ORAN-WG8.AAD-v01.0.0

Technical Specification

O-RAN Working Group 8

Base Station O-DU and O-CU Software Architecture and APIs

Revision History

Date	Revision	Company	Description
08/09/2019	v01.0.0	O-RAN WG8	First published version for Base Station O-DU and O-CU Software Architecture and APIs

Contents

Chapter 1 Introductory Material

1.1 Scope

This Technical Specification has been produced by the O-RAN Alliance.

The contents of the present document are subject to continuing work within O-RAN and may change following formal O-RAN approval. Should O-RAN modify the contents of the present document, it will be re-released by O-RAN with an identifying change of release date and an increase in version number as follows:

Version x.y.z

where:

- x the first digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc. (the initial approved document will have x=01).
- y the second digit is incremented when editorial only changes have been incorporated in the document.
- z the third digit included only in working versions of the document indicating incremental changes during the editing process.

This document contains RAN Requirements, reference O-CU and O-DU Software Architecture, Functional Blocks and API definitions. O-RU and Low-PHY references in this document are only informational to complete the architecture description. All hardware and/or software implementations of O-RU and Low-PHY are not in the scope of this document.

1.2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

[1] 3GPP TR 21.905: Vocabulary for 3GPP Specifications

[2] 3GPP TS 29.281: "General Packet Radio System (GPRS) Tunneling Protocol User Plane (GTPv1-U)".

[3] 3GPP TR 38.104: "NR; Base Station (BS) radio transmission and reception".

[4] 3GPP TS 38.211: "NR; Physical channels and modulation".

[5] 3GPP TS 38.212: "NR; Multiplexing and channel coding".

[6] 3GPP TR 38.300: "NR; NR and NG-RAN Overall Description".

[7] 3GPP TR 38.321: "NR; Medium Access Control (MAC) protocol specification".

[8] 3GPP TR 38.322: "NR; Radio Link Control (RLC) protocol specification".

[9] 3GPP TR 38.323: "NR; Packet Data Convergence Protocol (PDCP) specification".

[10] 3GPP TR 37.324: "NR; Service Data Adaptation Protocol (SDAP) specification".

[11] 3GPP TS 38.331: "NR; Radio Resource Control (RRC) Protocol specification".

[12] 3GPP TS 38.401: "NG-RAN; Architecture description".

[13] 3GPP TS 38.413: "NG-RAN; NG Application Protocol (NGAP)".

[14] 3GPP TS 38.423: "NG-RAN; Xn Application Protocol (XnAP)".

[15] 3GPP TS 38.425: "NG-RAN; NR user plane protocol".

[16] 3GPP TS 38.470: "NG-RAN; F1 general aspects and principles".

[17] 3GPP TS 38.472: "NG-RAN; F1 signaling transport".

[18] 3GPP TS 38.473: "NG-RAN; F1 Application Protocol (F1AP)".

[19] 3GPP TS 38.474: "NG-RAN; F1 data transport".

[20] ORAN-WG4.CUS.0-v01.00 Technical Specification, 'O-RAN Fronthaul Working Group Control, User and Synchronization Plane Specification'.

[21] ORAN-WG1.OAM Technical Specification, 'O-RAN Operations and Maintenance Architecture'

[22] SCF Release 10.0, Document 222.10.01, 5G FAPI: PHY API Specification, June 2019

1.3 Definitions and Abbreviations

1.3.1 Definitions

For the purposes of the present document, the terms and definitions given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1]. For the base station classes of Pico, Micro and Macro, the definitions are given in 3GPP TR 38.104 [3].

O-CU: O-RAN Control Unit – a logical node hosting PDCP, RRC, SDAP and other control functions.

O-DU: O-RAN Distributed Unit: a logical node hosting RLC, MAC, and High-PHY layers based on a lower layer functional split.

O-RU: O-RAN Radio Unit: a logical node hosting Low-PHY layer and RF processing based on a lower layer functional split.

E1 interface: The interface defined by 3GPP TS 38.460, 3GPP TS 38.462 and 3GPP TS 38.463 between CU control plane and CU user plane.

F1 interface: The interface defined by 3GPP TS 38.470 [16], 3GPP TS 38.472 [17] and 3GPP TS 38.473 [18], to be further interpreted as per O-RAN WG5 specification for interoperability between O-CU and O-DU from different vendors.

1.3.2 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

3GPP	Third Generation Partnership Project
5G	Fifth-Generation Mobile Communications
AMC	Adaptive Modulation and Coding
BWP	Bandwidth Part
CSI	Channel State Information
CU	Centralized Unit as defined by 3GPP
DCI	Downlink Control Information
DPDK	Data Plane Development Kit
DL	Downlink
DU	Distributed Unit as defined by 3GPP
E1AP	E1 Application Protocol
FAPI	Functional Application Platform Interface
F1AP	F1 Application Protocol
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
FSM	Finite State Machine
HARQ	Hybrid Automatic Repeat Request
LDPC	Low Density Parity Check code
LLR	Log Likelihood Ratio

MAC	Medium Access Control protocol
MIMO	Multiple Input Multiple Output
MT	Mobile-Termination
MU-MIMO	Multiple User MIMO
NG-RAN	Next Generation Radio Access Network
NR	New Radio
O-CU	O-RAN Centralized Unit as defined by O-RAN
O-DU	O-RAN Distributed Unit as defined by O-RAN
OFH	Open Front Haul protocol defined by O-RAN
OFH-C	OFH Control plane
OFH-U	OFH User plane
O-RU	O-RAN Radio Unit as defined by O-RAN
PBCH	Physical Broadcast Channel
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Control Protocol
PHY	Physical (L1) access layer of RAN
PRACH	Physical Random Access Channel
PUCCH	Physical Uplink Control Channel
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature (Quaternary) Phase Shift Keying
QoS	Quality of Service
RAN	Radio Access Network
Rel-x	Release number: where x is the actual release number
RF	Radio Frequency
RLC	Radio Link Control protocol
RRC	Radio Resource Control protocol
RU	Radio Unit as defined by 3GPP
Rx	Receiver
SCS	Sub-Carrier Spacing
SDAP	Service Data Adaptation Protocol
SDU	Service Data Unit
SRIOV	Single Root Input/Output Virtualization
SRS	Sounding Reference Signal
SU-MIMO	Singer User MIMO
TDD	Time Division Duplex
TS	Technical Specification
TTI	Transmission Time Interval
Tx	Transmitter
UE	User Equipment
UL	Uplink
URLLC	Ultra-Reliable Low Latency Communication
WG	Working Group

Chapter 2 RAN Deployment Scenarios and Requirements

2.1 Deployment scenario - Example

The reference design of the O-CU and O-DU is specified in this document to support all deployment scenarios. In this initial version, the deployment scenario of indoor small cell is used as an example.

2.2 Requirements

Table 2-1 lists the features and requirements supported by the reference design based on the target release specification. Requirements marked “R1” are addressed in this release of the document.

Table 2-1 Requirements

Feature		Requirement	WG8 Specification Release
L1	Carrier BW	100MHz	R1
	Subcarrier Spacing	30kHz, 120kHz	R1
	Number of carriers	1	R1
	Frame structural format	Static TDD	R1
	Antenna Number	2T2R	R1
		4T4R	R1
	Numerology/BWP number	1	R1
		4	R3
	BWP change	RRC signaling	R3
		MAC CE	R3
	MIMO	30K DL:2*2MIMO UL:2*2MIMO	R1
		30K DL:4*4MIMO UL:2*2MIMO	R1
	Modulation	DL: QPSK,16QAM,64QAM,256QAM UL: π/2-bpsk, QPSK, 16QAM, 64QAM	R1
		UL: 256QAM	R2
	Capacity	Support at least 4 100MHz bandwidth 2T2R cells	R1
		Support at least 2 100MHz bandwidth 4T4R cells	R3
		Support at least 8 100MHz bandwidth 2T2R cells	R2
		Support at least 4 100MHz bandwidth 4T4R cells	R3
	Peak Rate	With 100MHz bandwidth and 74% for DL, the DL peak throughput of one cell shall not be lower than 850Mbps and the UL peak throughput of one cell shall not be lower than 190Mbps. (2T2R）	R3
	Data Compression	Support	R3
	PRACH Format	Format 0	R1
		Format B4	R1
		Format C2	R1
	PDCCH Format	DCI 0-0	R1

		DCI 0-1	R1
		DCI 1-0	R1
		DCI 1-1	R1
	PUCCH Format	Format0	R1
		Format1+Format2	R1
		format 3	R2
	SCS of PBCH	30 KHz	R1
	Power control	Enable	R2
L2			
	HARQ	Enable	R1
	AMC	Enable	R1
	SRS	Enable	R2
	Scheduling algorithm	Round Robin	R1
		PF	R1
	Latency	Control Plane <20ms (def: message 1 to message 5) User Plane DL <4ms, UL<6 ms (def: PDCP SDU-> PDCP SDU)	R1
L3			
	Handover		R3
	Paging		R3
	F1AP		R1
	E1AP		R3

Chapter 3 RAN Architecture

3GPP specifies the 5G RAN architecture and interfaces between the logical functional blocks. The following diagram presents the overall 5G network architecture [12] as well as the logical partition of the main functions.

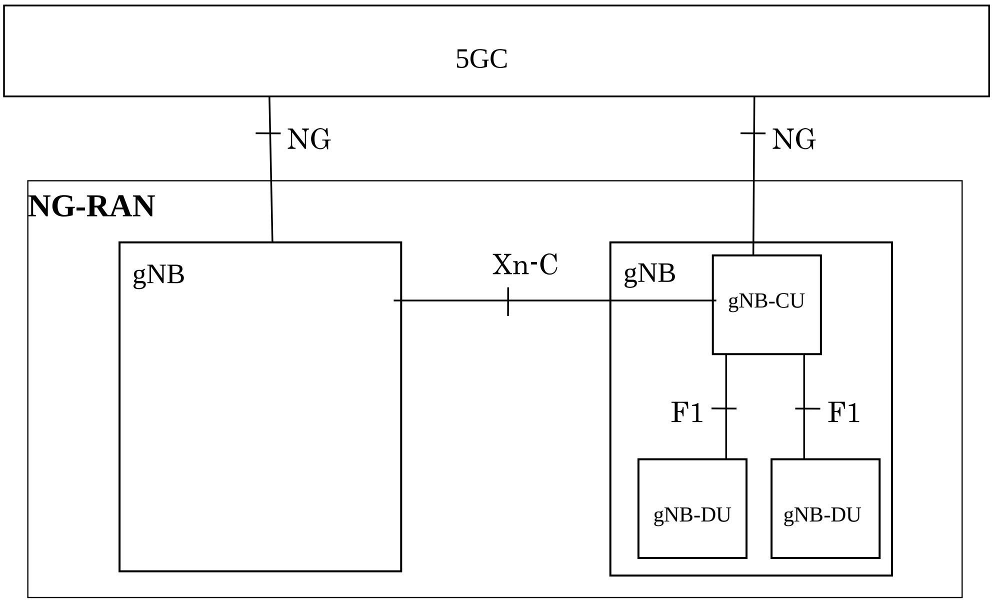

Figure 3-1 3GPP RAN Architecture

As shown in Figure 3-2 [21], O-RAN defines the RAN architecture with a focus on new, open interfaces between the logical nodes and physical partitions of the RAN functions.

