interface and to the User Plane Function (UPF) via the NG-U interface. Further it is connected to the O-CU-C via the E1 interface and to the Near-RT RIC via the E2 interface.

The rationale of splitting the CU into a CU-C and a CU-U follows the general principle of user and control plane separation and allows for more flexible deployments of the RAN. For example, in an edge networking scenario for low latency, the CU-U might be co-located with the DU near the edge of the network, while the CU-C is co-located with the other core network functions.

2.1.4 O-DU

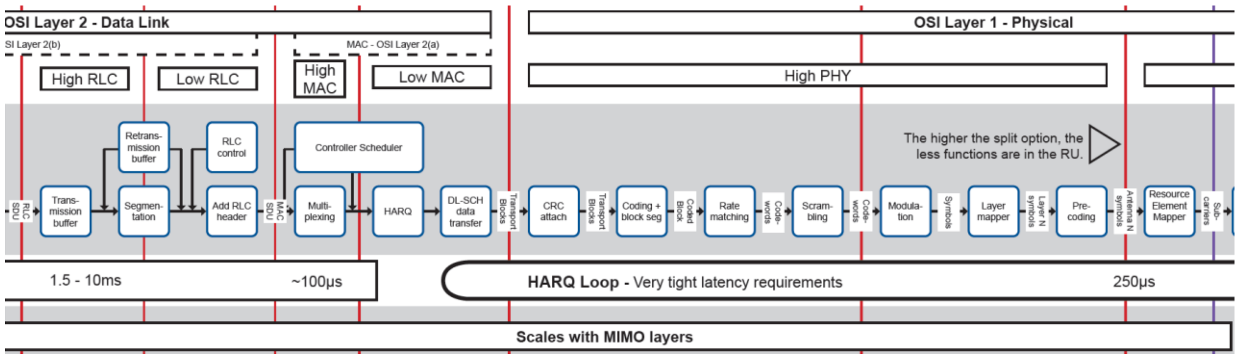

Figure 4 - 5G Fundamentals: Functional Split Overview - High PHY + MAC + RLC [3]

For the system architecture of this project the use of split option 7-2x, the Low Layer Split (LLS) option adopted by the O-RAN fronthaul specifications. This functional splitting between O-DU and O-RU divides the function of Phy Layer (Layer 1) named as “High Phy” inside the DU and “Low Phy” inside the in RU.

The functions to be implemented inside the O-DU are specified inside [4] and [5] and listed in the following:

- Resource Mapping
- Precoding
- Layer Mapping
- Modulation
- Scrambling
- CB Concatenation
- Rate Matching
- LDPC Coding
- CB Segmentation
- CB CRC Attachment

Precoding

Precoding is an optional and implementation-dependent method for beamforming of multi-stream communication.

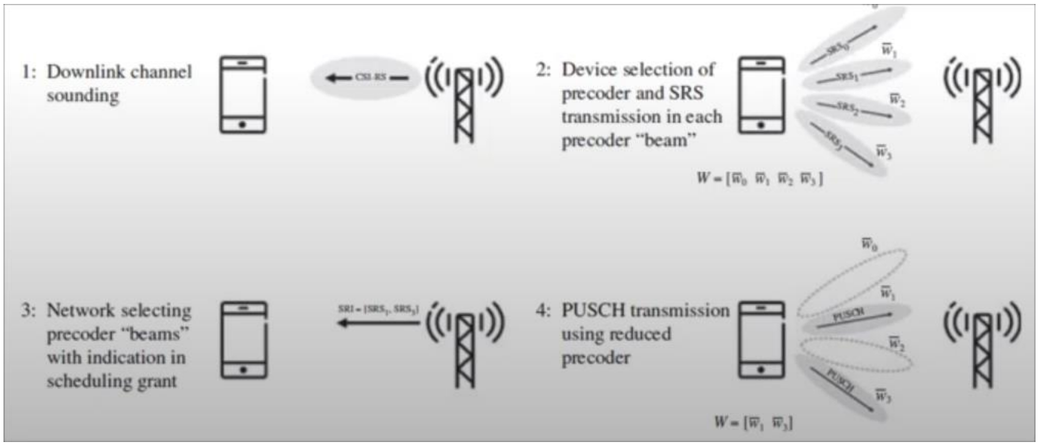

Figure 5 - Procedure for non-codebook-based transmission [1]

Layer Mapping

5G uses massive Multi Input Multi Output (MIMO) where "words" are split and transmitted over different antennas (Spatial Multiplexing). Estimating the individual channel properties and computing the inverse channel matrix is computationally intensive and can add significant overhead to the network, particularly as the number of antennas grows.

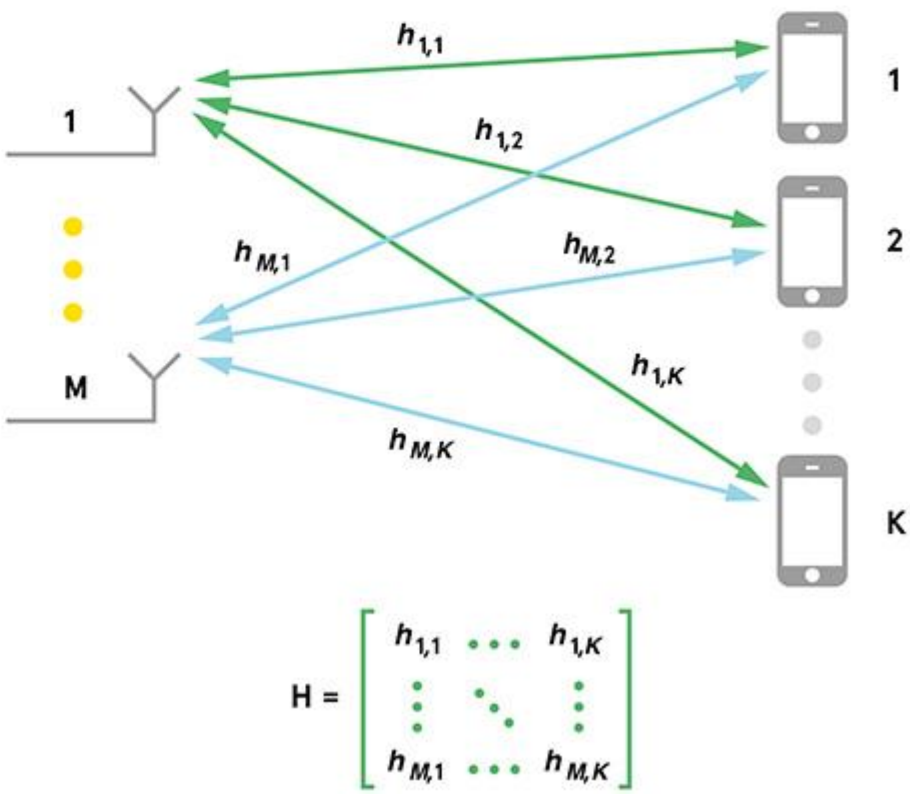

Figure 6 - Channel State Information used to characterize a Massive MIMO system [6]

For the high layer split option 2 has been selected which splits layer 2 into Medium Access Control (MAC)/ Radio Link Control (RLC) and PDCP. The MAC/ RLC functionalities to be implemented inside the O-DU are specified in [7] and partially listed in the following:

- Hybrid Automatic Repeat Request (HARQ)
- Multiplexing
- Logical Channel Prioritization
- Header Attachment
- Segmentation
- Service Data Unit (SDU)

2.1.4.1 Acceleration

Any HW acceleration inside the DU is following the specifications of [8] as indicated in Figure 7 - High Level AAL Architecture Diagram Figure 7. The goal of the Acceleration Abstraction Layer (AAL) is to specify a common and consistent interface for HW Device accelerators to the applications which facilitates decoupling of an application, e.g., O-RAN Cloudified Network Function, from a specific HW Accelerator device implementation.

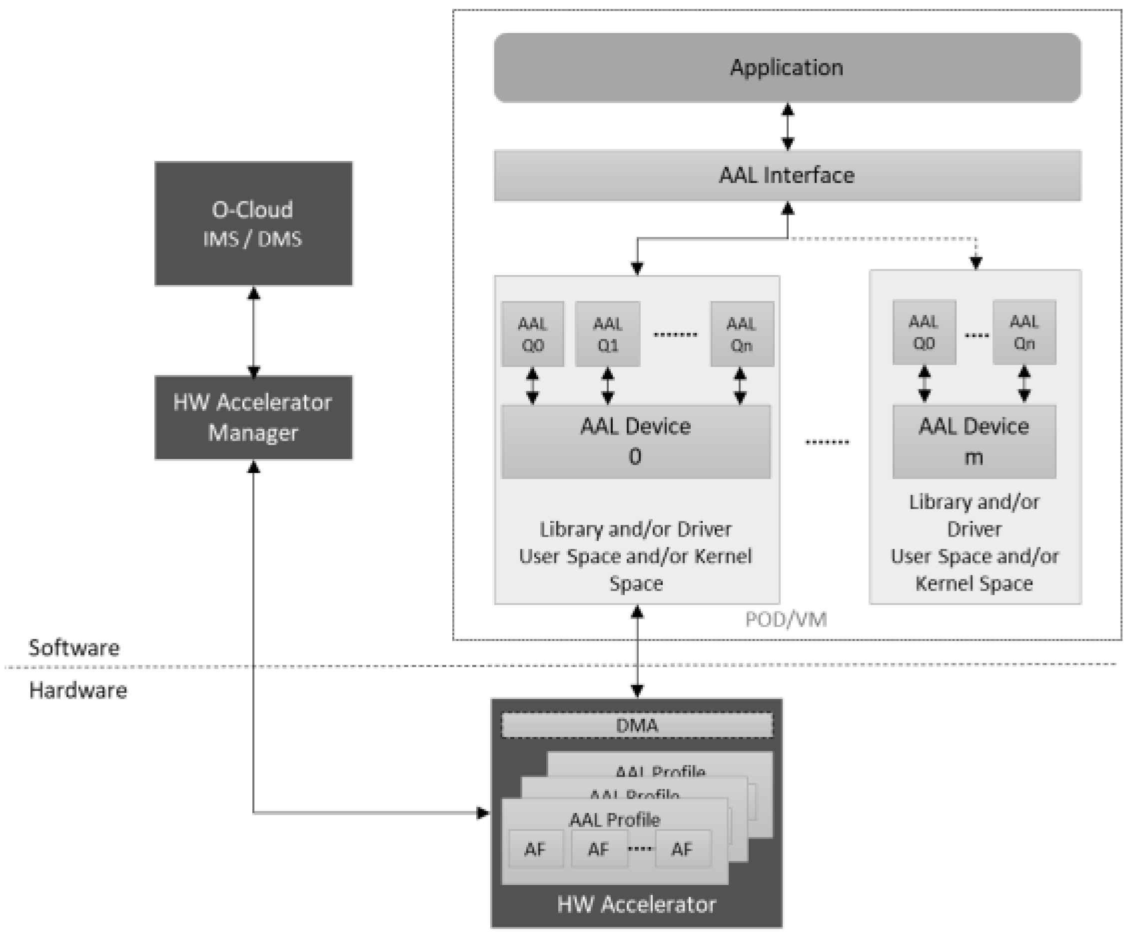

Figure 7 - High Level AAL Architecture Diagram [8]

The AAL interface has two distinct parts, the first a set of common methods ('AAL Common') which allows an application to query and identify the available AAL profiles that the underlying cloud platform offers and configure them for application use. The second is the AAL Profile APIs which are specific to each defined AAL profile. The AAL profile shall be common across the HW Accelerators accelerating the same set of functions. It enables the applications to efficiently offload the accelerated workload process to HW Accelerators in a consistent way without requiring them to know every single detail of the accelerators. All common functions and APIs are to be implemented as specified in [8] chapter 4.

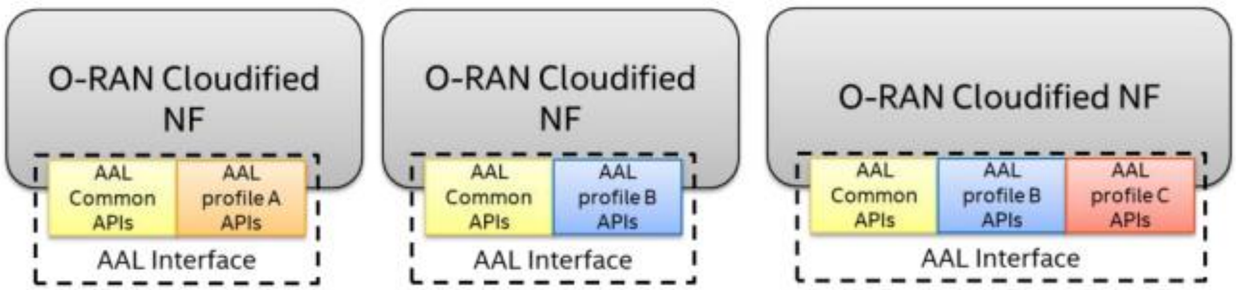

Figure 8 - AALI Common and profile APIs [8]

In order to accommodate the many different combinations of HW and Software (SW) implementation and also many different network deployment scenarios, the AAL introduces the concept of an AAL profile which is used to distinguish between the different combinations of accelerated functions to be offloaded. All AAL profiles are to be implemented as specified in [8], chapter 5, for both look-aside and inline acceleration.