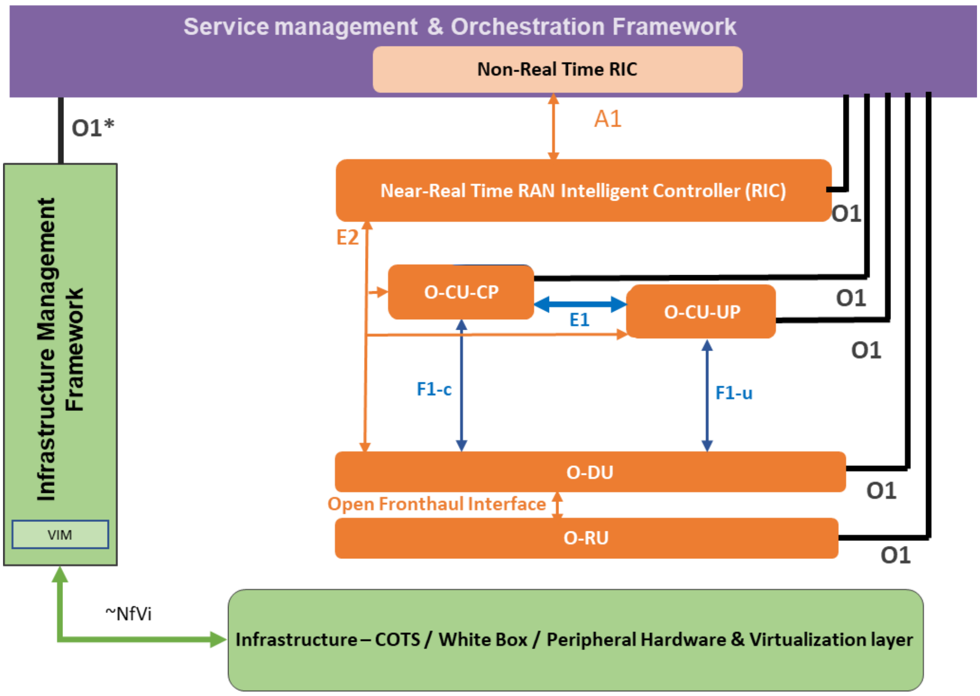

Figure 3-2 O-RAN Architecture and Interfaces

3.1 O-CU/O-DU Lower Layer Split Architecture

In some RAN deployment scenarios, e.g., a microcell, the physical layer is split between the O-DU and O-RU. O-RAN WG4 defines the open front haul interface which is adopted in the split architecture as shown in Figure 3-3. The O-DU contains the higher physical layer High-PHY functions while the O-RU contains the lower physical layer Low-PHY functions as specified in [20]. The fronthaul software interface is discussed in section 5.4.1 of this specification.

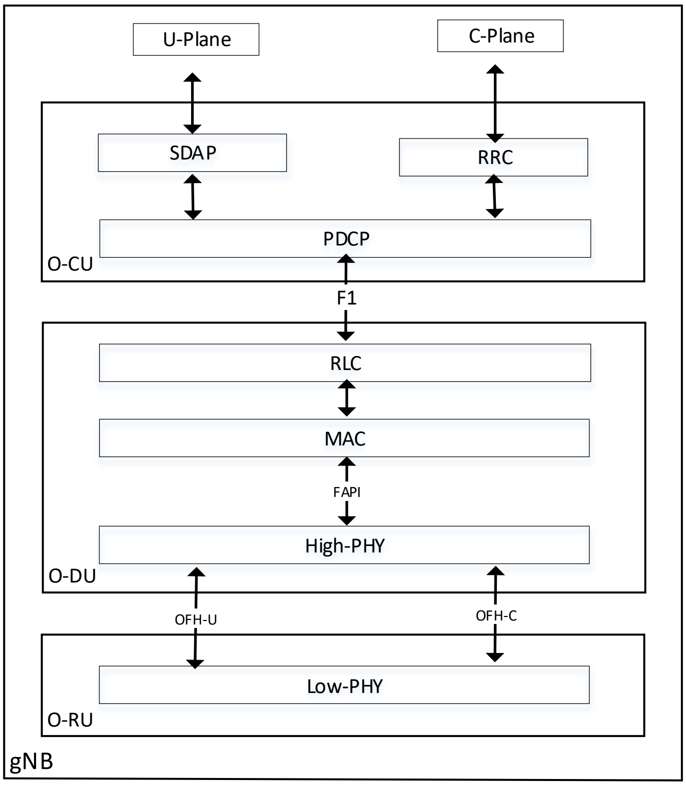

Figure 3-3 O-CU, O-DU and O-RU (Control and user plane)

Chapter 4 O-DU Software Architecture

The O-DU software architecture is illustrated in Figure 4-1. The O-DU is composed of L1 and L2 functional blocks which interface through the FAPI interface [22]. The functional blocks are further described in the following sections.

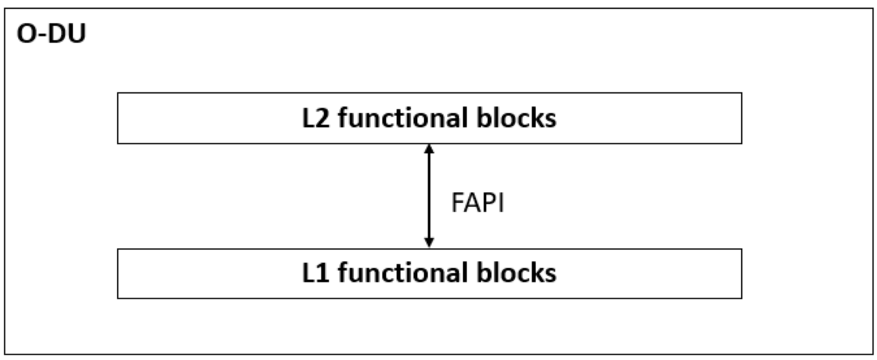

Figure 4-1 O-DU software architecture

Chapter 5 O-DU L1 Functional Blocks

In O-RAN architecture (refer to Figure 3-2), PHY layer functionality is realized as High-PHY in O-DU and Low-PHY in O-RU. Some of the PHY functionalities may be realized using hardware acceleration. The following sections describe the High-PHY and fronthaul library modules that reside in O-DU. Only the L1 functional blocks shown in Figure 5-1 are defined in Release 1 of this specification. A complete set of control, signalling, and data channels will be defined in future releases of the specification.

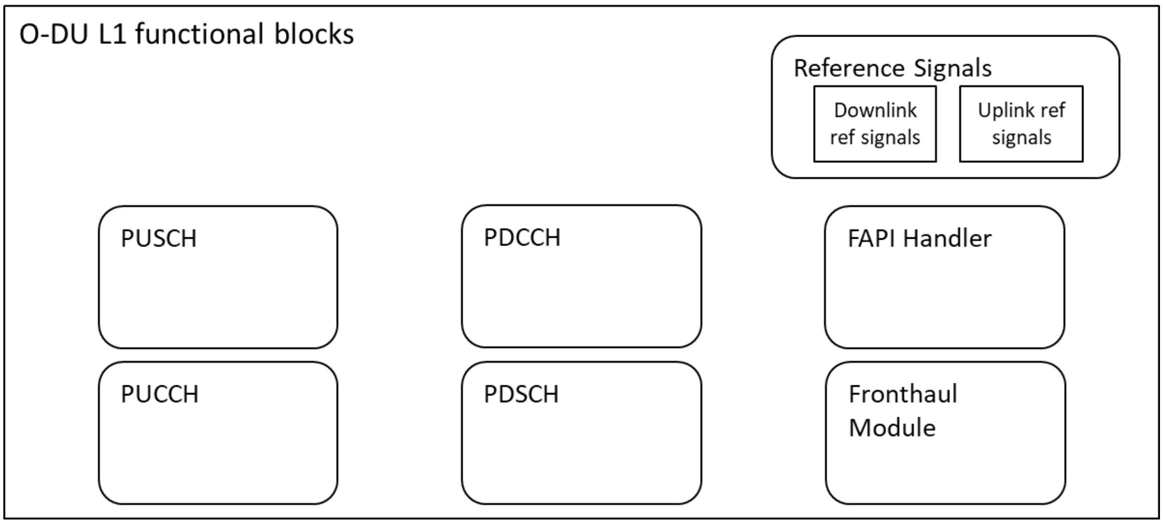

Figure 5-1 O-DU L1 functional modules

5.1 Physical Uplink Shared Channel

The uplink physical layer processing of transport channels consists of the following steps as described in [6]:

- Transport Block CRC attachment
- Code block segmentation and Code Block CRC attachment
- Channel coding: LDPC coding
- Physical layer hybrid-ARQ processing
- Rate matching
- Scrambling
- Modulation: π/2 BPSK (with transform precoding only), QPSK, 16QAM, 64QAM and 256QAM
- Layer mapping, transform precoding (enabled/disabled by configuration), and precoding
- Mapping to assigned resources and antenna ports

The frequency domain IQ data received by the fronthaul module are sent to the L1 PUSCH processing functions and the output of the PUSCH is the user bit stream. Figure 5-2 illustrates the PUSCH functional blocks.

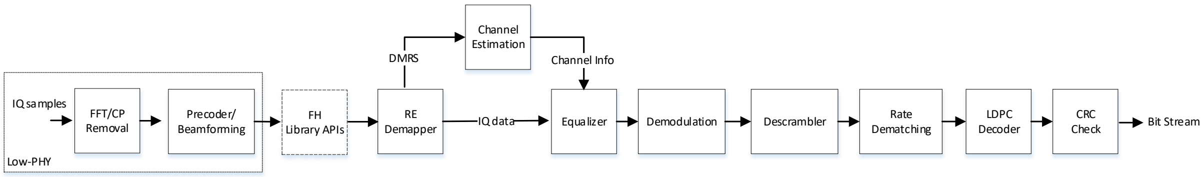

Figure 5-2 PUSCH functional blocks

Resource Element (RE) Demapper: The RE Demapper function separates the DMRS REs and the user data REs. The DMRS REs are provided to the channel estimation function.

Channel Estimation: The channel estimation functional block provides a channel estimate based on the DMRS of resource elements of the user data.

MIMO Equalizer: The MIMO equalizer function processes the received IQ data signals to reverse the distortion incurred during the signal transmission over the air. Using the channel information acquired via the channel estimation, the equalizer tries to restore the IQ symbol sent by the transmitter. The symbols may be conveyed as log-likelihood ratios (LLRs) for use by the LDPC decoder.

Rate Dematching: The rate dematching function performs the reverse operation steps of rate matching for LDPC code in clause 5.4.2 in 3GPP TS38.212 [5].

LDPC Decoder: The LDPC decoder function uses received log-likelihood ratios (LLRs) to compute the data bits based on selected decoder algorithm. The selection of the decoder algorithm is out of scope of this specification.

CRC Check: The CRC function block checks the parity bits using the generator polynomials in Subclause 5.1 of 3GPP TS38.212 [5]. Refer to the 3GPP specification for details.

5.2 Uplink Control Channels

Physical Uplink Control Channel (PUCCH) conveys Uplink Control Information (UCI) and supports all the formats defined in clause 6.3.2 of 3GPP TS38.211 specification [4]. Refer to this specification for details of the formats as well as the control message including:

- HARQ-ACK (Hybrid Automated Repeat Request Acknowledgement).
- Scheduling Request (SR)
- Channel State Information (CSI)

5.3 Uplink Reference Signals

5G NR introduces the following reference signals.

- Demodulation Reference Signal (DMRS) for PUSCH and PUCCH
- Phase Tracking Reference Signal (PTRS)
- Sounding Reference Signal (SRS)

Refers to clause 6.4.1 in 3GPP TS38.211 specification [4] for more details of the reference signals.

5.4 Physical Downlink Shared Channel

The downlink physical layer processing of transport channels consists of the following steps as described in [6]:

- Transport block CRC attachment
- Code block segmentation and code block CRC attachment
- Channel coding: LDPC coding
- Physical-layer hybrid-ARQ processing
- Rate matching
- Scrambling
- Modulation: QPSK, 16QAM, 64QAM and 256QAM
- Layer mapping
- Mapping to assigned resources and antenna ports

Figure 5-3 illustrates the functional blocks of the PDSCH.