2.1.5 O-RU

O-RAN split option 7-2x, considered for 5G-OPERA, requires the so called Low-Phy Layer 1 functions to be implemented in the O-RU, see Figure 9. Such functions-set includes, at a high-level view:

- Cyclic prefix insertion
- Inverse Fast Fourier Transform (IFTT).
- Beamforming port expansion

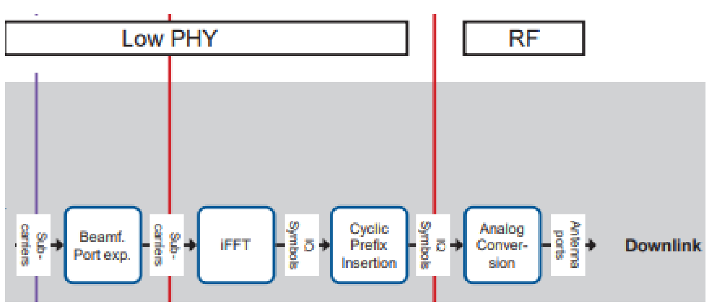

Figure 9 - O-RU Functional Split Overview – Low PHY [3]

Besides the Low Phy, the O-RU also implements the RF components where the Digital-Analog conversion functions, among others, are deployed.

2.1.5.1 Hardware perspective

A HW configuration for enabling an FR-1 O-RU is depicted in Figure 10. The HW architecture relies on efficient ARM-based multicore processors that uses Software Defined Radio (SDR) features to support the baseband functions and signal processing related to Low-PHY (e.g., Fast Fourier Transform (FTT)), as well as the management and interfacing towards the fronthaul (e.g., Enhanced Common Public Radio Interface ((e)CPRI)) through 10 Gbit/25 Gbit Ethernet ports. Same microprocessors also can interface with the beamforming Integrated Circuits (ICs) (not included in the diagram) if the O-RU design requires such control.

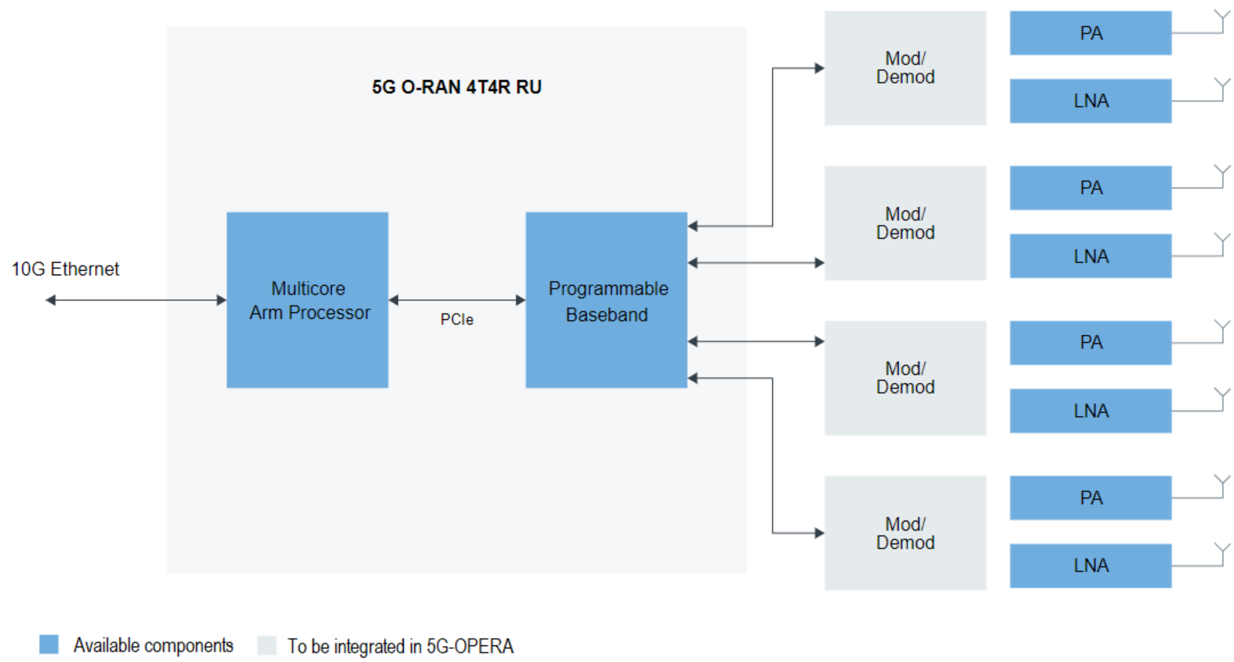

Figure 10 - HW Block diagram of a 4T4R FR-1 O-RU. Source: NXP Semiconductors

Main building blocks of the Radio Frequency (RF) system in the O-RU are Power Amplifiers (PA) and linearization, complemented by Modulation/Demodulation circuits, key components to be integrated as part of 5G-OPERA activities.

These RF blocks are also part of FR 2 beamformer chip developed and provided by NXP (see Figure 11). The circuit is a highly integrated 5G 4-channel dual-polarized analog beamforming IC, digitally controlled either via a high-speed Serial Peripheral Interface (SPI) bus or via a Low Voltage Differential Signaling (LVDS) link. The beamformer has an 8-bit phase, and gain resolution. Each channel consists of a transmit chain (TX) and a receive chain (RX). Both TX, and RX chains have a buffer, a phase shifter, and a Variable Gain Amplifier (VGA). On-chip power detectors allow measuring the power levels on all antenna ports in TX mode. The digital interface controls all circuit functional registers.

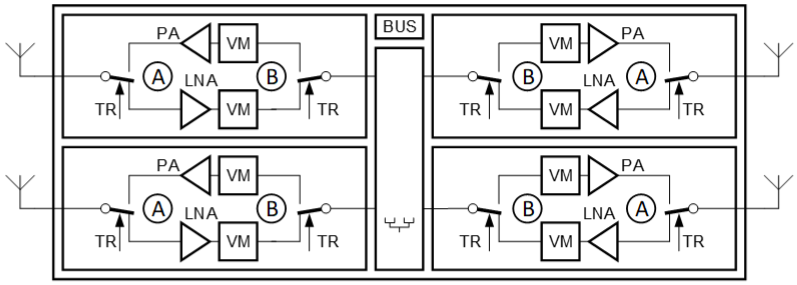

Figure 11 – Block diagram of FR 2 mmWave beamformer

2.2 Definition of Open RAN Interfaces

2.2.1 A1 Interface

A1 Interface is used for communication between the Non-RT RIC and the Near-RT RIC. The Non-RT RIC transmits the information captured in the SMO framework from various internal and external O-RAN sources to the Near-RT RIC via the A1 interface which depicted in reference: Figure 12. This information includes:

- Policy-based guidelines in declarative form (A1 policy) that contain statements on objectives and resources applicable to UEs and cells
- Machine Learning (ML) model management information (training, updating, deployment of ML models).
- A1 enrichment information from internal or external O-RAN data sources, where its availability or use is not critical for the task fulfilment of a unit, but only for its improvement

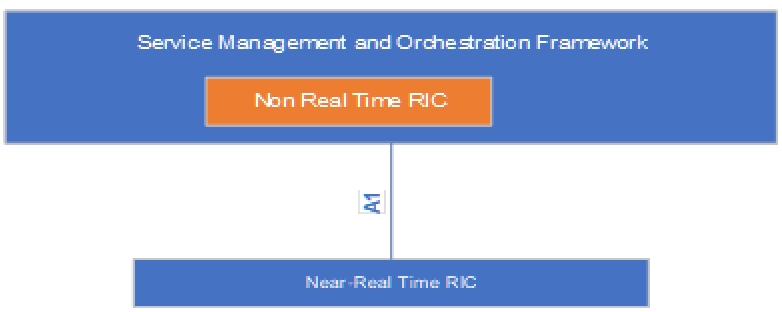

Figure 12: A1 Interface

The Near-RT RIC has the task of informing the Non-RT RIC about the status of the enforcement of an A1 policy by providing feedback via the A1 interface. If an A1 policy is related to a User Equipment (UE) (or a group of UEs), the UE is identified by the UE Id. The UE Id is to be formed using the RAN UE Id known to the RAN

2.2.2 O1 Interface

The O1 interface connects the SMO to the RAN managed elements. These include the near-RT-RIC, O-CU, O-DU, O-RU, and the Open Evolved NodeB (O-eNB), ref: Figure 13.

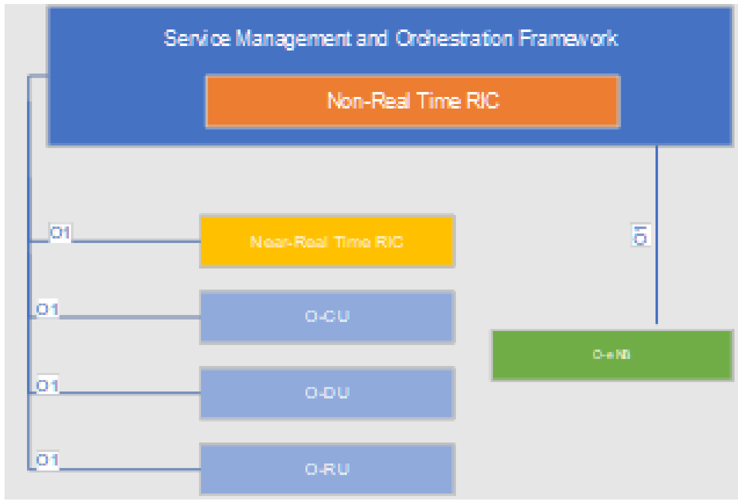

Figure 13: O1 Interface

O1 enables the SMO framework to access the O-RAN network functions. Network management is supported in line with the Fault, Configuration, Accounting, Performance Security (FCAPS) Model.

FCAPS allows following functions

- Discovery/registration
- Configuration of addressing
- Versioning
- Monitoring

The management functionalities are realized by using standard protocols for (example SSH, TLS, NETCONF) and data models (example YANG).

In O-RAN-based mobile networks supporting Artificial Intelligence (AI)/ML approaches, the O1 interface is used to collect (training) data that can be used for ML purposes from the Management Entities (MEs) O-DU and O-CU. The (ML-based) Non-RT RIC located in the SMO can offer policies to be considered in cell-level optimization.

The O-RAN architecture allows the collection, access to and management of data records (history) related to the traffic transferred over the RAN, the selected routing and the handover operations carried out. For this purpose, the data is transmitted via the O1 interface.

2.2.3 O2

The O2 interface is an open, logical interface within the O-RAN architecture and, like the O1 interface, is used as a vehicle for running open management and orchestration services.

The purpose is to ensure secure communication between the SMO framework and the O-Cloud platform. The SMO framework provides the ability to manage many O-Cloud instances in parallel, see Figure 14.

The O2 interface is needed and used to implement these SMO tasks. The O-Cloud platform offers various services and functions to the SMO framework via the O2 interface.

- Discovery and administration of O-Cloud resources
- Scale-in/scale-out of O-Cloud
- FCAPS (especially performance, configuration and fault management, as well as communication surveillance) of O-Cloud Software management of O-Cloud platform.

In relation to software deployments on the O-Cloud infrastructure, these functions are:

- Create/delete deployments and associated allocated O-Cloud resources
- FCAPS (especially performance and fault management) of deployments and allocated
- O-Cloud resources
- Scale-in/scale-out of deployments and allocated O-Cloud resources
- Software management of deployments

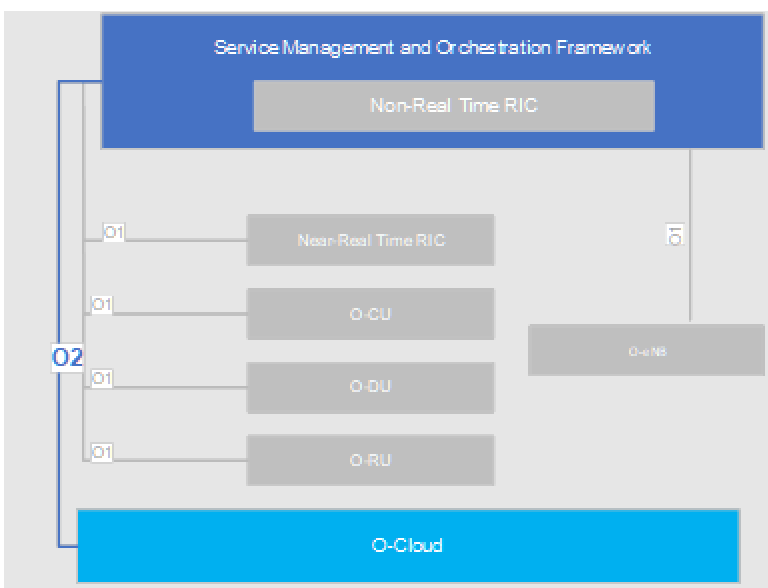

Figure 14:O2 Interface

2.2.4 E2 Interface

An E2 node is a collective term for all units to be controlled by the Near-RT RIC, namely O-CU-CP, O-CU-UP and O-DU in the case of 5G NR and O-eNB, see Figure 15.

The E2 nodes are to support all the protocol layers and interfaces defined in 3GPP radio access networks. Near-RT RIC has a one-to-many relationship with its E2 nodes, an E2 node can only have a one-to-one relationship with a Near-RT RIC. Each O-CU-CP, O-CU-UP, O-DU and O-eNB can only be connected to one near-RT-RIC at a time, just as a Near-RT RIC can only be connected to one Non-RT RIC

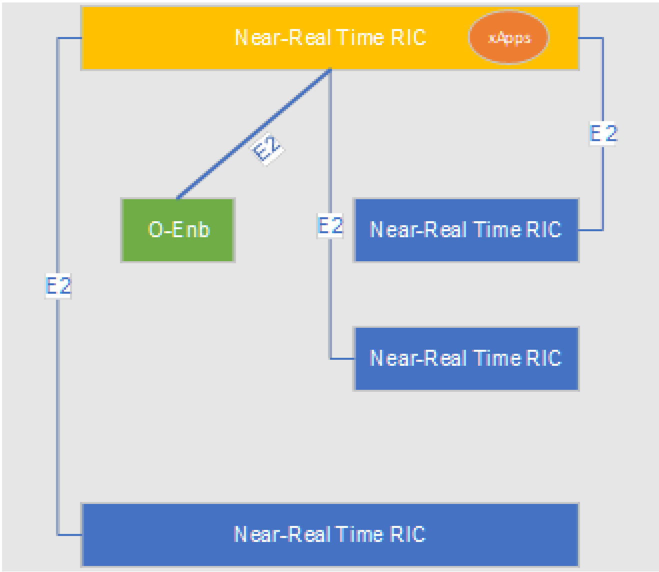

Figure 15: E2 Interface

E2 interface must be open. This is an essential requirement for achieving interoperability. An important test of O-RAN support will be the extent to which the E2 interface is supported by RAN equipment vendors.

Due to the one-to-many relationship between the Near-RT RIC and the E2 nodes, the E2 interface must support failure handling and improved resilience. Even in the event of a malfunction on the E2 interface or in the Near-RT RIC, an E2 node must be able to perform its function.

2.2.5 Fronthaul

The open fronthaul interface connects the O-DU and O-RU. It breaks down into the management plane (M-Plane) and the control user Synchronization Plane (CUS-Plane). The M-Plane connects the O-RU to the O-DU, and only optionally connects the O-RU to the SMO. The O-DU uses the M-Plane to manage the O-RU, while the SMO can provide FCAPS services to the O-RU. See Figure 16.

The CUS-Plane is multi-functional. The control and user aspects transfer control signals and user data respectively. The remaining aspect synchronizes activities between multiple RAN devices

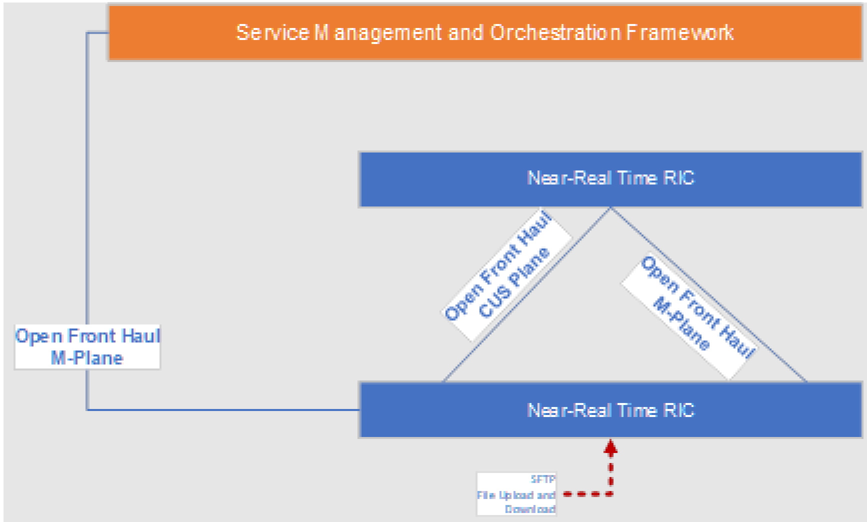

Figure 16: Open Fronthaul Interface

C-Plane

Messages that determine the processing of user data are exchanged via the control plane.

1. Information on scheduling or beamforming, if this information is not exchanged via the M-Plane. These messages are transmitted separately for uplink and downlink.
2. Uplink (UL)- and Downlink (DL)-specific information on numerology, i.e., slot and subcarrier definitions
3. If pre-coding is used in the O-RU, the configuration data is transmitted from the O-DU.
4. Information for functions such as Dynamic Spectrum Sharing (DSS)

U-Plane

Messages containing actual user data are transmitted via the user plane (also known as data plane). The focus is on efficient transmission, especially under the tight latency requirements in various 5G numerologies. The main functions provided are:

1. I/Q transmission of payload data, where each symbol is transmitted in a U-Plane message
2. . Data compression, where different methods can be defined per physical resource block (PRB), which are specified in associated control messages.
3. DL data precoding.

S-Plane

In the S-Plane, the Precision Time Protocol is used (PTP).

2.2.6 F1 Interface

The main objective of F1 interface is the inter-connection of a CU and a DU supplied by different manufacturers. Its supports:

1. Procedures to establish, maintain and release radio bearers for the NG-RAN part of Protocol Data Unit (PDU) sessions and for Evolved Universal Terrestrial Radio Access (E-UTRAN) Radio Access Bearers.
2. The separation of each UE on the protocol level for user specific signaling management; the transfer of RRC signaling messages between the UE and the CU

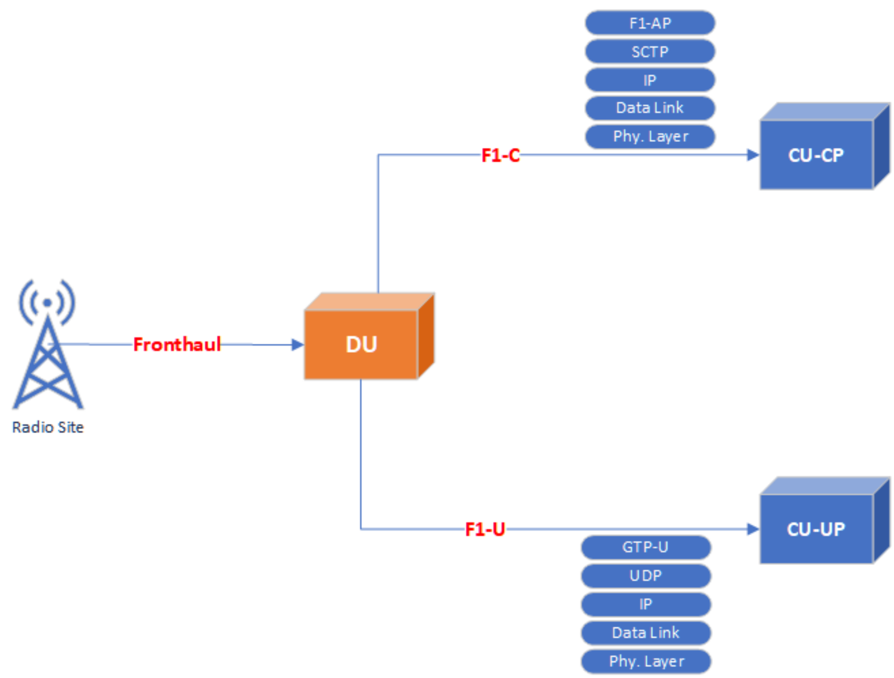

Figure 17: F1 Interface

F1 interface, again broken into control and user plane subtypes, connects the O-CU-CP and O-CU-UP to the O-DU. It exchanges data about the frequency resource sharing and other network statuses. One O-CU can communicate with multiple O-DU via F1 interfaces. See Figure 17.

2.2.6.1 F1-C

The control plane of the F1 (F1-C) allows signaling between the CU and DU. F1-C functionalities perform various management functions.

The F1 Setup procedure is used to create a logical F1 connection between the CU-CP and DU. It is necessary to establish an SCTP connection between the CU-CP and DU before the F1 Setup procedure can be initiated.

The DU initiates the procedure by sending an F1 Setup Request message, while the CU-CP completes the procedure by returning an F1 Setup Response.

The F1 Setup Request is used to inform the CU-CP about DU identity and the set of cells supported by the DU. The F1 Setup Response is used to indicate which DU cells should be activated.

Table 1: F1-C Interface Signaling

Interface Management	• F1 Setup • Reset • Error Indication • DU Configuration Updates • CU Configuration Updates • DU resource Indication
UE Context Management	• UE Context setup • UE Context modification • UE Context release • UE Inactivity notification
RRC Msg Transfer Management	• Initial • UE Context modification • UE Inactivity notification • UE Context release
S1 & paging Management	• System Information Delivery • Paging
Warning Msg Transfer management	• Write and Replace Warning • PWS Cancel • PWS Restart-Failure Indication

2.2.6.2 F1-U

The user plane of the F1 transfers application data between CU-UP and DU. GPRS Tunnelling Protocol (GTP-U) tunnels are used to transfer the application data. These tunnels are identified using their TEID. A tunnel is setup for each Data Radio Bearer (DRB).

The user plane protocol which runs above the GTP-U layer provides various control mechanisms associated with the transfer of downlink data. The frame formats used by the user plane protocol is referred as PDU Type 0 is sent by the CU, whereas PDU Type 1 is sent by the DU, see Figure 18.

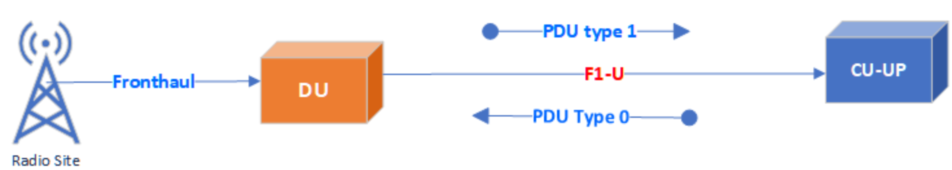

Figure 18: F1-U Interface

Downlink User Data (PDU Type 0): The CU-UP uses PDU Type 0 to add a sequence number to each downlink data packet. The DU uses this sequence number to detect lost packets. If the DU reports Radio link outage, then the CU-UP may attempt re-transmission from the PDCP layer using a second DU. If the second DU reports successful delivery of the PDCP PDU, the CU-UP instructs the original DU to discard the successfully delivered packets to avoid unnecessary transmission

Table 2: DL USER Data PDU Type 0

PDU Type 0	Spare	DL Discord Block	DL Flush	Report Polling
Spare	Report Delivery	User Data Exits	Assisted Report	Re Tx Flag
NR-U Sequence Number				
DL Discard NR PDCP and number of Blocks				
DL Discard NR PDCP PDU SN Number (First block)				
DL Discard NR PDCP PDU SN Number (Last block)				
DL Report NR PDCP POU SN Number				

Downlink Data Delivery (PDU Type 1): The DU uses PDU Type 1 to report any lost packets and also to control the rate at which downlink data is sent by the CU, i.e., it provides a mechanism for flow control to avoid the buffers within the DU becoming too full. The CU uses these information elements to determine the quantity of data to forward towards the DU. The DU can also use PDU Type 1 to indicate 'Radio Link Outage' or 'Radio Link Resume'.

Table 3: : DL USER Data PDU Type 1

PDU Type 1	Highest Tx NR PDCP SN indication	Highest Delivery NR PDCP SN indication	Final Frame	Last Packet
Spare	Data Rate Indication	Highest Tx NR PDCP Indication	Highest Delivered ReTx NR PDCP Indication	Cause Report
Desired Buffer size – DRB (Data Radio Bearer)				
Desired Data rate				
Numbers of lost NR-U PDCP SN				
Start and End of NR-U PDCP SN				
Cause Value				
Highest Successful delivered Rx TX NR PDCP SN				
Highest retransmitted NR PDCP SN				

2.2.7 E1 Interface

The E1 interface connects the two disaggregated O-CU user and control planes. It transfers configuration data and capacity information between the two O-CU planes. The configuration data ensures the two planes can interoperate. The capacity information is sent from the user plane to the control plane and includes the status of the user plane. E1 design in OAI follows the 3GPP specification in TS 38.460 document. The following sequence chart in Figure 19 shows the current E1AP message flow.