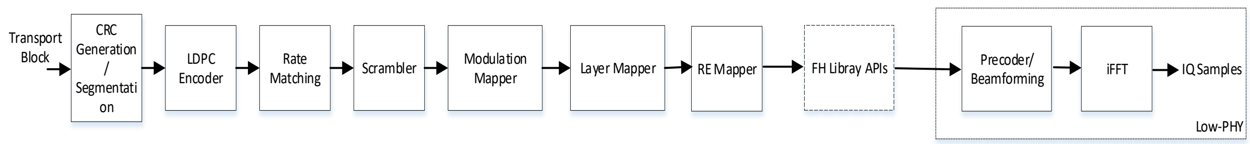

Figure 5-3 PDSCH Functional Blocks

Cyclic Redundancy Check Generation: The CRC function block computes the parity bits using the generator polynomials in Subclause 5.1 of 3GPP TS38.212 [5]. Refer to the 3GPP specification for details.

Segmentation: The transport block is segmented when it exceeds the code block size specified by 3GPP TS38.212 [5]. Refer to Subclause 7.2.3 for details.

LDPC Encoder: Refer to Subclause 5.3.2 in 3GPP TS38.212 [5] for details.

Rate Matching: Refer to Subclause 5.4.2 in 3GPP TS38.212 [5] for details.

Scrambler: Refer to Subclause 7.3.1.1 in 3GPP TS38.211 [4] for details.

Modulation Mapper: Refer to Subclause 7.3.1.2 in 3GPP TS38.211 [4] for details.

Layer Mapper: Refer to Subclause 7.3.1.3 in 3GPP TS38.211 [4] for details.

RE Mapper: Refer to Subclause 7.3.1.5 and Subclause 7.3.1.6 in 3GPP TS38.211 [4] for details.

5.4.1 Fronthaul Module

The fronthaul module supports the open fronthaul interface specified by WG4 [20] lower level split distributed gNB architecture. The details requirements, control and data plane protocol are described in O-RAN WG4 CUS-plane specification. The module carries out the communication between the O-DU and O-RU. The fronthaul module is expected to process incoming WG4 CUS-plane packets and construct outgoing CUS-plane packets. The following diagram illustrates an example implementation of hardware accelerated packet processing.

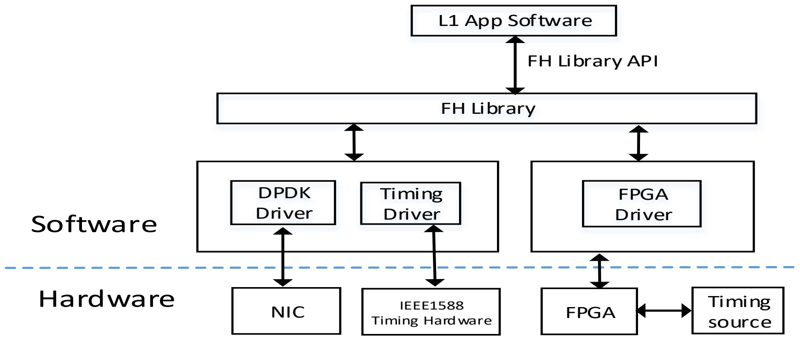

Figure 5-4 Fronthaul library and interfaces

The FH library APIs are listed in the following table.

Table 5-1 Fronthaul library APIs

API Name	**Parameters**	**Description**
FH Init	returns handle which is used later	instantiate the lib memory model and thread
FH start	FH handle	start processing front haul packets for DL and UL
FH stop	FH handle	stop processing of DL and UL
FH close	FH handle	remove usage of front haul resources
FH mm destroy	FH handle	destroy memory structure

5.5 Physical Downlink Control Channel

A physical downlink control channel (PDCCH) carries control information (DCI) such as scheduling information and resource grant to UEs. The PDCCH includes one or more control channel elements (CCE, consists of 6 resource element group) based on the aggregation level defined by 3GPP specification [4]. The PDCCH processing flow is similar to the PDSCH. The control channel uses a polar code instead of LDPC. QPSK modulation is the designated modulation scheme for the PDCCH bits block.

5.6 Downlink Reference Signals

The downlink reference signals include:

- Demodulation Reference Signal (DMRS) for PDSCH, PDCCH and PBCH.
- Phase Tracking Reference Signal (PTRS)
- Channel State Information Reference Signal (CSI-RS)

Refers to clause 7.4.1 in 3GPP TS38.211 specification [4] for more details related to the reference signals.

Chapter 6 O-DU L2 Functional Blocks

Figure 6-1 illustrates the L2 functional blocks of O-DU as a reference design. An implementation may specify the modules differently.

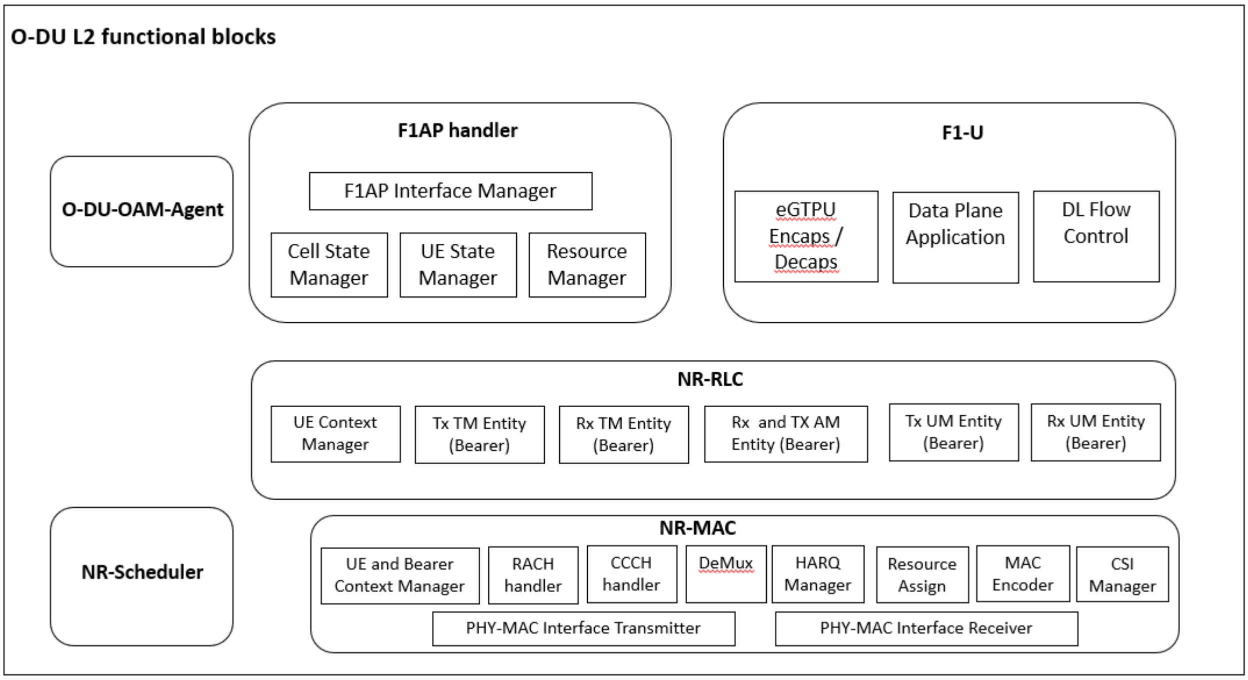

Figure 6-1 O-DU L2 functional blocks

F1 Control Plane interface handling modules (F1AP handler): It consists of tasks related to cell management, UE management and semi-static Air Interface Resource Management at the cell level. It does tasks defined in 3GPP TS 38.473 [18].

1. Cell State Manager: It handles all the tasks related to the handling of cells at O-DU Cell Start, Cell Stop, etc. It also manages a Finite State Machine (FSM) for handling cell specific procedures. This includes maintaining the cell broadcast information. There would be per cell FSM which would run independently of another cell's FSM.
2. UE State Manager: It handles the procedures related to a UE, e.g., SRB packet transfer, UE Context Setup, Release procedure, UE Context Modification procedure, etc. It also manages an internal state machine for handling UE specific procedures. It interacts with other layers like RLC/MAC/F1U for UE level interactions and signaling.
3. F1AP Interface Manager: This interacts with the O-CU-CP (Control Unit) to control communication setup, and it exchanges F1AP messages over SCTP interface. It also decodes/encodes the messages and exchanges the same messages with other tasks.
4. Resource Manager: This block performs tasks like Admission Control, Bearer Control, etc. It also takes care of managing all the air interface resources for a UE, e.g., physical level resource allocation (SR, CSI resources), etc.

F1 User Plane interface handling modules: It consists of tasks related to Tunnel management, DL and UL Data and Downlink flow control. It does tasks defined in 3GPP TS 29.281 [2] and TS 38.425 [15].

1. Data Plane Application: Handles DL Data packets received within 3GPP TS 29.281 [2] defined NR RAN Container and performs UL Data packet transmission for packets received from RLC. This Application invokes eGTPU encapsulation/decapsulation functionality for eGTPU header processing.
2. eGTPU encaps/decaps: This functional block performs eGTPU header decapsulation and processing in DL and eGTPU header encapsulation for the UL packets at F1-U.
3. Downlink Flow Control: Downlink Data Delivery Status generation with feedback received from RLC.

RLC Protocol modules: These modules handle processing related to SRB and DRB plane. It does tasks defined in 3GPP TS 38.322 [8]. RLC uses the logical channel for data transfer. MAC layer indicates the downlink data notification request for a logical channel along with the desired RLC PDU size. RLC segments (optionally) the SDUs depending upon the size requested from MAC and sends the RLC PDUs to MAC. MAC layer also indicates uplink data by sending RLC PDUs. RLC layer forms SDUs by reassembling the received PDUs and transmits SDUs to upper Layer via F1 interface. It does tasks defined in 3GPP TS 38.322 [8].

1. UE and Bearer Context management
2. RLC Mode Receiver and Transmitter
    a. TM Mode
    b. UM Mode
    c. AM Mode

MAC Protocol modules: MAC modules include RACH management, HARQ Management, DL and UL Data, BCCH/PCCH/CCCH processing, MAC Transport Block formation, etc. It does tasks defined in 3GPP TS 38.321 [7].

1. UE and Bearer Context Management: Stores the semi-static information on air interface resources for the UE. It keeps the QoS related information for the scheduler.
2. HARQ Management: Performs DL and UL HARQ management by keeping track of HARQ feedback, HARQ timer and providing free HARQ processes information to the scheduler.
3. RACH Manager: RACH (Preamble) resource management, CRNTI Assignment, Message-2,3,4 resource allocation and handling.
4. CCCH Manager: Handles the DL and UL CCCH message and corresponding HARQ.
5. Resource Assign: PDCCH, PDSCH, PUCCH and PUSCH Resource Assignment based on resource allocation schedule from the scheduler.
6. MAC Encoder: It creates MAC Transport block based on input from the scheduler. It interfaces with RLC to get RLC PDUs.
7. Demultiplexer: Demultiplexing UL Transport block containing MAC CE and RLC PDUs and sends it to respective tasks.
8. CSI Manager: Configuration of “Channel State Information” and informing the CSI feedback from UE to the scheduler.
9. PHY-MAC Interface: Receive and transmit the L1-L2 interface messages.

6.1 L2 MAC Scheduler

Figure 6-2 illustrates the MAC scheduler components present in O-DU architecture. It is assumed that the DU includes complete MAC and scheduler functions implemented in the same physical platform.

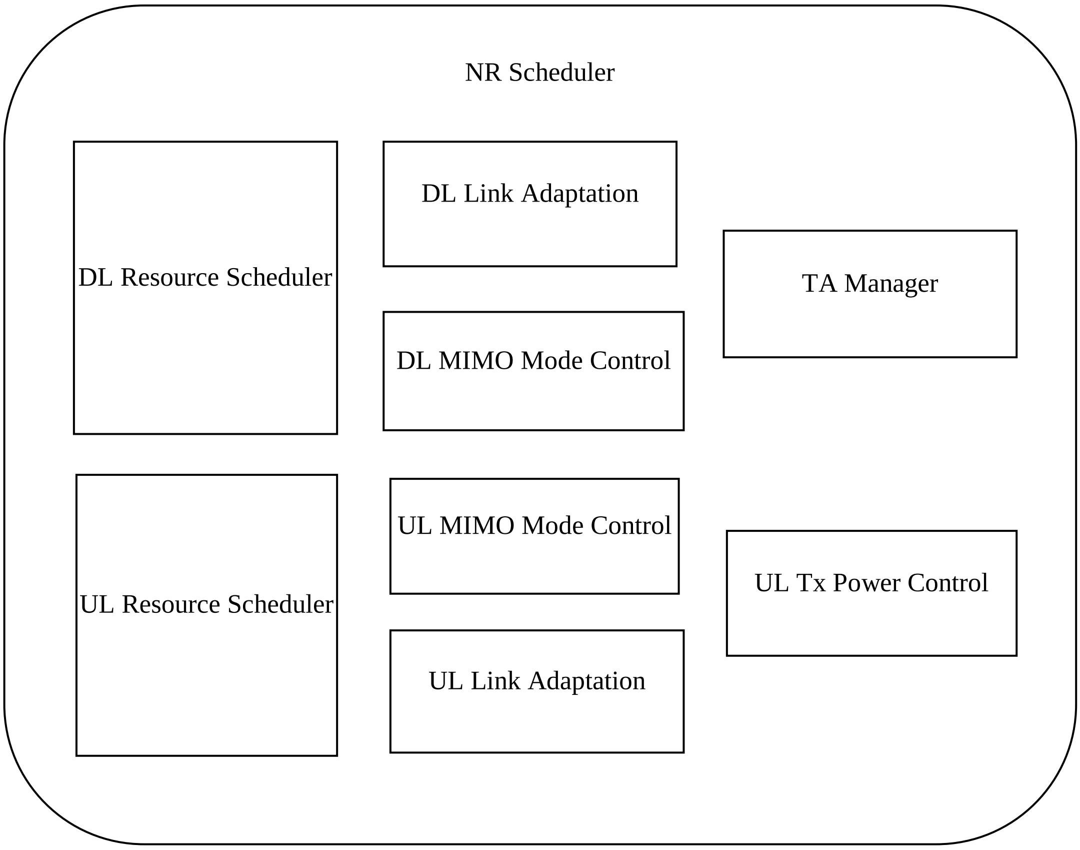

Figure 6-2 L2 MAC scheduler components

NR Scheduler functional block has been further expanded into indicative smaller functional sub-blocks to capture the scheduler functionality.

Note: An actual implementation may divide the scheduler into functional sub-blocks differently.

- DL/UL Resource Scheduler: This corresponds to functionality of time-domain and frequency domain scheduling in DL and UL, respectively. Resource scheduling is performed per scheduling period and may be performed for a single slot or multiple slots. It may include functions such as beam selection, selecting of UEs and associated bearers per scheduling period, allocation of radio resources for PDCCH, PUSCH, PDSCH and associated channels like DMRS.
- DL/UL Link Adaptation (LA): This functionality performs per UE Link Adaptation in DL and UL, respectively. Link Adaptation may be performed based on channel quality reported by UE or estimated at gNB corrected by BLER. LA would return effective MCS to be used for channel allocation to the UE.
- UL Tx Power Control: Performs Closed loop UL power control for PUSCH, SRS and PUCCH. It may estimate the UL Tx power based on UE feedback (eg: Power Headroom Report) or measured UL channels.
- DL/UL MIMO Mode Control: Determines per UE the MIMO mode, in DL and UL, respectively, to be used along with the corresponding precoding matrix.
- TA Manager: Estimating the TA Command for UE based on feedback from L1 using PUSCH, PUCCH and SRS.

Performance metrics (Capacity, throughput etc.) will be dependent on software implementation and underlying hardware.

6.2 O-DU Cloudification

To be addressed in accordance with recommendations from WG6 on O-DU cloudification.

Chapter 7 O-CU Software Architecture

O-CU node interacts with one or more O-DU nodes through F1 interface.

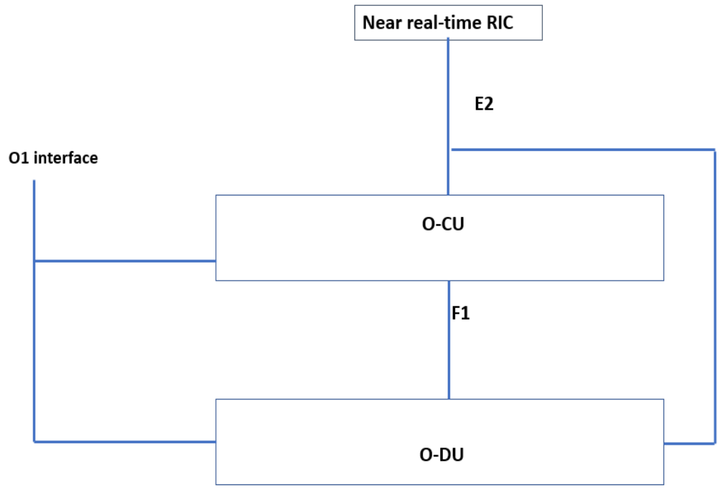

Figure 7-1 O-CU interfaces

7.1 O1 interface

To be addressed in a later release of this specification.

7.2 F1 interface

F1 interface supports control plane and user plane separation. The following describe the functions supported over F1-C and F1-U.

The main services and functions of the F1-C:

- F1 interface management function
- System Information management function
- F1 UE context management function
- RRC message transfer function
- Paging function
- Warning messages information transfer function

The main services and functions of the For F1-U:

- Transfer of user data
- Flow control function

7.3 E2 interface

To be addressed in later release of this specification.

7.4 O-CU Cloudification Aspects

To be addressed in accordance with recommendations from WG6 on O-DU cloudification.

Chapter 8 O-CU Functional Blocks

Figure 8-1 below outlines the O-CU functional blocks. An implementation may specify the modules differently.

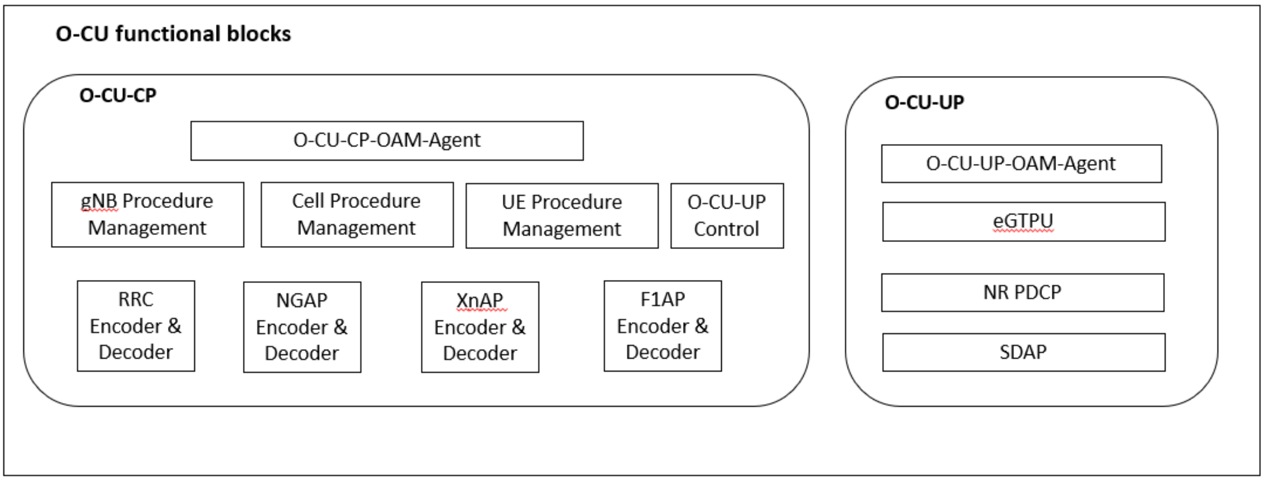

Figure 8-1 O-CU Functional Blocks

The O-CU comprises of O-CU-CP and O-CU-UP.

8.1 O-CU-CP Functional Blocks

O-CU-CP handles the control plane functionality of O-CU.

8.1.1 O-CU-CP-OAM-Agent

O-CU-CP-OAM-Agent manages following services of O-CU-CP:

- Configuration and Control Management
- Performance Counter Management
- Fault Management

O-CU-CP-OAM receives the configuration for O-CU-CP and configures all the modules of O-CU-CP. It may perform operations like spawning of O-CU-CP modules, and software downloading for O-CU-CP.

O-CU-CP-OAM collects the performance counters of O-CU-CP and reports it to performance management entity present in the network.

O-CU-CP-OAM manages the faults and alarms raised at O-CU-CP and reports it to fault management entity present in the network.

8.1.2 gNB Procedure Management

Figure 8-2 shows the detailed view of gNB Procedure Management functional block. gNB Procedure Management manages the non-UE associated NGAP and XnAP procedures like NG/Xn Interface Management and Configuration Transfer procedures as defined in 3GPP TS 38.413 [13], TS 38.423 [14] and TS 38.473 [18]. The functional sub-blocks shown in figure below are indicatively used to capture the functionality of gNB Procedure Management functional block and could be realized differently.

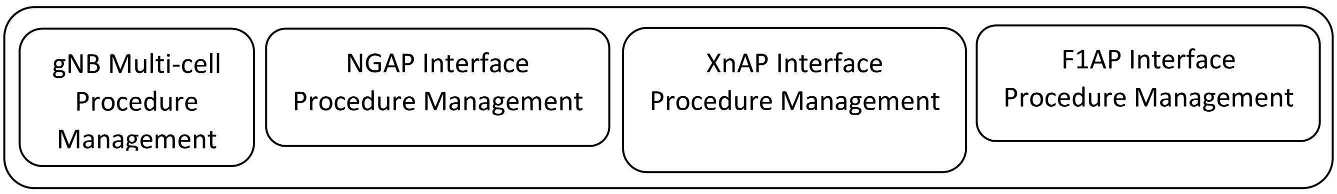

Figure 8-2 gNB Procedure Management Functional Blocks

Procedure Management: This functionality handles procedures and business logic involving application of the procedure across multiple cells of the gNB. For example, reset triggered due to NGAP link down involving coordination among multiple cells and UE specific paging as described in 3GPP TS 38.413 [12].

NGAP Interface Management: This functionality manages Interface Management procedures, Configuration Transfer procedures, and Warning Message Transmission Procedures over NGAP interface with AMFs as described in 3GPP TS 38.413 [12]. It establishes the association with AMFs. It monitors the association with AMFs. It also maintains context for each AMF with which O-CU is connected and stores information like link status with AMF.

XnAP Interface Management: This functionality manages the Global procedures over XnAP interface with peer O-CUs as described in 3GPP TS 38.423 [13]. It establishes the association with peer O-CUs and also accepts association requests from peer O-CUs based on configuration provided by higher layers. It monitors the association with peer O-CUs. It also maintains context for each peer O-CU with which O-CU is connected and stores information like link status with peer O-CU.

F1AP Interface Procedure Management: This functionality manages Interface Management procedures over F1AP interface with O-DUs as described in 3GPP TS 38.470 [16] and 38.473 [18]. It establishes the association with O-DUs and also accepts association requests from O-DUs based on configuration provided by higher layers. It monitors the association with O-DUs. It also maintains context for each O-DU with which O-CU is connected and stores information like link status with O-DU.