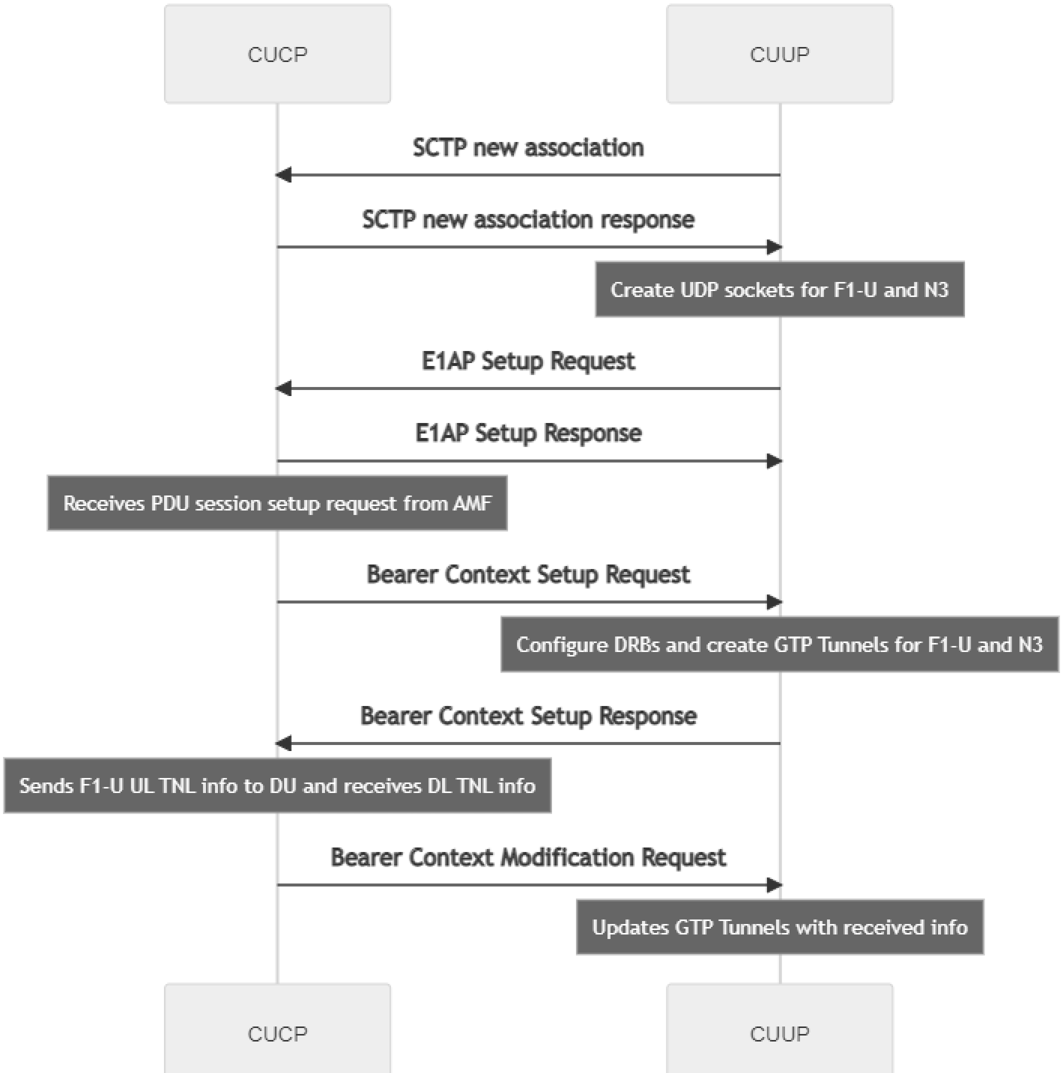

Figure 19: E1AP message flow

2.2.8 Xn

Mobility (Handover) is an important feature in any telecom generation and so it is in 5G.

UE reports measurement report to neighbor cell. Then the source cell take the decision to start handover procedure to best target cell.

The Xn interface is broken up into the Xn-C and Xn-U interfaces, where the former is for the control plane and the latter is for the user plane. Ref : Figure 20 In the O-RAN the interface has the same principles and protocols adopted from 3GPP standards.

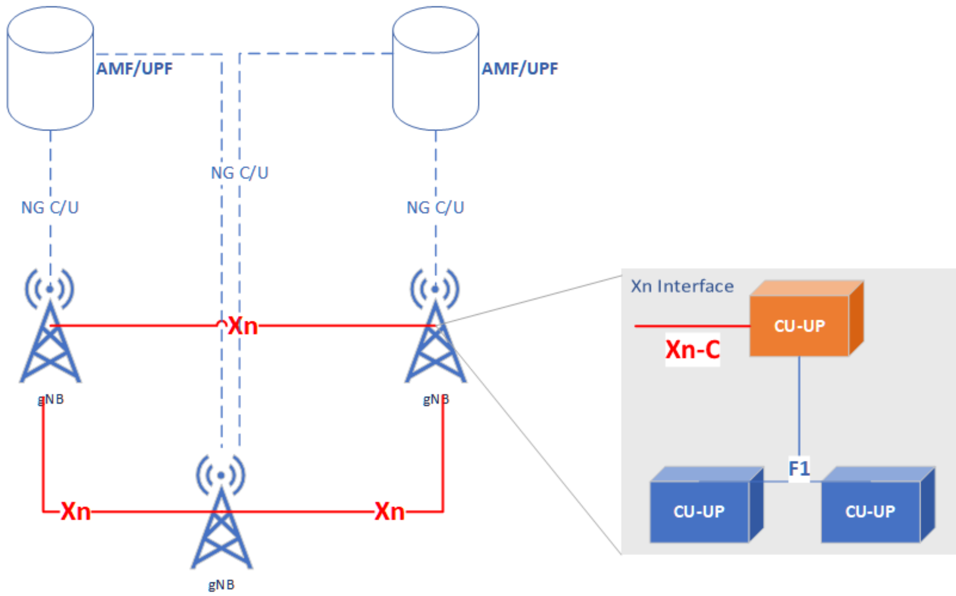

Figure 20: Xn Interface

Handover Xn Stages

a) Xn Handover is similar X2 Handover in 4G LTE
b) Xn handover prerequisite is that an Xn interface must be up between source and Target gNB
c) This type of Handover is only applicable for intra-AMF mobility, i.e. Xn handover cannot be used if Source and Target gNB is connected to different AMF
d) Xn Handover can be Intra Frequency HO and Inter Frequency HO
e) Source and Target gNB can be connected two different UPFs
f) Re-Registration is required after Successful Handover if the Source gNB and Target gNB belong to different Tracking Area (TAC)

2.2.8.1 Xn-C

The control plane protocol Reference: Figure 21 stack of the Xn interface is the transport network layer built on IP transport. For the reliable transport of signaling messages, SCTP is added on top of IP. The application layer signaling protocol is referred to as XnAP (Xn Application Protocol).

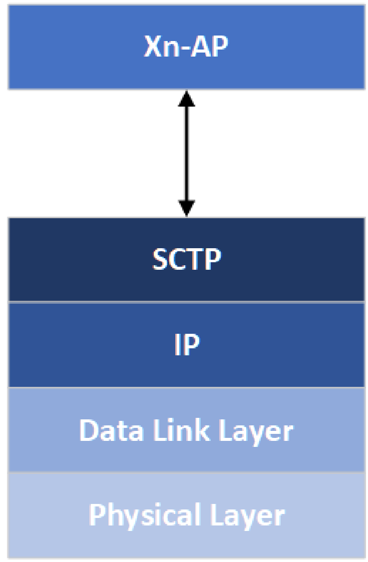

Figure 21: Xn-C Layer

Table 4: Xn – Conrtol Plane Format

Xn-C Interface Management and Error handling functions	**UE Mobility Management Function**
Xn Setup function	Handover Preparation function
Error Indication function	Handover Cancellation function
Xn Reset and removal function	Retrieve UE Context function
	RAN paging function
	Data Forwarding Control function
Dual Connectivity function	
Energy Saving function	

2.2.8.2 Xn-U

The Xn user plane (Xn-U) interface shown in reference Figure 22 is defined between two NG-RAN nodes. The Xn-U interface provides non-guaranteed delivery of user plane PDUs between two NG-RAN nodes.

a) Transfer of Downlink User Data procedure enables the node hosting the NR PDCP entity to provide user plane information .
b) Downlink Data Delivery Status procedure: enables the corresponding node to provide feedback to the node hosting the NR PDCP entity.
c) Transfer of PDU Session Information procedure: enables an NG-RAN node to provide user plane information associated with the forwarding of data towards a peer NG-RAN node, when using PDU session tunnels

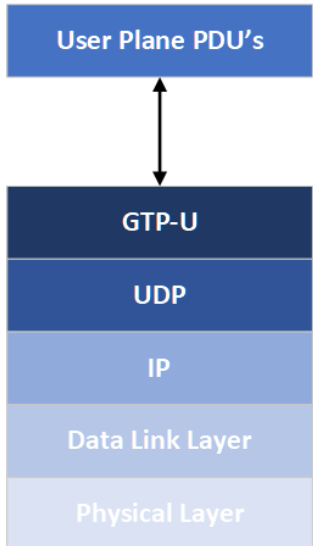

Figure 22: Xn-U Layer

2.2.9 NG

The NG control and user plane interfaces respectively connect an O-CU control plane (O-CU-CP) and O-CU user plane (O-CU-UP) to the 5G core. The control plane information goes to the 5G access and AMF, which receives connection and session information from the user equipment. The user plane information goes to the 5G User Plane Function (UPF), which handles many aspects of routing, forwarding, and tunneling, see Figure 23.

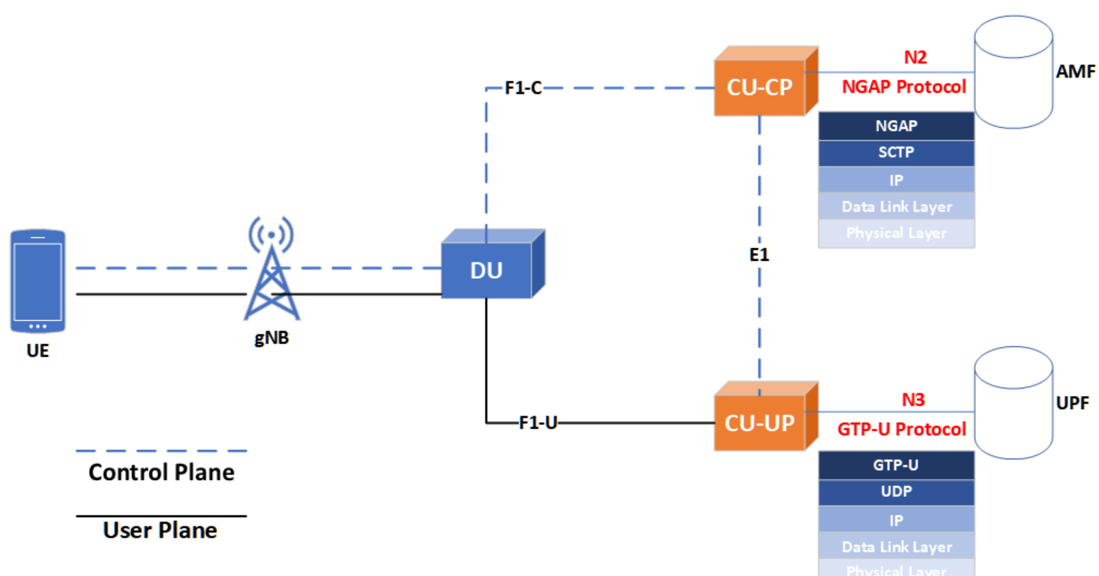

Figure 23: NG Interface

NGAP Procedure

a) NG Application Protocol (NGAP) supports all mechanisms requires to manage the procedures between gNB and AMF
b) NGAP also supports transparent transport for Non-Access Stratum (NAS) procedures that are executed between the UE and the AMF
c) NGAP is applicable both to 3GPP access and non-3GPP accesses integrated with 5GC
d) NGAP relies on a reliable transport mechanism and is designed to run on top of SCTP
e) The key difference between NGAP and S1AP is that S1AP was designed only for 3GPP access (E-UTRAN) and not non-3GPP accesses
f) N2 interface between gNB and AMF performs management functions, for example NG Setup, Reset, Error Indication, and Load Balancing
g) NGAP supports Initial UE Context Setup functionality for establishment of an initial UE context at gNB
h) NGAP Provides the UE capability information to the AMF during UE capability exchange
i) It also supports PDU Session Setup, modification, and release for user plane resources
j) Paging over NGAP, providing the functionality to page UE within 5GC
k) NGAP allows Trace of active UEs.
l) UE location reporting and positioning protocol support.
m) NGAP supports Warning message transmission for emergency services.

Sequence of interaction between the gNB and AMF and 3GPP specifications has defined two types of elementary procedure, see Figure 24.

a) **Request Response Procedure:** In these types of procedures, the initiator gets a response from the receiver of the request, indicating whether the request was successfully handled or not or a failure response.
b) **No Response Procedures**: These elementary procedures does not expect a response from the receiver. These messages are used, e.g., when AMF wants to only deliver a downlink NAS message. There is no need for gNB to provide a response in that case since error handling is handled on NAS level.

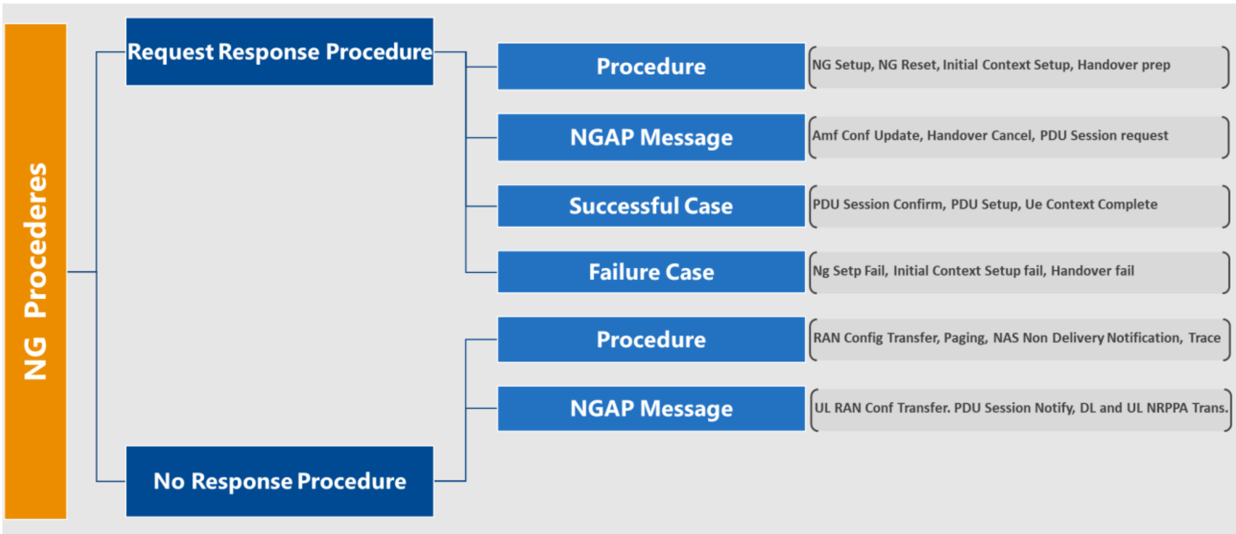

Figure 24: NG Procedure

2.2.10 FAPI/nFAPI

Open network Functional Application Platform Interface (Open-nFAPI) is implementation of the Small Cell Forum's network functional API or nFAPI for short. nFAPI defines a network protocol that is used to connect a Physical Network Function (PNF) running LTE Layer 1 to a Virtual Network Function (VNF) running LTE layer 2 and above.

The aim of open-nFAPI is to provide an open interface between LTE layer 1 and layer 2 to allow for interoperability between the PNF and VNF and also to facilitate the sharing of PNF's between different VNF's.

Open-nFAPI implements the P4, P5 and P7 interfaces as defined by the nFAPI specification.

- The P5 interface allows the VNF to query and configure the 'resources' of the PNF; i.e slice it into 1 or more PHY instances.
- The P7 interface is used to send the subframe information between the PNF and VNF for a PHY instance.
- The P4 interface allows the VNF to request the PNF PHY instance to perform measurements of the surrounding network.

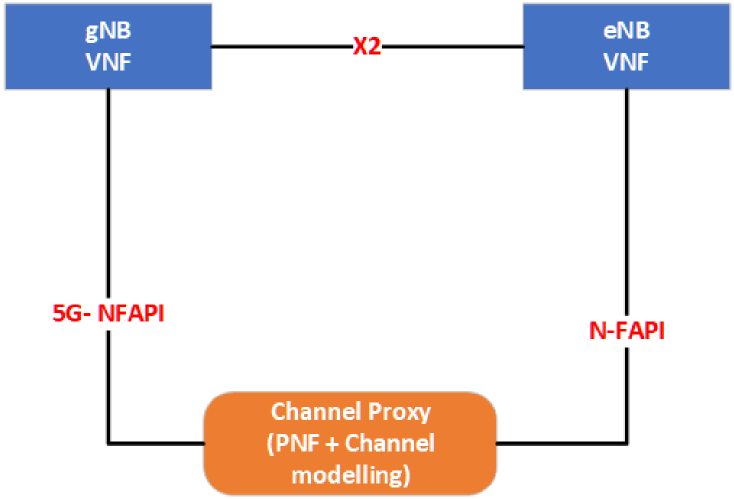

Figure 25: nFAPI Interface

nFAPI splits the xNB reference: Figure 25 into a MAC entity and a PHY entity. The xNB MAC connects through the nFAPI interface to a channel proxy that simulates the channel and allows to connect many UEs to the MAC stub. Each UE is the simulated OAI UE that connects to the proxy.

3 Overall Architecture of Open Core

3.1 Definition of Network Functions

3GPP describes 5G-Core functions and internal and external interfaces. Some functions are use case specific. We have listed and described functions relevant to 5G-OPERA.

3.1.1 Network Repository Function (NRF)

NRF supports NFs to discover each other. It notifies the subscribed NF service consumer or Service Communication Proxy (SCP) about newly registered/updated/ deregistered NF and SCP instances. See TS 23.501 [9] for full of the supported functionalities as well as TS 29.510 [10] for offered services by the NRF.

3.1.2 Access and Mobility Management Function (AMF)

AMF connects with the UE via N1 interface, whereas it connects with RAN via N2 interface. It controls which UEs can access the 5GC to exchange traffic with the Data Network (DN)s. AMF is mainly responsible for handling connection and mobility management. It also manages the mobility of UEs when they roam from one gNB to another for session continuity. The entire list of the AMF functionalities can be seen in Section 6.2.1 TS 23.501 [9]. Some of them are termination of RAN CP interface (N2), registration and connection management. In addition, the functionalities to support non-3GPP access network and monitoring in roaming scenario are also listed in same

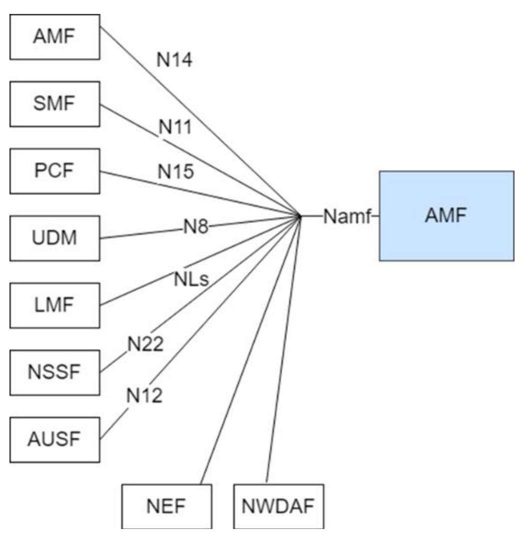

Figure 26: Interfaces between AMF and other NFs

section. Moreover, the policy related functionalities are listed in TS 23.503 [11]. AMF has connection with many other network functions, e.g., SMF (via N11 interface), Location Management Function (LMF) (via NLs interface), see **Error! Reference source not found.**.

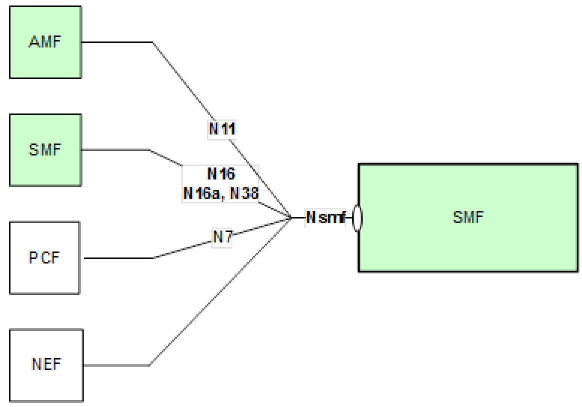

Figure 28: Interfaces between SMF and other NFs [34]

3.1.3 Session Management Function (SMF)

The primary aim of SMF, see **Error! Reference source not found.**, is creating, updating and removing PDU sessions. Moreover, it traces QoS Flows in the 5GS for UEs and makes sure that their states and status are in sync between the network functions. It has connection with Policy Charging Function (PCF) to receive Policy and Charging Control (PCC) rules and to convert PCC Rules into Service Data Flows (SDF) *Templates*, *QoS Profiles* and *QoS Rules* for the UPF, gNB and UE respectively. Interface between CP and UP is also provided by SMF. In summary, it communicates with UPF, PCF, and Unified Data management (UDM) to control and orchestrate these components according to the request from AMF. Section 6.2.2 in TS 23.501 [9] describes all functionality of SMF, while Section 6.2.2 in [11] describes policy related functionalities. The network function services are listed in TS 23.502 [12].

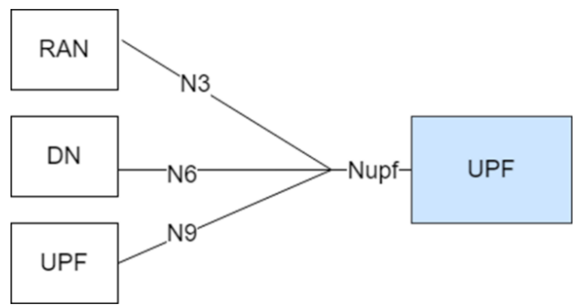

Figure 27: Interfaces of UPF

3.1.4 User Plane Function (UPF)

UPF forwards the traffic coming from UE between gNB and DN. N3 interface connects Intermediate UPF (I-UPF) with gNB, while N9 interface connects I-UPF with UPF, see **Error! Reference source not found.**. It also enforces QoS on UE's uplink and downlink traffic in 5GC using the *SDF Templates* sent by the SMF over the N4 Packet Forwarding Control Packet PFCP interface for the UEs. More functionalities of UPF can be found in TS 23.501 [9].

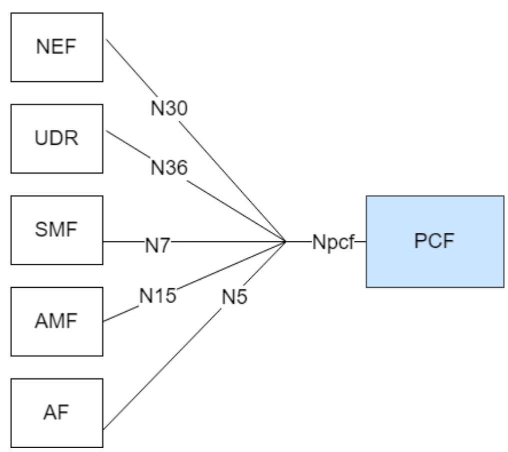

Figure 29: PCF

3.1.5 Policy Control Function (PCF)

Rules for CP functions including network slicing, roaming, and mobility management are provided by PCF. It also supports 5G QoS policy and charging control functions, and accesses subscription information related for policy decisions in a Unified Data Repository (UDR). The detail of the PCF functionalities can be reached in TS 23.503 [11] and related interfaces in **Error! Reference source not found.**.

3.1.6 Unified Data Management (UDM)

UDM stores and manages Subscriber Permanent Identifier (SUPI) for each UE and supports the de-concealment of Subscriber Concealed Identifier (SUCI). The supported functionalities are listed in TS 23.501 [9].

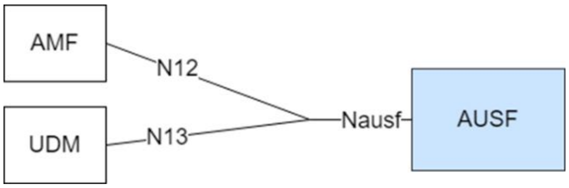

Figure 30: AUSF

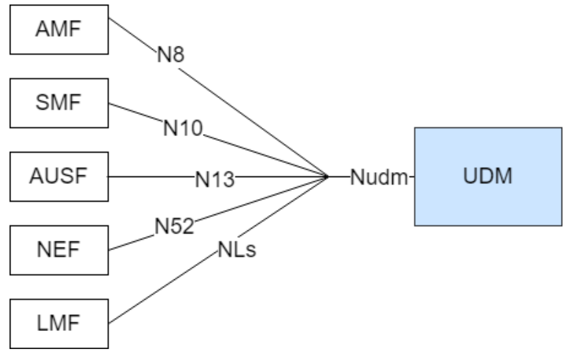

Figure 31: UDM

3.1.7 Unified Data Repository (UDR)

UDR supports storage and retrieval of subscription data by the UDM via N35 interface, see Figure 32, of policy data by the PCF via N36 interface, of structured data for exposure, and of application data TS 23.501 [1].