8.1.3 Cell Procedure Management

Cell Procedure Management manages the cell level procedures at O-CU like system information management described in 3GPP TS 38.331, procedures for dual connectivity, global procedures like Cell Activation described in 3GPP TS 38.423 [13], Warning Message Transmission procedures, and System Information Procedures described in 3GPP TS 38.473 [18].

It maintains multiple state machines to handle various cell level procedures. It may have separate state machines for various cell procedures like Cell Setup, Cell Delete, Cell Start, Cell Stop, and Cell Reconfiguration. It also maintains context of each cell to store information like cell state, number of UEs served by the cell, and cell broadcast information.

It manages the cell level performance counters and provides this information to O-CU-CP-OAM.

8.1.4 UE Procedure Management

UE Procedure Management manages the UE Access Control and signalling procedures at O-CU by binding together UE associated RRC, NGAP, XnAP, and F1AP signalling transactions into end-to-end procedures.

This functionality binds together the following signalling procedures on different 3GPP interfaces:

- 3GPP TS 38.331 defined procedures like RRC Connection Control, Inter-RAT mobility, Measurements, UE capabilities and other UE associated procedures.
- 3GPP TS 38.413 [12] defined procedures like UE Context Management procedures, UE Mobility Management procedures, PDU Session Management procedures, Transport of NAS Messages procedures, Trace Procedures, Location Reporting procedures, UE Radio Capability Management procedures, and Data Usage Reporting Procedures.
- 3GPP TS 38.423 [13] defined inter-gNB procedures for Basic mobility and for gNB-gNB Dual Connectivity.
- 3GPP TS 38.473 [18] defined procedures like UE Context Management procedures, and RRC Message Transfer procedures.

This functionality maintains multiple state machines to handle various UE associated procedures. It may have separate state machines for different UE procedures like UE attach, UE handover, UE context modification, and UE measurement. The single FSM handles NGAP and RRC messages involved in a UE associated procedure, coordinating among AMF, UE, O-DU and other modules of O-CU. It also maintains context of each UE to store information like UE state, various UE AP Ids, and ongoing procedure related information.

8.1.5 RRC Encoder & Decoder

RRC Encoder & Decoder encodes and decodes all RRC ASN content as described in 3GPP TS 38.331. RRC ASN encoding is performed for sending message to UE and for preparing containers to be exchanged during handover, etc. RRC ASN decoding is performed on receiving messages from UE and on receiving containers exchanged during handover, etc. RRC Encoder & Decoder is accessed by Cell Procedure Management and UE Procedure Management functional blocks. Cell Procedure Management accesses it for RRC ASN encoding of broadcast messages and paging message. UE Procedure Management accesses it for encoding and decoding of all the messages exchanged with UE and for populating the RRC ASN content in handover containers.

8.1.6 NGAP Encoder & Decoder

NGAP Encoder & Decoder encodes and decodes all NGAP ASN message as described in 3GPP TS 38.413 [12]. NGAP ASN encoding is be performed for sending message to AMF. NGAP ASN decoding is performed on receiving messages from AMF. NGAP Encoder & Decoder is accessed by gNB Procedure Management and UE Procedure Management functional blocks. gNB Procedure Management accesses it for non-UE associated procedures between O-CU and AMF. UE Procedure Management accesses it for encoding and decoding of all the UE associated messages exchanged with AMF.

8.1.7 XnAP Encoder & Decoder

XnAP Encoder & Decoder encodes and decodes all XnAP ASN message as described in 3GPP TS 38.423 [13]. XnAP ASN encoding is performed for sending message to peer O-CU. XnAP ASN decoding is performed on receiving messages from peer O-CU. XnAP Encoder & Decoder is accessed by gNB Procedure Management and UE Procedure Management functional blocks. gNB Procedure Management accesses to perform non-UE associated procedures with peer O-CU. UE Procedure Management accesses it for encoding and decoding of all the UE associated messages exchanged with peer O-CU.

8.1.8 F1AP Encoder & Decoder

F1AP Encoder & Decoder encodes and decodes all F1AP ASN content at O-CU as described in 3GPP TS 38.473 [18]. F1AP ASN encoding is performed for sending message to O-DU. F1AP ASN decoding is performed on receiving messages from O-DU. F1AP Encoder & Decoder is accessed by gNB Procedure Management and UE Procedure Management functional blocks. gNB Procedure Management accesses it to perform non-UE associated procedures with O-DU. UE Procedure Management accesses it for encoding and decoding of all the UE associated messages exchanged with O-DU.

8.1.9 O-CU-UP Control

O-CU-UP Control function configures and controls the CU User Plane entities as per the E1 interface defined by 3GPP. This function is invoked primarily by the UE Procedure Management functionality though the non-UE associated procedures would be invoked by the gNB and Cell Procedure Management functionality.

8.2 O-CU-UP Functional Blocks

O-CU-UP handles the user plane functionality at O-CU.

8.2.1 O-CU-UP-OAM-Agent

O-CU-UP-OAM-Agent manages following services of O-CU-UP:

- Configuration and Control Management
- Performance Counter Management
- Fault Management

O-CU-UP-OAM receives the configuration for O-CU-UP and configures all the modules of O-CU-UP. It may perform operations like spawning of O-CU-UP modules and software downloading for O-CU-UP.

O-CU-UP-OAM collects the performance counters of O-CU-UP and reports it to performance management entity present in the network.

O-CU-UP-OAM manages the faults and alarms raised at O-CU-UP and reports it to fault management entity present in the network.

8.2.2 eGTPu

Figure 8-3 shows the detailed view of eGTPu functional block.

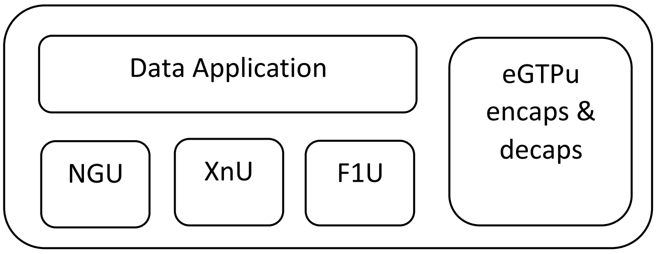

Figure 8-3 eGTPu Functional Blocks

eGTPu encaps & decaps: It handles the eGTPu protocol stack. It performs eGTPu encapsulation and decapsulation as described in 3GPP TS 29.281 [2] and TS 38.425 [15].

Data Application: This function receives the data packet from UPF, peer O-CU and O-DU over eGTPu interface. It calls eGTPu encaps & decaps to remove the eGTPu header. It identifies the corresponding UE and DRB Id based on mapping of TEID and IP address maintained at eGTPu. It then forwards the data packet to SDAP, which maps the PDU Session to appropriate DRB and passes data to NR PDCP along with information of UE and DRB Id. While sending packet to NR PDCP, it also indicates from which interface this packet has been received, i.e., from UPF or from peer O-CU or from O-DU.

Data Application also processes the data packets received from SDAP. On receiving data packet, it adds the eGTPu header by calling eGTPu encaps & decaps. On the basis of destination, UE and DRB Id received from NR PDCP, packet relay fetches the TEID and IP address from the mapping maintained at eGTPu and sends the data packet to the destination provided by NR PDCP.

NGU: It exchanges ECHO request and response over NGU interface. It takes care of the error handling on NGU interface.

XnU: It exchanges ECHO request and response over XnU interface. It takes care of the error handling on XnU interface. It also takes care of data flow control on XnU interface.

F1U: It exchanges ECHO request and response over F1U interface defined in [19]. It takes care of the error handling on F1U interface. It also takes care of data flow control on F1U interface.

8.2.3 NR PDCP

NR PDCP transfers user plane and control plane data. It maintains PDCP SNs of 12 bits or 18 bits for DRBs and 12 bits for SRBs. It performs header compression and decompression, integrity protection and verification, ciphering and deciphering, timer based SDU discard, routing for split bearers, duplication, reordering and in-order delivery, out of order delivery, and duplicate discarding as described in 3GPP TS 38.323 [9].

8.2.4 SDAP

It performs QoS flow to DRB mapping and implements the procedure described in 3GPP TS 37.324 [10]. In case of a DRB where SDAP header to/from UE is not configured, SDAP entity may not be present.

Chapter 9 O-DU Interfaces

9.1 L1/L2 Interface

NR FAPI being standardized by Small Cells Forum (SCF) will be used for defining L1 and L2 interactions. Plan is to first use FAPI interface from SCF as reference and later add NFAPI reference when it becomes available.

Small Cell Forum 5G FAPI includes the following interfaces:

- P5: –PHY configuration interface
- P7: –Main data path interface
- P19: RF control interface

O-RAN based implementation of O-DU will use an adaptation module at Frontend to handle P19 interface.

9.2 L2 Interfaces

9.2.1 RLC-MAC Interface

The following table details the interactions between RLC and MAC for data transfer and reporting operations.

Table 9-1 RLC-MAC Interface

Direction	Message/API	Description
RLC to MAC	Data transfer (DL)	API to transfer downlink data
MAC to RLC	Data transfer (UL)	API to transfer uplink data
MAC to RLC	Schedule result reporting (DL)	DL schedule result Reporting to RLC
RLC to MAC	Buffer status reporting (DL)	DL data volume in the RLC entity

Note:
DL:

1. RLC -> MAC: the Buffer status in RLC
2. MAC -> RLC: the schedule result Reporting to RLC, then RLC decide how to implement the RLC segment.
3. RLC->MAC: DL data

UL:

1. MAC-> RLC: UL data

The detailed description of the above messages is below:

Table 9-2 RLC-MAC Data transfer (DL) message contents

Element	Description
Frame Number	Air interface time
Slot Number	Air interface time
Cell index	Identification of the Cell
UE index	Identification of the UE
Number of RLC PDU	Number of RLC PDU to be send
RLC PDU info(LCID,PDU LEN,RLC PDU)	LCID and length for the RLC PDU, RLC PDU data

Table 9-3 RLC-MAC Data transfer (UL) message contents

Element	Description
Frame Number	Air interface time
Slot Number	Air interface time
Cell index	Identification of the Cell
UE index	Identification of the UE
Number of RLC PDU number	Number of RLC PDU receive from MAC
RLC PDU info (RB id, PDU LEN, RLC PDU)	LCID and length for the RLC PDU, RLC PDU data

Table 9-4 RLC-MAC Schedule result reporting (DL) message contents

Element	Description
Frame Number	Air interface time
Slot Number	Air interface time
Cell index	Identification of the Cell
UE index	Identification of the UE
Number of RB	Number of RBs to send
RLC PDU info (RB id, overall length for each RB)	RB id and length overall length for each RB

Table 9-5 RLC-MAC Buffer Status reporting (DL) message contents

Element	Description
Cell index	Identification of the Cell
UE index	Identification of the UE
Number of RLC PDU	Number of RLC PDU in RLC buffer
RLC PDU info(RB id, PDU LEN)	LCID and length for each RLC PDU

9.2.2 MAC – Scheduler Interface

5GNR MAC and scheduler modules interact via well-defined APIs. The APIs ensure any scheduler implementation interworks with MAC. This ensures the freedom of choice for OEMs and operators to plug in a scheduler implementation of choice from a third-party vendor in O-DU.

The functionalities of scheduler module are restricted to optimal allocation of radio resources at every TTI while catering to the need of gNB for transmission of:

- UE specific UL/DL data and signalling messages and
- broadcast messages

To achieve the above objective, the APIs defined below abstract the scheduler of any protocol specific operations like handling payloads. The interfaces shown below and the APIs may evolve/change further in future releases of this document to achieve a more optimized scheduler implementation.

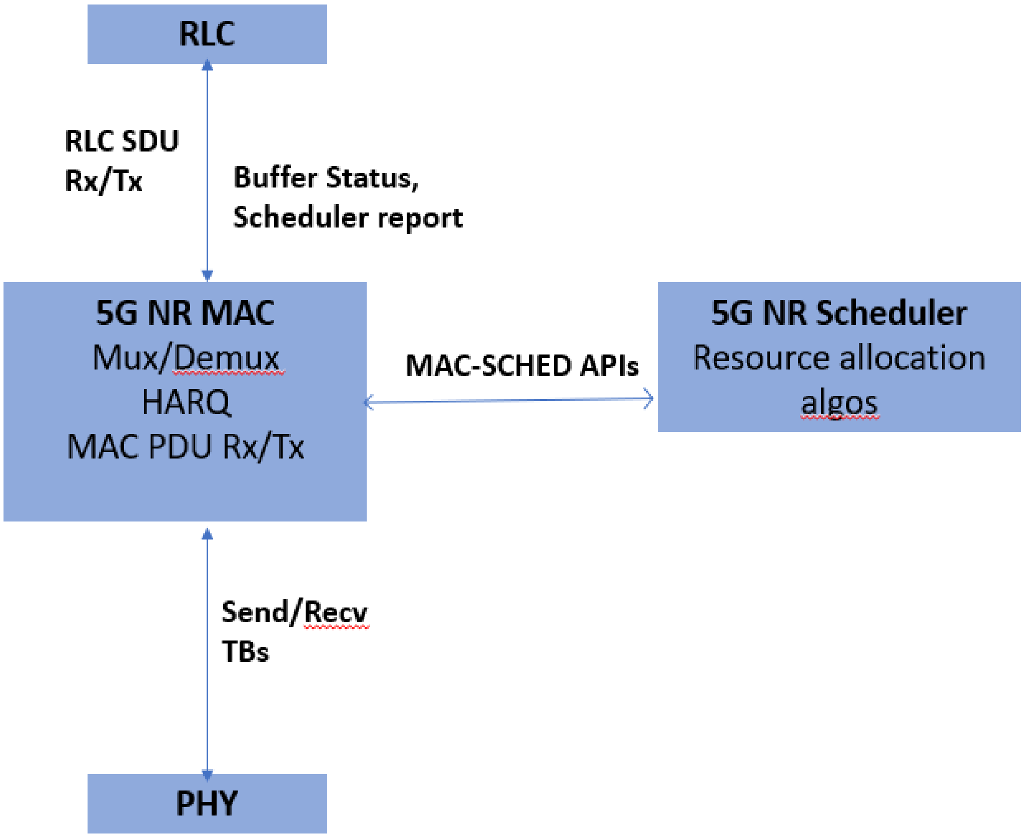

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Figure 9-1 MAC-Scheduler interface

The following tables detail the interactions between MAC and scheduler both for configuration and data transfer operations.

Table 9-6 MAC to Scheduler APIs

Direction	Message/API	Description
MAC to SCH	Cell configuration	MAC provides SCH the cell configuration
MAC to SCH	UE configuration	MAC provides SCH the configuration/capabilities of a UE
MAC to SCH	Radio bearer configuration	MAC provides SCH the configuration of a radio bearer
MAC to SCH	DL HARQ Indication	Contains the list of UEs for which DL HARQ ACK / NACK received from UE in a given TTI. **Note**: It is responsibility of the SCH to associate the DL HARQ ACK/NACKs received in a TTI to the corresponding HARQ process Ids.
MAC to SCH	UL HARQ Indication	Contains the list of UEs for which UL Data on PUSCH was received. Per UE, indication of CRC check success or failure is sent by MAC to SCH based on CRC Indication received from L1. **Note**: It is responsibility of the SCH to associate the UL HARQ Indication received in a TTI to the corresponding HARQ process Ids.
MAC to SCH	Uplink channel condition information	MAC provides SCH channel condition (including RI, PMI, CQI) information for UEs for scheduling UL
MAC to SCH	Downlink channel condition information	MAC provides SCH channel condition (including RI, PMI, CQI) information for UEs for scheduling DL
MAC to SCH	RACH Indication Contents	MAC receives the RACH Indication and share the contents with SCH

MAC to SCH	Paging Indication Contents	MAC indicates Paging message (F1AP Paging) contents to scheduler
MAC to SCH	RACH Resource Request	This API is used to get CRNTI, preamble information from MAC for Contention Free Random Access
MAC to SCH	RACH Resource Release	This API is used to release the Contention Free RACH Resources at MAC
MAC to SCH	RLC Buffer Status Info	DL data volume in the RLC entity
MAC to SCH	Scheduling request indication	MAC provides SCH scheduling request information for UL
MAC to SCH	Buffer status report indication	MAC provides SCH buffer status report for UL scheduling
MAC to SCH	Power headroom indication	MAC provides SCH power headroom for UL scheduling

Table 9-7 Scheduler to MAC APIs

Direction	Message/API	Description
SCH to MAC	Scheduled Bytes in DL	SCH provides scheduling information for a given TTI for scheduling DL data. The scheduling information provides time and frequency domain resources to be scheduled with a list Logical Channels (LC) and transport block size opportunity per LC.
SCH to MAC	Scheduled Bytes in UL	SCH provides scheduling information for a given TTI for scheduling UL data. The scheduling information provides time and frequency domain resources to be scheduled based on the LC Group (LCG) buffer status or Scheduling Request from UE.
SCH to MAC	RAR Information	SCH shares the RAR and uplink scheduling and Msg3 scheduling information with MAC
SCH to MAC	Downlink control channel information	SCH provides to MAC information for DCI scheduling on PDCCH

9.2.3 F1AP handler – MAC Interface

The following section captures the interface APIs between F1AP handler and MAC:

Table 9-8 F1AP handler –MAC Cell Specific API

Note: Cell State Manager in the F1AP module interfacing with MAC

Direction	Message/API	Description
F1AP handler to MAC	Cell Start	This API is used to start the Cell at MAC, i.e., to start broadcasting the system information. MAC starts the cell at L1 before sending the confirmation to the F1AP handler.
F1AP handler to MAC	Cell Stop	This API is used to stop the broadcast at MAC, i.e., to stop broadcasting the system information. MAC stops the cell at L1 before sending the confirmation to the F1AP handler. MAC may also delete the cell configuration at SCH in which case it needs to configure the SCH with stored cell configuration before the start of the cell.

Table 9-9 F1AP handler - MAC UE Specific APIs

Note: UE State Manager in the F1AP module interfacing with MAC

Direction	Message/API	Description
F1AP handler to MAC	UE Create Request	This API adds the UE information, such as, BWP, channel information, etc, at MAC.
F1AP handler to MAC	UE Reconfiguration	This API is used to reconfigure the UE information, such as, BWP, channel information, etc, at MAC. MAC returns an error if the UE has not been already added at MAC.
F1AP handler to MAC	UE Delete	This API is used to delete the dedicated UE information at MAC
F1AP handler to MAC	RACH Resource Request	This API is used to get the CRNTI, preamble information from MAC for Contention Free Random Access
F1AP handler to MAC	RACH Resource Release	This API is used to release the Contention Free RACH Resources at MAC
F1AP handler to MAC	UE Reset	This API is used to reset the UE associated dynamic information (eg: HARQ processes) and release the UL Control channels (PUCCH, SRS) at MAC. MAC may use invoke the API at SCH to release the UE associated resources, as above, at the SCH.
F1AP handler to MAC	Get UE CRNTI	This API is used by F1AP to fetch the CRNTI of UE from MAC.
MAC to F1AP handler	Report CRNTI	MAC Report CRNTI to F1AP

The detailed description of the APIs is below:

Table 9-10 F1AP handler - MAC Cell Start message contents

Element	Description
Cell index	Identification of the Cell
Frame Number	Start time
Slot Number	Start time

Table 9-11 F1AP handler - MAC Cell Stop message contents

Element	Description
Cell index	Identification of the Cell
Frame Number	Stop time
Slot Number	Stop time

9.2.4 F1AP handler – RLC Interface

The following section captures the interface APIs between F1AP and RLC:

Table 9-12 F1AP handler - RLC Specific APIs

Direction	Message/API	Description
F1AP handler to RLC	UE Create	This API is used to add the UE associated RLC entity and related information (e.g.: sn field length, t reassembly timer etc.). Refer to subclause 8.3 in 3GPP TS 38.473 for details of related F1 procedure [18]. Note: One or more RLC entities of the UE may be created in the same API.
F1AP handler to RLC	UE Reconfiguration	This API is used to reconfigure the UE associated RLC entity previously added at RLC. Refer to subclause 8.3 in 3GPP TS 38.473 for details of related F1 procedure [18]. Note: One or more RLC entities of the UE may be re-configured in the same API.
F1AP handler to RLC	UE Delete Request	This API is used to delete the UE and associated RLC entities at RLC. Refer to subclause 8.3 in 3GPP TS 38.473 for details of related F1 procedure [18]. Note: One or more RLC entities of the UE may be deleted in the same API.
F1AP handler to RLC	RLC Re-establish UE Request	This API is used to re-establish all the RLC entities associated with the UE. Refer to subclause 8.3 in 3GPP TS 38.473 for details of related F1 procedure [18].

The detailed description of APIs is below.

Table 9-13 F1AP handler - RLC UE Create message contents

Element	Description
Cell index	Identification of the Cell
UE index	Identification of the UE
Frame Number	Start time
Slot Number	Start time
Number of RB	The number of RB
RB information list (Rb Id, logicalChannelIdentity,RB type, SN Bit, Timer)	See RLC-BearerConfig in TS 38.331

Table 9-14 F1AP handler - RLC UE Reconfiguration message contents

Element	Description
Cell index	Identification of the Cell
UE index	Identification of the UE
Frame Number	Start time
Slot Number	Start time

Number of RB ToAddModList	The number of RB ToAddMod
RB ToAddModList (Rb Id, logicalChannelIdentity,RB type, SN Bit, Timer)	See RLC-BearerConfig in 38.331
Number of RB ToReleaseList	The number of RB ToRelease
RB ToReleaseList (Rb Id)	The RB to Release

Table 9-15 F1AP handler - RLC UE Delete message contents

Element	**Description**
Cell index	Identification of the Cell
UE index	Identification of the UE
Frame Number	Delete time
Slot Number	Delete time

9.2.5 O1 Interface

The O1 interface is terminated by the O-DU-OAM-Agent at O-DU to handle all configurations of L1 and L2 layers.

9.2.6 Support for hierarchical DU-RU mode

To be addressed in a later release of this specification.

Chapter 10 O-CU APIs

APIs between the following layers of O-CU are described in this section.