3.1.8 Authentication Server Function (AUSF)

AUSF offers services to the UDM as seen in Figure 30 to authenticate UEs for accessing the 5GS as well as authentication of untrusted non-3GPP access as specified in TS 33.501 [13].

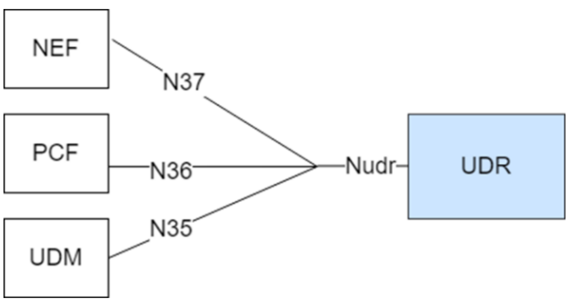

Figure 32: UDR

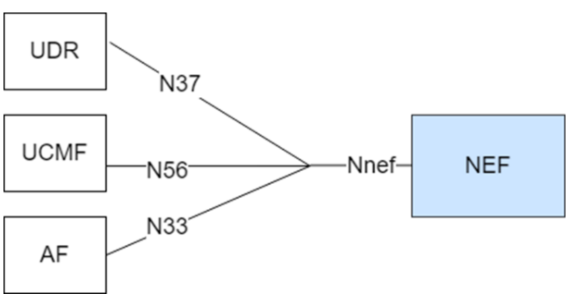

Figure 33: NEF

3.1.9 Network Exposure Function (NEF)

NEF stores and retrieves information as structured data using N37 interface to the UDR, see Figure 33. Furthermore, NEF manages the masking user and network sensitive information to external Application Function (AF) according to the network policy TS 23.501 [9]. Interaction between NEF and other Network Functions (NFs) are described in TS 23.501 [9] with corresponding specifications.

3.1.10 Location Management Function (LMF)

As described in TS 23.273 [14], the co-ordination and scheduling of required resources for location of a UE is managed by LMF. This UE needs to be registered or have access to 5GC. The detail of functionality of LMF is described in TS 23.273 [14].

Network Slice Selection Function (NSSF)AMF uses NSSF as assistance to select network slice instance that will serve a specific UE. Moreover, NSSF can allocate a suitable AMF if the current one cannot serve for all instances of network slices for a given UE. See TS 23.501 [9] for details and Figure 34 for interfaces.

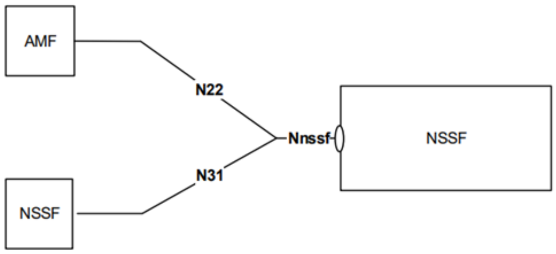

Figure 34: Interfaces related NSSF

3.1.11 Network Slice Specific Authentication and Authorization Function (NSSAAF)

NSSAAF has connection with AMF via N58, and with UDM via N59 interfaces. As specified in TS 23.502 [12], it supports Network Slice- Specific Authentication and Authorization (NSSAA) service with AAA Server (AAA-S) or AAA proxy (AAA-P) when AAA-S belongs to third party. See TS 33.501 [13] for detail of service operations.

3.1.12 Application Function (AF)

AF is a control plane function which provides application services to the subscriber, e.g., video streaming service. Technical specification of AF event exposure service can be found in TS 29.517 [15].

3.2 Definition of internal Interfaces

3.2.1 N1 – Non-Access Stratum (NAS)

N1 which is a logical interface connects UE and AMF. Communication between UE and AMF is done by NAS protocol over the N1. Some main functions of NAS protocol are listed in TS 24.501 [16] as:

- support of mobility of the user UE including also common procedures such as authentication, identification, generic UE configuration update and security mode control procedures;
- support of session management procedures to establish and maintain data connectivity between the UE and the data network; and
- NAS transport procedure to provide a transport of SMS, LPP, LCS, UE policy container, SOR transparent container and UE parameters update information payload.

The TS 23.501 [9] can be seen for N1 that supports both 3GPP and non-3GPP access. See TS 24.501 [16] for detailed description of NAS.

3.2.2 N2 – NG Application Protocol (NGAP)

N2 interface supports control plane signaling between AMF and gNB based on the NGAP protocol. Some functionalities are supported by NGAP are: mobility management, paging, PDU session management, NAS transport, etc. See TS 138 410 [17] for full set of functionalities as well as for signaling procedures and interface protocol structure. Moreover, NGAP procedures, elements for NGAP Communication, and handling unknown, unforeseen, erroneous protocol data can be found in TS 38.413 [18].

3.2.3 N3 - GPRS Tunnelling Protocol (GTP)

N3 interface transports user plane data from gNB to the UPF. GTP User Plane (GTP-U) protocol is the application protocol. GTP tunnel carries encapsulated Transport Packet Data Unit (T-PDU) and signaling messages between a given pair of GTP-U tunnel endpoints, for details see TS 29.281 [19].

3.2.4 N4 – Packet Forwarding Control Protocol (PFCP)

N4 interface supports signaling interaction between the SMF and UPF based on the PFCP which is used on the interface between the control plane and the user plane function. The high level of principle of PFCP is specified in TS 29.244 [20]. The interaction between SMF and UPF is explained in 23.502 [12].

3.2.5 N5

This interface is the reference point between the PCF and an AF and specified in 3GPP TS 29.514 [21].

3.2.6 NLs interface

The NLs interface, between the LMF and the AMF, is transparent to all UE related, gNB related and ng-eNB related positioning procedures. It is used only as a transport link for the LTE Positioning Protocols LPP and NRPPa.

3.2.7 SBI – Service Based Interface

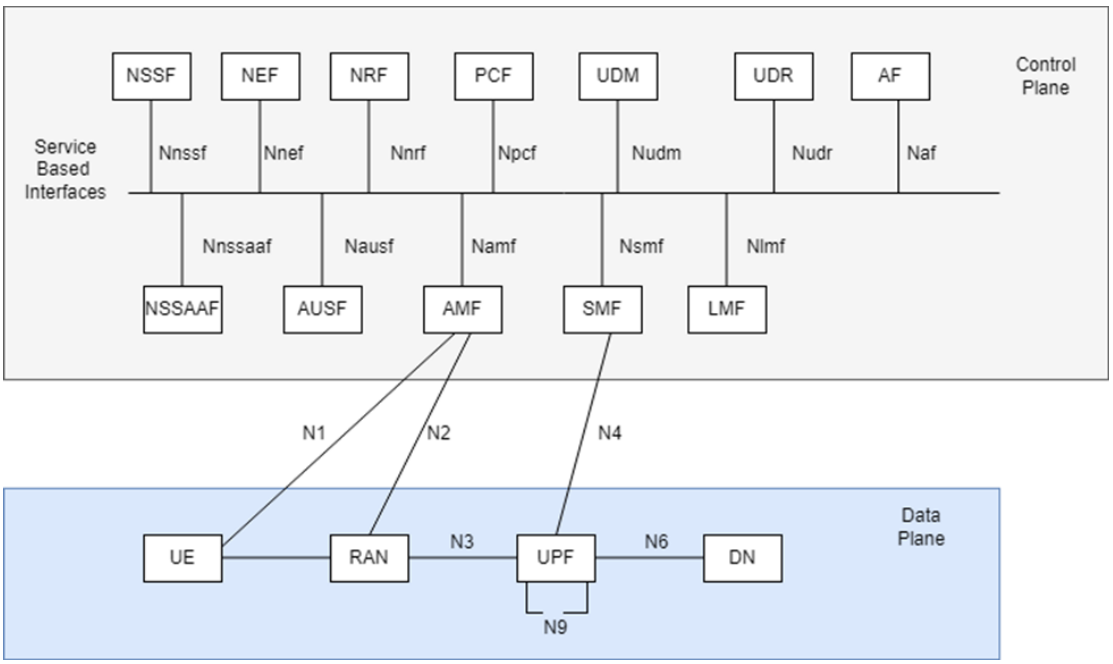

Figure 35: SBI in the 5G system architecture. Taken from TS 23.501 *[9]*

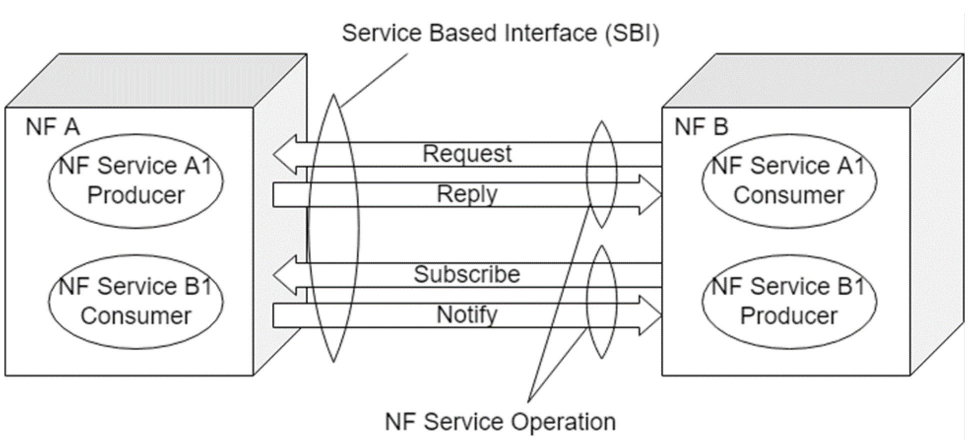

Figure 36: Service based interface operations (request-reply and subscribe-notify). Credit *[22]*

Service based interfaces are used for control plane as seen in Figure 35. These SBI are used to exhibit corresponding NFs. For instance, Namf is a SBI exhibited by AMF. SBI allows control plane network functions to access their services, via NRF using HTTP API. A NF belongs to the control plane can provide one or more NF services. As shown in Figure 36, a NF service consist of operations based on two models: request-response or subscribe-notify.

4 Reference Architecture for TSN over 5G

Integrating Time Sensitive Network (TSN) with 5GS will enable devices, across classical TSN and which are on 5G wireless network, to synchronize with one more clock domains, with ability to control, schedule, prioritize end ports and traffic using a set of QoS standards. Based on the target network architecture and system layout, there are many possible combinations for placing components of the TSN system such as the Centralized Network Controller (CNC), Centralized User Configuration entity (CUC), Controllers, Devices and Clock Domains. This section layouts one of many possible ways to integrate TSN & 5GS. Figure 37Figure 4 depicts the basic components to enable TSN over a 5G network.

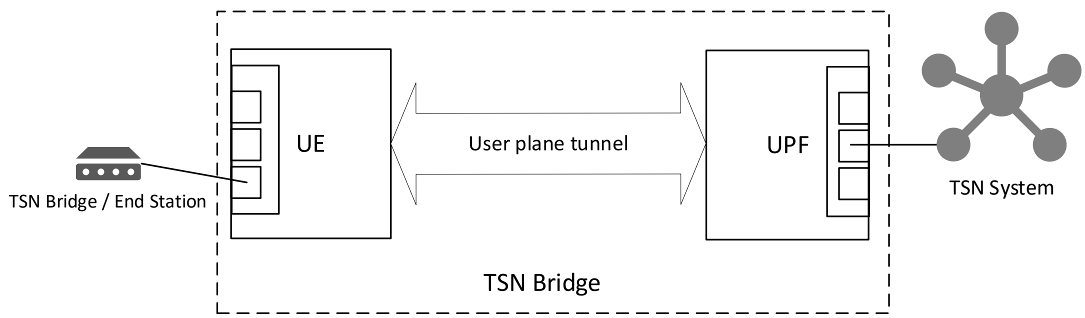

Figure 37: 5GS Bridge-Simplified View. Source: Adapted from [9]

Time critical devices, such as sensors and actuators, that require synced clocks and that are controlled in one or more time domain require integrated 5GS TSN when one or more of said devices reside in a terminating 5G radio network. Towards the 5G device side (e.g, UE or CPE) integration is done using Device-side TSN Translator (DS-TT). However, not all devices require to implement the DS-TT. Some instances of such devices are those connected over ethernet or an IP network, those that do not require time-critical performance, or those not using clock synchronization.

The 5GS will require to implement the so called Network-side TSN Translator (NW-TT) to interface with the TSN network which the GrandMaster or BoundaryClock has to be forwarded to. NW-TT will make the 5GS TSN-aware and has functionality similar to a TSN Node, i.e., computing ingress/egress timestamps and managing control ports. Both DS-TT and NW-TT are managed and controlled by CNC from traditional TSN network, by means of a broking Application Function service at TSN-AF. That application function is responsible for the registry of contexts, DS-TT ports, configuration and reporting, for both inward and outward TSN traffic.