- RRC-SDAP
- RRC-PDCP
- SDAP- PDCP

10.1 RRC-SDAP Interface

Table 10-1 RRC-SDAP APIs

Direction	**Message/API**	**Description**
RRC to SDAP	QoS flow to DRB mapping	QoS mapping when a DRB is added/modified. RRC indicates in this API if reflective QoS is used.
RRC to SDAP	DRB release	To remove all QoS flow to DRB mappings

The detailed description of RRC-SDAP APIs is below:

Table 10-2 RRC-SDAP QoS flow to DRB mapping message contents

Element	**Description**
Frame Number	Start time
Slot Number	Start time
Cell index	Identification of the Cell

UE index	Identification of the UE
Mapping list number	The number of mapping list
Mapping list(QFI, RB id)	Identification of the mapping between QFI and RB id

Table 10-3 RRC-SDAP DRB release message contents

Element	**Description**
Frame Number	Start time
Slot Number	Start time
Cell index	Identification of the Cell
UE index	Identification of the UE
DRB id	Identification of the Released DRB

10.2 SDAP-PDCP Interface

Table 10-4 SDAP-PDCP Interface

Direction	**Message/API**	**Description**
SDAP to PDCP	Transfer data PDU (DL)	Transfer of SDAP PDU (with or without SDAP header) in downlink direction
PDCP to SDAP	Transfer data PDU (UL)	Transfer of SDAP PDU (with or without SDAP header) in uplink direction
SDAP to PDCP	End-marker control PDU (DL)	Control PDU (only SDAP header) to indicate end of mapping of QoS flow

The detailed description of SDAP-PDCP APIs is below:

Table 10-5 SDAP-PDCP Transfer Data PDU (DL) message contents

Element	**Description**
Frame Number	Start time
Slot Number	Start time
Cell index	Identification of the Cell
SDAP PDU number	PDU number
SDAP PDU info (UE index, DRB id, PDU length, PDU data)	Identification of the UE, PDU length and SDAP PDU data

Table 10-6 SDAP-PDCP Transfer Data PDU (UL) message contents

Element	**Description**
Frame Number	Start time
Slot Number	Start time
Cell index	Identification of the Cell

SDAP PDU number	PDU number
SDAP PDU info (UE index, DRB id, PDU length, PDU data)	Identification of the UE, PDU length and SDAP PDU data

Table 10-7 SDAP-PDCP End-marker control PDU (UL) message contents

Element	**Description**
Frame Number	Start time
Slot Number	Start time
Cell index	Identification of the Cell
UE index	Identification of the UE
DRB id	Identification of the DRB
EndMarker	End of the QoS flow-DRB mapping

10.3 RRC-PDCP Interface

Table 10-8 RRC-PDCP Interface

Direction	**Message/API**	**Description**
RRC to PDCP	PDCP entity establishment	To establish a PDCP entity for radio bearers
RRC to PDCP	PDCP entity re-establishment	To re-establish PDCP entity
RRC to PDCP	PDCP entity release	To release PDCP entity
RRC to PDCP	SRB Data Request	To Deliver SRB(s) Data from RRC to PDCP (DL)
PDCP to RRC	SRB Data Indication	To Deliver SRB(s) Data from PDCH to RRC (UL)

The detailed description of RRC-PDCP APIs is below:

Table 10-9 RRC-PDCP PDCP entity establishment

Element	**Description**
Cell index	Identification of the Cell
UE index	Identification of the UE
Frame Number	Start time
Slot Number	Start time
RB number	The number of RB
RB information list (Rb Id, logicalChannelIdentity, RB type, discardTimer, t-Reordering, SN Bit, headerCompression, securityConfig)	See *RadioBearerConfig*, PDCP-Config in 38.331

Table 10-10 RRC-PDCP PDCP entity release

Element	Description
Cell index	Identification of the Cell
UE index	Identification of the UE
Frame Number	Start time
Slot Number	Start time

Table 10-11 RRC-PDCP SRB Data Request

Element	Description
Cell index	Identification of the Cell
UE index	Identification of the UE
Frame Number	Start time
Slot Number	Start time
SRB PDU Number	The number of RB
SRB PDU info(SRB id, data length, SRB PDU data)	

Table 10-12 RRC-PDCP SRB Data Indication

Element	Description
Cell index	Identification of the Cell
UE index	Identification of the UE
Frame Number	Start time
Slot Number	Start time
SRB PDU Number	The number of RB
SRB PDU info(SRB id, data length, SRB PDU data)	

10.4 Ciphering & Integrity Protection

Support for software implementation and hardware acceleration. This will be addressed in a later release of this specification.

10.5 Header Compression

Support for software implementation and hardware acceleration. This This will be addressed in a later release of this specification.

Annex A (Informative)

A.1 L1 APIs

Table A-1 Uplink Module APIs

API	Description
FFT	Perform the FFT operation
Layer demapping	Layer De-mapping for 5GNR providing support for a single code word. The algorithm is defined in section 7.3.1.3 in TS38.211 [4]
Channel estimation	Performance channel estimation based on the DMRS symbols
MIMO equalizer	5G NR MIMO equalization algorithm
Demodulation	Modulation demapper for 5GNR that conforms to section 5.1 in 3GPP TS38.211 [4]
Descrambler	Descrambling procedure as defined in TS38.211 [4], which takes a sequence of LLRs and descrambles them based on a scramble code sequence
Rate Dematching	LDPC rate dematching operation
Polar Decoder	Polar Decoder 5G NR function
LDPC Decoder	LDPC Decoder 5G NR function
CRC Check	The CRC validate function. It calculates a CRC value and then compares that value to the one at the end of the data
Beamforming	Perform the spatial combining of the data from antennas to reduce the number of radio data streams

Table A-2 Layer Demapping Parameters

Parameter Fields	Description
Layer data size	The layer data length
Number of layers	Layer count
Input Data	Layer demapping input data

Table A-3 Channel Estimation API Parameters

Parameter Fields	Description
Start PRB	PRB start position
Number of PRB	PRB counts
Start Rx Antenna	Start antenna number of contiguous antenna numbers

Number of Rx Antenna	Rx antenna count
Number of Layers	Layer count
Number of DMRS	Number of DMRS symbols per TTI
DMRS configuration type	DMRS configuration type
DMRS in slot	Slot contains the DMRS
First DMRS in Slot Position	Position in the slot of the first DMRS symbol
PUSCH symbols in TTI	Number of PUSCH symbols in the TTI
Received Data	Received DMRS Data from antennas
Reference DMRS	Reference DMRS used

Table A-4 Downlink Module APIs

API	Description
Layer mapping	Layer mapping for 5GNR providing support for a single code word. The algorithm is defined in section 7.3.1.3 in TS38.211 [4]
Demodulation	Modulation mapper for 5GNR that conforms to section 5.1 in 3GPP TS38.211 [4]
Scrambler	A.1.1 Scrambling procedure as defined in TS38.211 [4]
Rate matching	LDPC rate dematching operation
Polar Encoder	Polar Encoder 5G NR function
LDPC Encoder	LDPC Encoder 5G NR function
CRC Generation	The CRC generation function. It calculates a CRC value
Beam Forming	Performs Beamforming function based on the selected algorithm.
Precoder	Precoder combines the information from beamforming with several layers of subcarriers to create a set of antenna outputs.

A.2 Call Flows

A.2.1 F1 startup and cells activation

Figure below describes F1 interface setup and cell enabling across O-CU and O-DU as specified in subclause 8.5 of 3GPP TS 38.401 [12] when O-CU and O-DU nodes are brought up. The O-DU and its cells are configured by OAM in the pre-operational state.

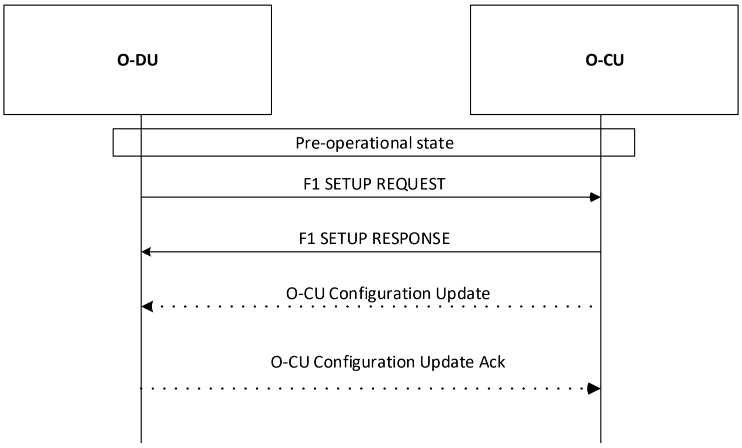

Figure A-1 F1 interface setup and cell enabling across O-CU and O-DU

A.2.2 UE Initial Access

The following diagram describes message sequence in O-CU and O-DU during UE initial access.

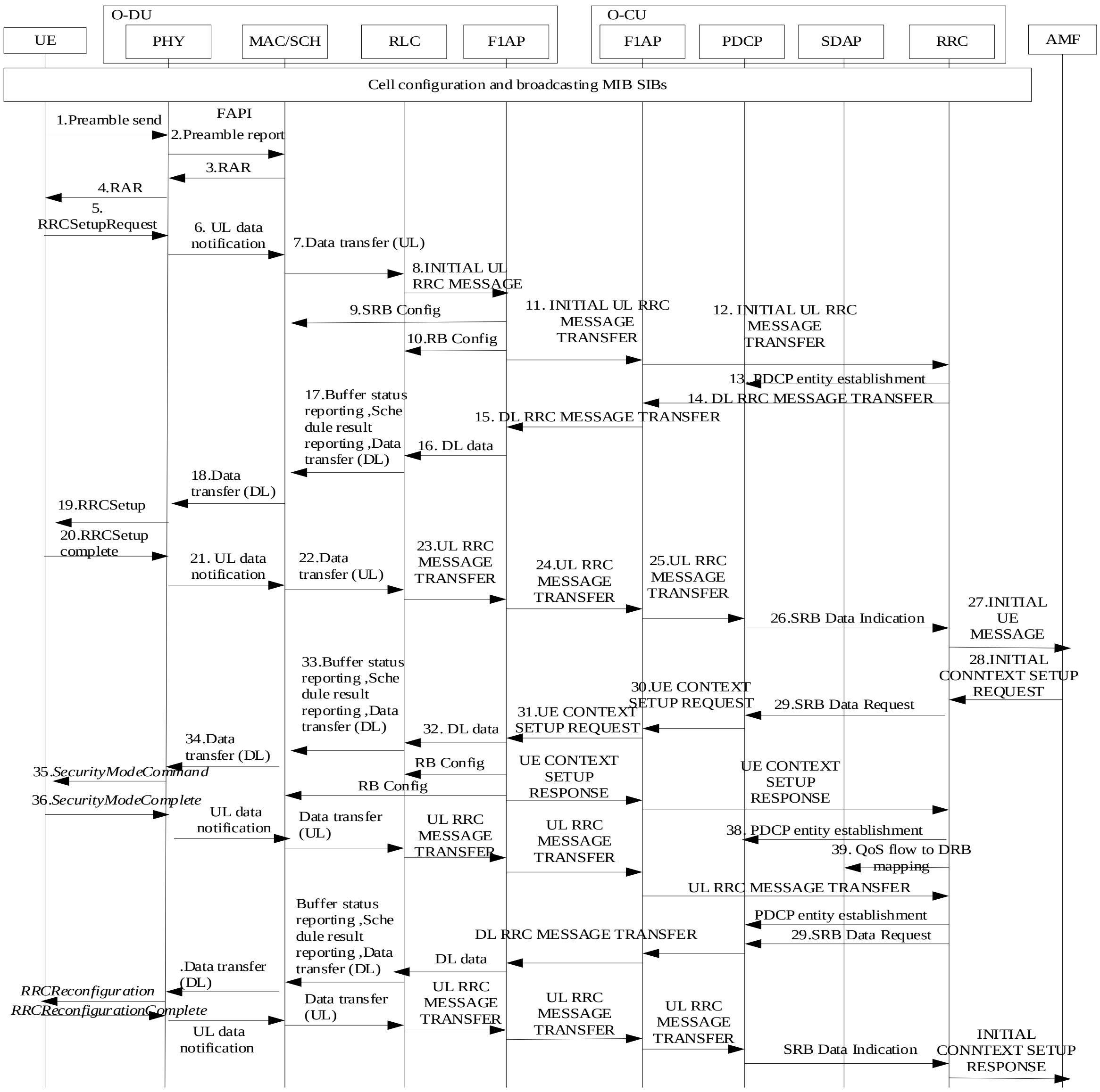

Figure A-2 Message sequence for UE initial Access

Annex ZZZ : O-RAN Adopter License Agreement

BY DOWNLOADING, USING OR OTHERWISE ACCESSING ANY O-RAN SPECIFICATION, ADOPTER AGREES TO THE TERMS OF THIS AGREEMENT.

This O-RAN Adopter License Agreement (the "Agreement") is made by and between the O-RAN Alliance and the entity that downloads, uses or otherwise accesses any O-RAN Specification, including its Affiliates (the "Adopter").

This is a license agreement for entities who wish to adopt any O-RAN Specification.

Section 1: DEFINITIONS

1.1 "Affiliate" means an entity that directly or indirectly controls, is controlled by, or is under common control with another entity, so long as such control exists. For the purpose of this Section, "Control" means beneficial ownership of fifty (50%) percent or more of the voting stock or equity in an entity.

1.2 "Compliant Implementation" means any system, device, method or operation (whether implemented in hardware, software or combinations thereof) that fully conforms to a Final Specification.

1.3 "Adopter(s)" means all entities, who are not Members, Contributors or Academic Contributors, including their Affiliates, who wish to download, use or otherwise access O-RAN Specifications.

1.4 "Minor Update" means an update or revision to an O-RAN Specification published by O-RAN Alliance that does not add any significant new features or functionality and remains interoperable with the prior version of an O-RAN Specification. The term "O-RAN Specifications" includes Minor Updates.

1.5 "Necessary Claims" means those claims of all present and future patents and patent applications, other than design patents and design registrations, throughout the world, which (i) are owned or otherwise licensable by a Member, Contributor or Academic Contributor during the term of its Member, Contributor or Academic Contributorship; (ii) such Member, Contributor or Academic Contributor has the right to grant a license without the payment of consideration to a third party; and (iii) are necessarily infringed by a Compliant Implementation (without considering any Contributions not included in the Final Specification). A claim is necessarily infringed only when it is not possible on technical (but not commercial) grounds, taking into account normal technical practice and the state of the art generally available at the date any Final Specification was published by the O-RAN Alliance or the date the patent claim first came into existence, whichever last occurred, to make, sell, lease, otherwise dispose of, repair, use or operate a Compliant Implementation without infringing that claim. For the avoidance of doubt in exceptional cases where a Final Specification can only be implemented by technical solutions, all of which infringe patent claims, all such patent claims shall be considered Necessary Claims.

1.6 "Defensive Suspension" means for the purposes of any license grant pursuant to Section 3, Member, Contributor, Academic Contributor, Adopter, or any of their Affiliates, may have the discretion to include in their license a term allowing the licensor to suspend the license against a licensee who brings a patent infringement suit against the licensing Member, Contributor, Academic Contributor, Adopter, or any of their Affiliates.

Section 2: COPYRIGHT LICENSE

2.1 Subject to the terms and conditions of this Agreement, O-RAN Alliance hereby grants to Adopter a nonexclusive, nontransferable, irrevocable, non-sublicensable, worldwide copyright license to obtain, use and modify O-RAN Specifications, but not to further distribute such O-RAN Specification in any modified or unmodified way, solely in furtherance of implementations of an ORAN Specification.

2.2 Adopter shall not use O-RAN Specifications except as expressly set forth in this Agreement or in a separate written agreement with O-RAN Alliance.

Section 3: FRAND LICENSE

3.1 Members, Contributors and Academic Contributors and their Affiliates are prepared to grant based on a separate Patent License Agreement to each Adopter under Fair Reasonable And Non- Discriminatory (FRAND) terms and conditions with or without compensation (royalties) a nonexclusive, non-transferable, irrevocable (but subject to Defensive Suspension), non-sublicensable, worldwide patent license under their Necessary Claims to make, have made, use, import, offer to sell, lease, sell and otherwise distribute Compliant Implementations; provided, however, that such license shall not extend: (a) to any part or function of a product in which a Compliant Implementation is incorporated that is not itself part of the Compliant Implementation; or (b) to any Adopter if that Adopter is not making a reciprocal grant to Members, Contributors and Academic Contributors, as set forth in Section 3.3. For the avoidance of doubt, the foregoing licensing commitment includes the distribution by the Adopter's distributors and the use by the Adopter's customers of such licensed Compliant Implementations.

3.2 Notwithstanding the above, if any Member, Contributor or Academic Contributor, Adopter or their Affiliates has reserved the right to charge a FRAND royalty or other fee for its license of Necessary Claims to Adopter, then Adopter is entitled to charge a FRAND royalty or other fee to such Member, Contributor or Academic Contributor, Adopter and its Affiliates for its license of Necessary Claims to its licensees.

3.3 Adopter, on behalf of itself and its Affiliates, shall be prepared to grant based on a separate Patent License Agreement to each Members, Contributors, Academic Contributors, Adopters and their Affiliates under Fair Reasonable And Non-Discriminatory (FRAND) terms and conditions with or without compensation (royalties) a nonexclusive, non-transferable, irrevocable (but subject to Defensive Suspension), non-sublicensable, worldwide patent license under their Necessary Claims to make, have made, use, import, offer to sell, lease, sell and otherwise distribute Compliant Implementations; provided, however, that such license will not extend: (a) to any part or function of a product in which a Compliant Implementation is incorporated that is not itself part of the Compliant Implementation; or (b) to any Members, Contributors, Academic Contributors, Adopters and their Affiliates that is not making a reciprocal grant to Adopter, as set forth in Section 3.1. For the avoidance of doubt, the foregoing licensing commitment includes the distribution by the Members', Contributors', Academic Contributors', Adopters' and their Affiliates' distributors and the use by the Members', Contributors', Academic Contributors', Adopters' and their Affiliates' customers of such licensed Compliant Implementations.

Section 4: TERM AND TERMINATION

4.1 This Agreement shall remain in force, unless early terminated according to this Section 4.

4.2 O-RAN Alliance on behalf of its Members, Contributors and Academic Contributors may terminate this Agreement if Adopter materially breaches this Agreement and does not cure or is not capable of curing such breach within thirty (30) days after being given notice specifying the breach.

4.3 Sections 1, 3, 5 - 11 of this Agreement shall survive any termination of this Agreement. Under surviving Section 3, after termination of this Agreement, Adopter will continue to grant licenses (a) to entities who become Adopters after the date of termination; and (b) for future versions of ORAN Specifications that are backwards compatible with the version that was current as of the date of termination.

Section 5: CONFIDENTIALITY

Adopter will use the same care and discretion to avoid disclosure, publication, and dissemination of O-RAN Specifications to third parties, as Adopter employs with its own confidential information, but no less than reasonable care. Any disclosure by Adopter to its Affiliates, contractors and consultants should be subject to an obligation of confidentiality at least as restrictive as those contained in this Section. The foregoing obligation shall not apply to any information which is: (1) rightfully known by Adopter without any limitation on use or disclosure prior to disclosure; (2) publicly available through no fault of Adopter; (3) rightfully received without a duty of confidentiality; (4) disclosed by O-RAN Alliance or a Member, Contributor or Academic Contributor to a third party without a duty of confidentiality on such third party; (5) independently developed by Adopter; (6) disclosed pursuant to the order of a court or other authorized governmental body, or as required by law, provided that Adopter provides reasonable prior written notice to O-RAN Alliance, and cooperates with O-RAN Alliance and/or the applicable Member, Contributor or Academic Contributor to have the opportunity to oppose any such order; or (7) disclosed by Adopter with O-RAN Alliance's prior written approval.

Section 6: INDEMNIFICATION

Adopter shall indemnify, defend, and hold harmless the O-RAN Alliance, its Members, Contributors or Academic Contributors, and their employees, and agents and their respective successors, heirs and assigns (the "Indemnitees"), against any liability, damage, loss, or expense (including reasonable attorneys' fees and expenses) incurred by or imposed upon any of the Indemnitees in connection with any claims, suits, investigations, actions, demands or judgments arising out of Adopter's use of the licensed O-RAN Specifications or Adopter's commercialization of products that comply with O-RAN Specifications.

Section 7: LIMITATIONS ON LIABILITY; NO WARRANTY

EXCEPT FOR BREACH OF CONFIDENTIALITY, ADOPTER'S BREACH OF SECTION 3, AND ADOPTER'S INDEMNIFICATION OBLIGATIONS, IN NO EVENT SHALL ANY PARTY BE LIABLE TO ANY OTHER PARTY OR THIRD PARTY FOR ANY INDIRECT, SPECIAL, INCIDENTAL, PUNITIVE OR CONSEQUENTIAL DAMAGES RESULTING FROM ITS PERFORMANCE OR NON-PERFORMANCE UNDER THIS AGREEMENT, IN EACH CASE WHETHER UNDER CONTRACT, TORT, WARRANTY, OR OTHERWISE, AND WHETHER OR NOT SUCH PARTY HAD ADVANCE NOTICE OF THE POSSIBILITY OF SUCH DAMAGES. O-RAN SPECIFICATIONS ARE PROVIDED "AS IS" WITH NO WARRANTIES OR CONDITIONS WHATSOEVER, WHETHER EXPRESS, IMPLIED, STATUTORY, OR OTHERWISE. THE O-RAN ALLIANCE AND THE MEMBERS, CONTRIBUTORS OR ACADEMIC CONTRIBUTORS EXPRESSLY DISCLAIM ANY WARRANTY OR CONDITION OF MERCHANTABILITY, SECURITY, SATISFACTORY QUALITY, NONINFRINGEMENT, FITNESS FOR ANY PARTICULAR PURPOSE, ERROR-FREE OPERATION, OR ANY WARRANTY OR CONDITION FOR O-RAN SPECIFICATIONS.

Section 8: ASSIGNMENT

Adopter may not assign the Agreement or any of its rights or obligations under this Agreement or make any grants or other sublicenses to this Agreement, except as expressly authorized hereunder, without having first received the prior, written consent of the O-RAN Alliance, which consent may be withheld in O-RAN Alliance's sole discretion. O-RAN Alliance may freely assign this Agreement.

Section 9: THIRD-PARTY BENEFICIARY RIGHTS

Adopter acknowledges and agrees that Members, Contributors and Academic Contributors (including future Members, Contributors and Academic Contributors) are entitled to rights as a third-party beneficiary under this Agreement, including as licensees under Section 3.

Section 10: BINDING ON AFFILIATES

Execution of this Agreement by Adopter in its capacity as a legal entity or association constitutes that legal entity's or association's agreement that its Affiliates are likewise bound to the obligations that are applicable to Adopter hereunder and are also entitled to the benefits of the rights of Adopter hereunder.

Section 11: GENERAL

This Agreement is governed by the laws of Germany without regard to its conflict or choice of law provisions.

This Agreement constitutes the entire agreement between the parties as to its express subject matter and expressly supersedes and replaces any prior or contemporaneous agreements between the parties, whether written or oral, relating to the subject matter of this Agreement.

Adopter, on behalf of itself and its Affiliates, agrees to comply at all times with all applicable laws, rules and regulations with respect to its and its Affiliates' performance under this Agreement, including without limitation, export control and antitrust laws. Without limiting the generality of the foregoing, Adopter acknowledges that this Agreement prohibits any communication that would violate the antitrust laws.

By execution hereof, no form of any partnership, joint venture or other special relationship is created between Adopter, or O-RAN Alliance or its Members, Contributors or Academic Contributors. Except as expressly set forth in this Agreement, no party is authorized to make any commitment on behalf of Adopter, or O-RAN Alliance or its Members, Contributors or Academic Contributors.

In the event that any provision of this Agreement conflicts with governing law or if any provision is held to be null, void or otherwise ineffective or invalid by a court of competent jurisdiction, (i) such provisions will be deemed stricken from the contract, and (ii) the remaining terms, provisions, covenants and restrictions of this Agreement will remain in full force and effect.

Any failure by a party or third party beneficiary to insist upon or enforce performance by another party of any of the provisions of this Agreement or to exercise any rights or remedies under this Agreement or otherwise by law shall not be construed as a waiver or relinquishment to any extent of the other parties' or third party beneficiary's right to assert or rely upon any such provision, right or remedy in that or any other instance; rather the same shall be and remain in full force and effect.