4.1 Overview

The DS-TT is deployed at the UE-side edge and the NW-TT is deployed at the network-edge in order to interface with a TSN Network while achieving transparency [9].

For control path such as from CNC, the new 5G Application Function TSN-AF is required to allow interfacing with the TSN bridge. TSN support in 5G Network is transparent, hence translation layers DS-TT and NW-TT will be implemented as additional features. Similarly, from TSN network point of view, 5GS is simply viewed as a TSN-Bridge, and hence no changes required at TSN network (see Figure 38).

As of Release 16, the architecture for 5GS includes IEEE 802.1 TSN Networks that apply fully centralized configuration model as defined in IEEE 802.1Qcc. DS-TT optionally support link layer connectivity discovery and reporting as define in IEEE 802.1AB. And per-stream filtering and policy as per IEEE 802.1Q.

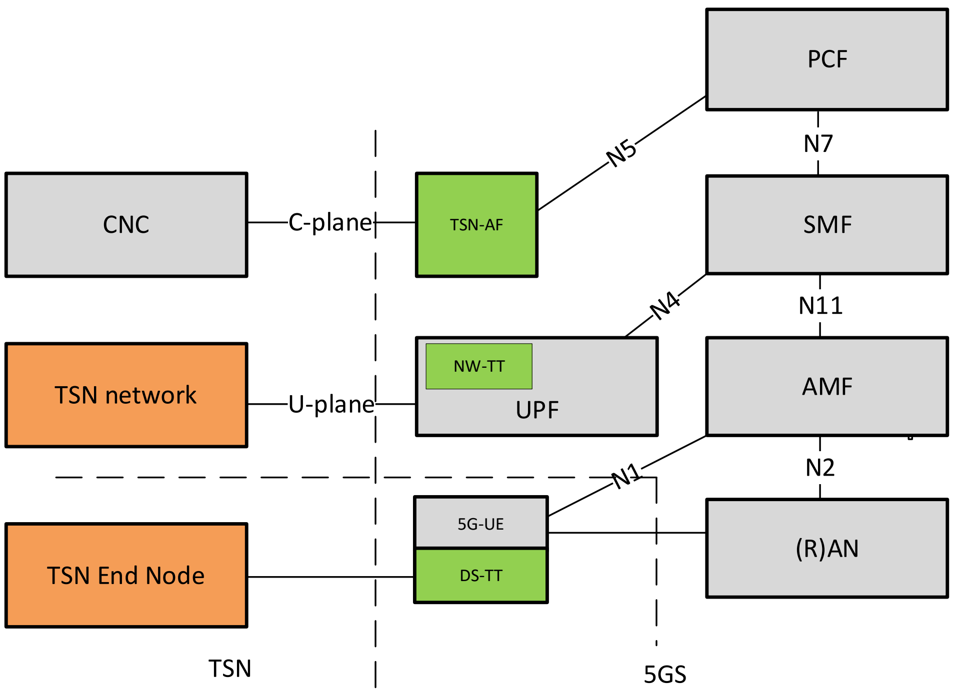

Figure 38: Logical (TSN) Bridge - Breakout Diagram. Source: Adapted from [9]

Figure 38 shows the logical TSN Bridge, TSN Network in orange is a network with TSN capable devices & nodes, most importantly it's a talker. The TSN Entity connected to 5G-UE via DS-TT will be listener from Time synchronizing part. Controlling of TSN end node ports are done using TSN-AF, which is connected on C-plane to traditional the CNC of the TSN Network.

Boundary Clock/Grand Master Clock is served from TSN Network. These events reach 5GS network side over U-plane as gPTP messages from TSN Network to UPF. From TSN point of view 5GS UPF is just a TSN-Bridge, from 5GS point of it's a gPTP message payload at UPF. Further ingress timestamp updated gPTP events from UPF are transparently sent to DS-TT via 5G-UE. DS-TT computes 5GS delay and remote NW-TT prefixes from gPTP and forwards them to TSN End Node port. gPTP events on ingress port of TSN End Node will now be able to process one-step or two-step events as if this node is part of TSN network (which is on the other part of 5GS). NW-TT can support multiple TSN time domains, and it will independently handles all incoming gPTP events from each domains and forwards to respective DS-TTs. The relationship between the Time domains and respective devices are managed by TSN-AF.

4.2 NW-TT

Network-side TSN Translator (NW-TT), see Figure 39, is implemented in UPF, and uses UPF to measure and report clock drift between the TSN time and 5GS time for one or more TSN working domains. To do so, NW-TT provisions the TSN Clock Drift Report.

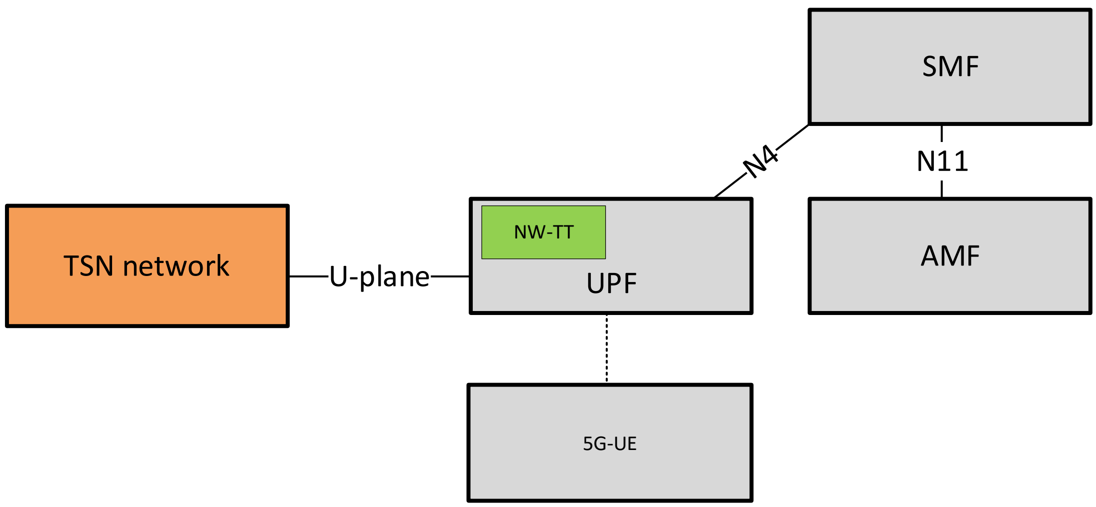

Figure 39: Network-Side TSN Translator (NW-TT). Source: Adapted from [9]

UPF in 5GS Core Network interfaces with TSN network over U-plane, and with CNC using TSN-AF by means of C-plane. NW-TT is add-on functionality that will be implemented over UPF Messaging and Interfaces.

4.3 DS-TT

5G-UE can be either a 5G modem or a Customer Premises Equipment (CPE) which can (1) provide 5G System Clock to DS-TT, (2) be able to create Always-On PDP context for DS-TT Session, (3) be able to forward payload from UPF to DS-TT and vice-versa. 3GPP 23.502 [12] Section 4.3.2.2 details how UE will establish session for TSN.

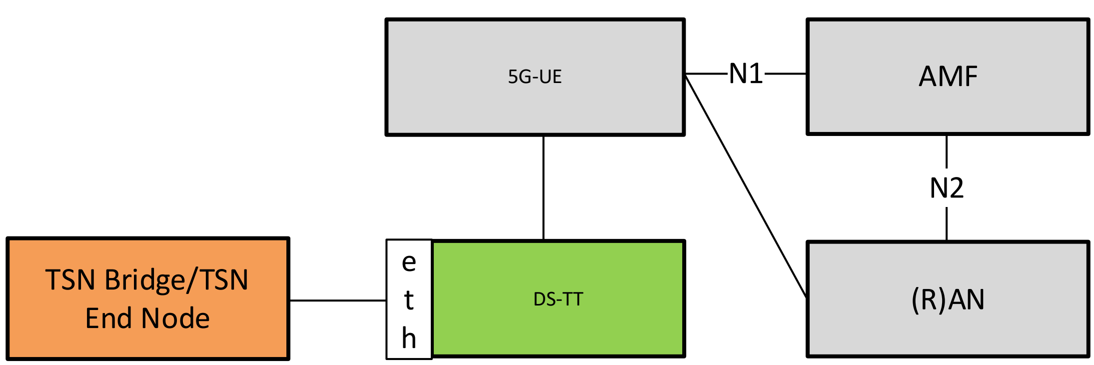

Figure 40: Device-side TSN Translator (DS-TT). Source: Adapted from [9].

Figure 40 shows breakout, interface and layout relevant to 5G-UE towards DS-TT and TSN End Node. Standard interfaces between 5G systems such as UE to AMF is N1, RAN to AMF is N2, UE to RAN is N3. Details are provided in 3GPP 5G NR specifications [9].

5G-UE interface between DS-TT is hardware specific, it can be interfaced via AT commands for modem class, API on CPE devices. Each DS-TT port will have a PDP session to UPF thus creating a tunnel between DS-TT to UPF. Information about each DS-TT port and PDP Context are registered in TSN-AF.

5 Cloud Architecture and Deployment Scenarios

According to the definition in [23], the O-Cloud Cloud Platform includes the following characteristics:

- The Cloud Platform is a set of hardware and software components that provide cloud computing capabilities to execute RAN network functions.
- The Cloud Platform hardware includes compute, networking and storage components, and may also include various acceleration technologies required by the RAN network functions to meet their performance objectives.
- The Cloud Platform software exposes open and well-defined APIs that enable the management of the entire life cycle for network functions.
- The Cloud Platform software is decoupled from the Cloud Platform hardware (i.e., it can typically be sourced from different vendors).

The management aspects of O-Cloud platform, key O-Cloud concepts, and deployment scenarios can also be found in specifications in [23].

5.1 Overview of Deployment Scenarios Specified by O-RAN Alliance

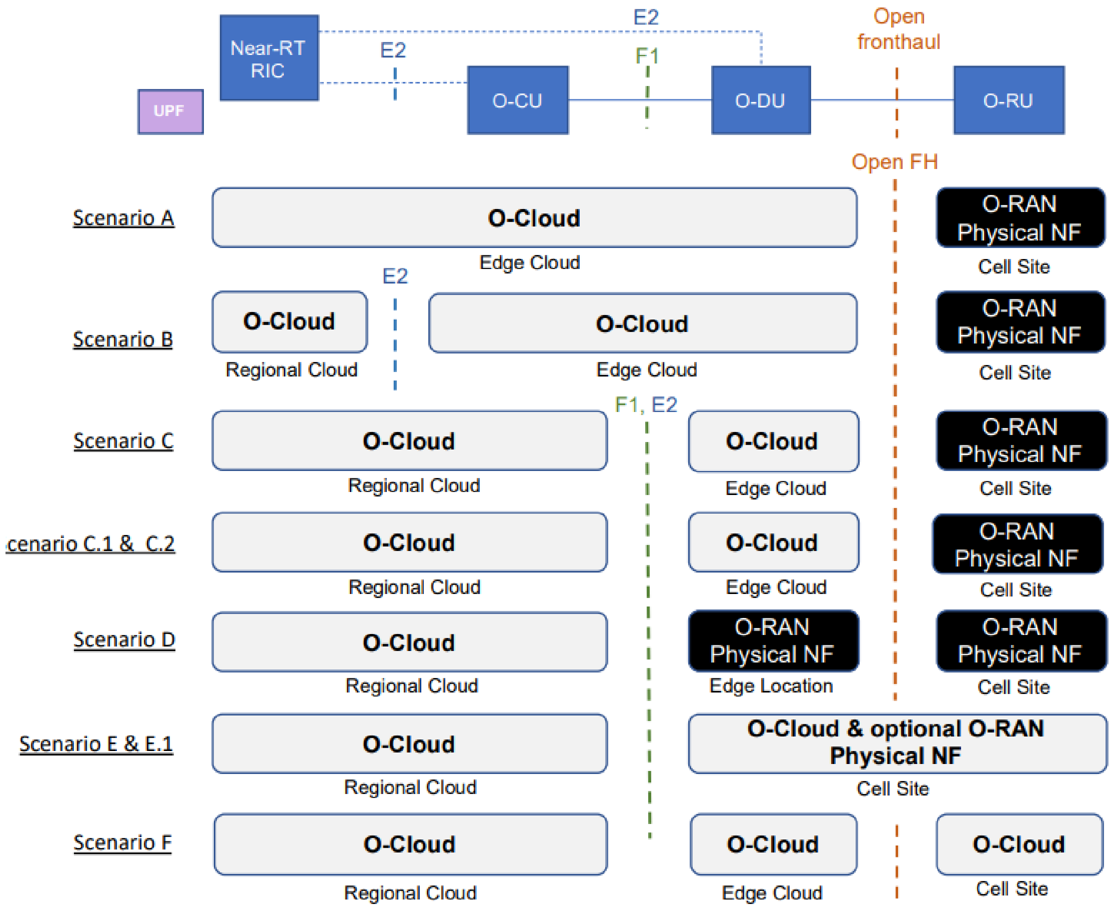

Figure 41: High-level Overview of Deployment Scenarios [23]

As described in Figure 41, each NF can be hosted on different devices (nodes or server) inside the same O-cloud, or separated by physical transport connection. Each NF could be from same or different provider. Deployment options in the figure are for short and long time. Deployment of all scenarios are not required and selection of deployment scenario is business decision.

The dimensioning of the scenarios is described as: O-DU per O-RU Ratio 1:N, O-CU per O-DU ratio 1:M, and NRT-RIC per O-CU ratio 1:L.

5.2 Reference Deployment Scenario for the 5G-OPERA

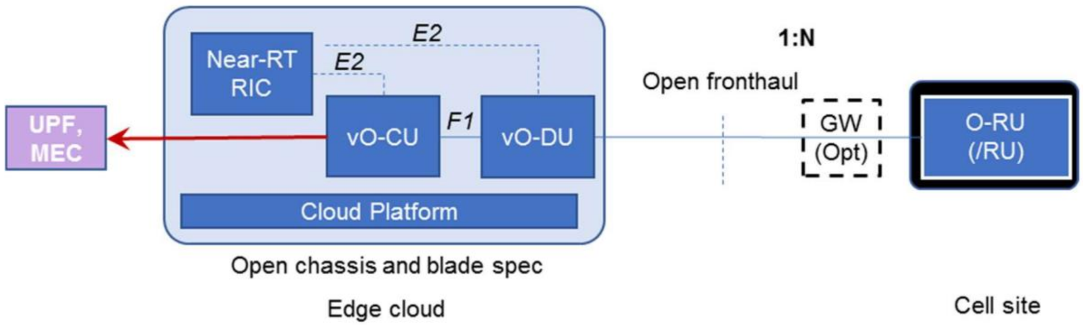

Figure 42: Deployment Scenario A [23]

Although scenarios B & C explained in [23] are more flexible in terms of dimensioning and more adapted for large deployment with 2 Cloud locations, i.e., Regional and Edge, scenario A is easier to deploy and manage on a single lab and single location. And it is most suitable scenario for 5G private network.

In this scenario, RAN functions are virtualized on same cloud deployment. Interfaces are within in same cloud. This scenario supports dense urban area.

F1 and E2 interfaces may be physical link or logical link. NFs can be run on different servers. For dimensioning, for initial Proof of Concept (PoC) deployment, one O-CU, one O-DU and multiple O-RUs are needed. Generally, the ratio between O-RU to O-DU can be based on cell characteristics per O-RU, capacity of servers hosting O-DU and O-CU and hardware acceleration capabilities of O-DU.

5.3 Cloud Platform Time Synchronization Architecture

Currently most of the implemented DUs are working as a slave and cannot provide clocking to the fronthaul network. Therefore, LLS-C3 topology is expected to be used in the project for synchronization. Figure 43 illustrates the LLS-C3 topology. As seen in the figure, network timing can be distributed towards O-RU and O-DU by implementing one or more PRTC / Telekom Grand Master.

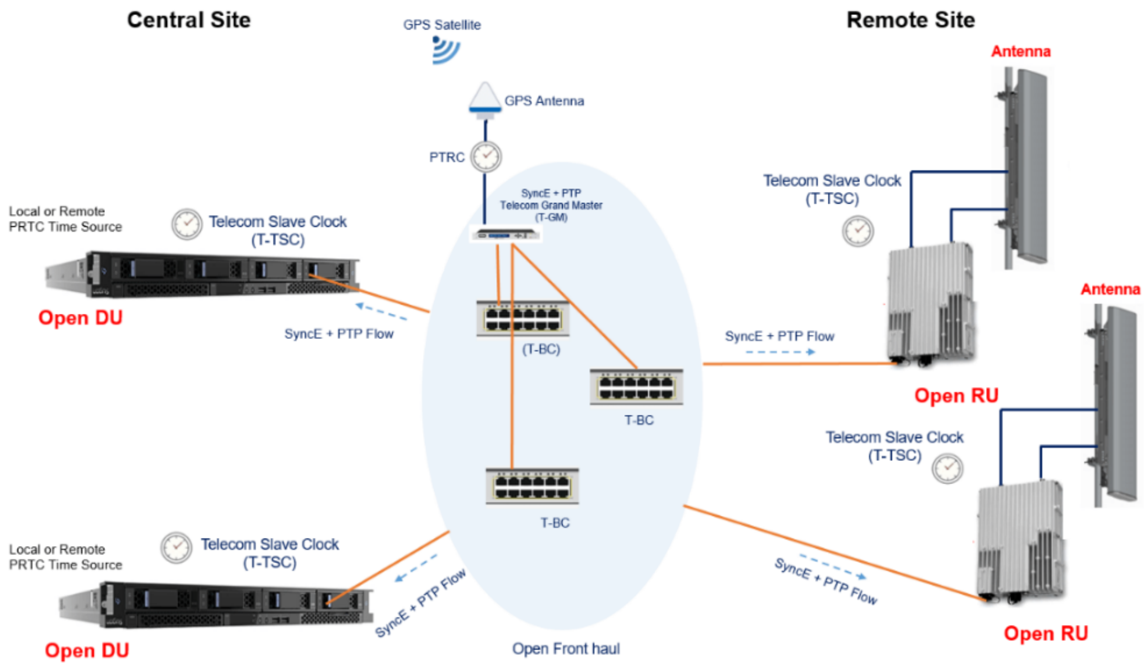

Figure 43: LLS-C3 topology. Source: Techplayon [24]

6 Conclusions

This deliverable presents the components of the reference architecture of open RAN and 5G core network. These components have been selected according to the necessities of the 5G private networks. All functions and interfaces have a short description, and then related standards has been cited. The descriptions do not explain all specifications in the standards in order to avoid unnecessary extension of the report.

This deliverable covers network functions and interfaces of RAN and 5G core. Related standards have been searched and cited. Furthermore, the reference architecture for TSN over 5G, deployment scenario and fronthaul synchronization topology has been described.

This deliverable is the second in a series that will define the work that we will carry out in the 5G-OPERA project. Deliverable3.3 and Deliverable3.4 are following deliverables that will define the requirements of open RAN and core solutions.

7 References

[1] C. Being, Director, *5G NR Physical Layer | Chapter 12| Uplink Transmission Schemes | Codebook & Non-Codebook Based.* [Film]. 2020.

[2] O-RAN Alliance, "O-RAN Resources," October 2018. [Online]. Available: https://assets-global.website-files.com/60b4ffd4ca081979751b5ed2/60e5afb502810a0947b3b9d0_O-RAN%2BWP%2BFInal%2B181017.pdf. [Accessed January 2023].

[3] Huber+Suhner, "5G Fundamentals : Functional Split Overview," [Online]. Available: https://www.hubersuhner.com/en/documents-repository/technologies/pdf/fiber-optics-documents/5g-fundamentals-functional-split-overview. [Accessed January 2023].

[4] 3GPP, "Physical channels and modulation (3GPP TS 38.211 version 17.3.0 Release 17)," ETSI, September 2022. [Online]. Available: https://www.3gpp.org/dynareport?code=status-report.htm#activeRel-17. [Accessed January 2023].

[5] 3GPP, "Multiplexing and channel coding (3GPP TS 38.212 version 17.3.0 Release 17)," ETSI, September 2022. [Online]. Available: https://www.3gpp.org/dynareport?code=status-report.htm#activeRel-17. [Accessed January 2023].

[6] AVNET, "Understanding Massive MIMO technology," AVNET, [Online]. Available: https://www.avnet.com/wps/portal/abacus/solutions/markets/communications/5g-solutions/understanding-massive-mimo-technology/. [Accessed January 2023].

[7] 3GPP, "Digital cellular telecommunications system (Phase 2+) (GSM); General Packet Radio Service (GPRS); Mobile Station (MS) - Base Station System (BSS) interface; Radio Link Control / Medium Access Control (RLC/MAC) Protocol (3GPP TS 44.060 version 17.0.0)," ETSI, May 2022. [Online]. Available: https://www.3gpp.org/dynareport?code=status-report.htm#activeRel-17. [Accessed January 2023].

[8] O-RAN Alliance, "O-RAN Acceleration Abstraction Layer General Aspects and Principles (O-RAN.WG6.AAL-GAnP)," O-RAN Alliance, October 2022. [Online]. Available: https://orandownloadsweb.azurewebsites.net/specifications. [Accessed January 2023].

[9] 3GPP, "System architecture for the 5G System (5GS) (3GPP TS 23.501 version 16.14.0 Release 16)," ETSI, September 2022. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/123500_123599/123501/16.14.00_60/ts_123501v161400p.pdf. [Accessed January 2023].

[10] 3GPP, "5G System; Network function repository services; Stage 3 (3GPP TS 29.510 version 16.12.0 Release 16)," ETSI, July 2022. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/129500_129599/129510/16.12.00_60/ts_129510v161200p.pdf. [Accessed January 2023].

[11] 3GPP, "Policy and charging control framework for the 5G System (5GS); Stage 2 (3GPP TS 23.503 version 16.12.0 Release 16)," ETSI, July 2022. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/123500_123599/123503/16.12.00_60/ts_123503v161200p.pdf. [Accessed January 2023].

[12] 3GPP, "Procedures for the 5G System (5GS) (3GPP TS 23.502 version 16.14.0 Release 16)," September 2022. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/123500_123599/123502/16.14.00_60/ts_123502v161400p.pdf. [Accessed January 2023].

[13] 3GPP, "Security architecture and procedures for 5G System (3GPP TS 33.501 version 16.11.0 Release 16)," July 2022. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/133500_133599/133501/16.11.00_60/ts_133501v161100p.pdf. [Accessed January 2023].

[14] 3GPP, "5G System (5GS) Location Services (LCS); Stage 2 (3GPP TS 23.273 version 16.10.0 Release 16)," July 2022. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/123200_123299/123273/16.10.00_60/ts_123273v161000p.pdf. [Accessed January 2023].

[15] 3GPP, "5G System; Application Function Event Exposure Service; Stage 3 (3GPP TS 29.517 version 16.5.0 Release 16)," August 2021. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/129500_129599/129517/16.05.00_60/ts_129517v160500p.pdf. [Accessed January 2023].

[16] 3GPP, "Non-Access-Stratum (NAS) protocol for 5G System (5GS); Stage 3 (3GPP TS 24.501 version 16.12.0 Release 16)," July 2022. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/124500_124599/124501/16.12.00_60/ts_124501v161200p.pdf. [Accessed January 2023].

[17] 3GPP, "NG-RAN; NG general aspects and principles (3GPP TS 38.410 version 17.1.0 Release 17)," July 2022. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/138400_138499/138410/17.01.00_60/ts_138410v170100p.pdf. [Accessed January 2023].

[18] 3GPP, "NG-RAN; NG Application Protocol (NGAP) (3GPP TS 38.413 version 17.2.0 Release 17)," October 2022 . [Online]. Available: https://www.etsi.org/deliver/etsi_ts/138400_138499/138413/17.02.00_60/ts_138413v170200p.pdf. [Accessed January 2023].

[19] 3GPP, "General Packet Radio System (GPRS) Tunnelling Protocol User Plane (GTPv1-U) (3GPP TS 29.281 version 16.2.0 Release 16)," May 2021. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/129200_129299/129281/16.02.00_60/ts_129281v160200p.pdf. [Accessed January 2023].

[20] 3GPP, "Interface between the Control Plane and the User Plane nodes (3GPP TS 29.244 version 16.10.0 Release 16)," July 2022. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/129200_129299/129244/16.10.00_60/ts_129244v161000p.pdf. [Accessed January 2023].

[21] 3GPP, "5G System; Policy Authorization Service; Stage 3 (3GPP TS 29.514 version 17.7.0 Release 17)," January 2023. [Online]. Available: https://www.etsi.org/deliver/etsi_ts/129500_129599/129514/17.07.00_60/ts_129514v170700p.pdf. [Accessed January 2023].

[22] Internatioanl Telecommunication Union (ITU), "5G Network Architecture and FMC," July 2017. [Online]. Available: https://www.itu.int/en/ITU-T/Workshops-and-Seminars/201707/Documents/Joe-Wilke-%205G%20Network%20Architecture%20and%20FMC.pdf. [Accessed January 2023].

[23] O-RAN Alliance, "O-RAN Cloud Architecture and Deployment Scenarios for O-RAN Virtualized RAN 4.0," October 2022. [Online]. Available: https://orandownloadsweb.azurewebsites.net/specifications. [Accessed January 2023].

[24] Techplayon, "O-RAN Fronthaul Transport Synchronization Configurations," October 2020. [Online]. Available: https://www.techplayon.com/o-ran-fronthaul-transport-synchronization-configurations/. [Accessed January 2023].