LAB MANUAL

CORAN 5G LAB MANUAL

1. Introduction

In the rapidly evolving domain of 5G technology, the need for hands-on, practical experience in the field has become more crucial than ever. Historically, experimentation and in-depth study of cellular networks were confined to network vendors and telecommunication operators, mainly due to high costs and stringent licensing requirements. However, with the advent of more accessible **SDR** (*Software-Defined Radio*) systems and the development of open-source 3GPP protocol stacks, this landscape is changing. It is within this transformative environment that our products, specifically designed for research purposes, positions itself as a vital tool for understanding and leveraging the power of 5G technology.

Our lab manual is specifically crafted to address the needs of a diverse audience comprising students, researchers, and telecom engineers. These individuals are at the forefront of navigating through the complex world of 5G cellular networks. The manual is structured to provide a comprehensive yet practical understanding of 5G technology, making it an essential tool for both educational and professional advancement.

This manual covers several key areas, including:

- **Overview**: An overview of our 5G solutions, tailored for research applications, providing a deep dive into the practical implementation of 5G technology.
- **Dashboard**: Our user-friendly web-based platform, offers predefined and accessible 5G configurations. Its intuitive interface streamlines hands-on experimentation for diverse 5G use cases, enhancing the learning experience.
- **Practical Lab Exercises**: Step-by-step lab exercises that offer hands-on experience with various aspects of the 5G protocol stack, offering a holistic learning experience.
- **Pre-Lab Background**: The Pre-Lab section offers a concise overview of the 3GPP NR standard, essential for understanding each experiment. It includes critical references to TS (*Technical Specifications*) and essential 5G terminology, ensuring comprehensive insight into the experimental process and expected results.
- **Configuration Guidance**: Selected labs in this manual guide users on adjusting 5G settings through the Dashboard. This empowers learners to delve into more complex applications of our solution, going beyond the fundamental lab exercises.
- **Real-Time Data Analysis**: Real-time data and **KPIs** (*Key Performance Indicator*) analysis, enabling users to measure and store test results for further study and discussion.

Our approach transcends traditional methods of teaching wireless networks, which often relied heavily on theoretical models and simulations. By offering a tangible, over-the-air transmission experience with a full 5G stack, we aim to bridge the gap between academic learning and industry standards.

We thank our users for their invaluable feedback and support. Your insights inspire us to continuously enhance our offerings and develop new training materials in the ever-evolving world of 5G technology.

2. Overview

Our range of cloud-native 5G solutions (5G Core+gNB), is expertly crafted for research in telecommunications. Compliant with 3GPP standards, they facilitate comprehensive learning and experimentation in the ever-evolving field of 5G technology. These solutions provide various disaggregated deployment choices:

- ❑ **Compact 5G Kit**: A 5G-in-a-Box solution, designed for streamlined, small-scale research applications.
- ❑ **Modular 5G Kit**: Offers a comprehensive, disaggregated approach to 5G Core and RAN Stack, enabling detailed study of individual network components.
- ❑ **Flexible 5G Kit**: Features a disaggregated 5G Core and DU-CU, allows for an in-depth exploration of 5G Core functionalities alongside the DU-CU split architecture.

This Lab Manual includes a detailed exploration of the 3GPP 5G NR protocol stack, along with step-by-step practical exercises tailored for students, researchers and telecom engineers. Additionally, it introduces a cloud-based Dashboard for efficient real-time monitoring and management of 5G networks.

Our portfolio encompasses six distinct 5G solutions, each meticulously tailored to meet unique user needs. These deployment options are enhanced with additional technologies to enrich the user experience. Each deployment option is tested with different SDRs, ensuring flexibility and reliability for various research needs.

2.1 PrivateTerra5G

PrivateTerra5G offers a DU-CU split 8 architecture 5G solution (CN5G+gNB), adaptable for various network setups. Utilizing a cloud-native framework, it's engineered for deployment in diverse environments and has been reliably tested with different SDRs, ensuring stability and user satisfaction.

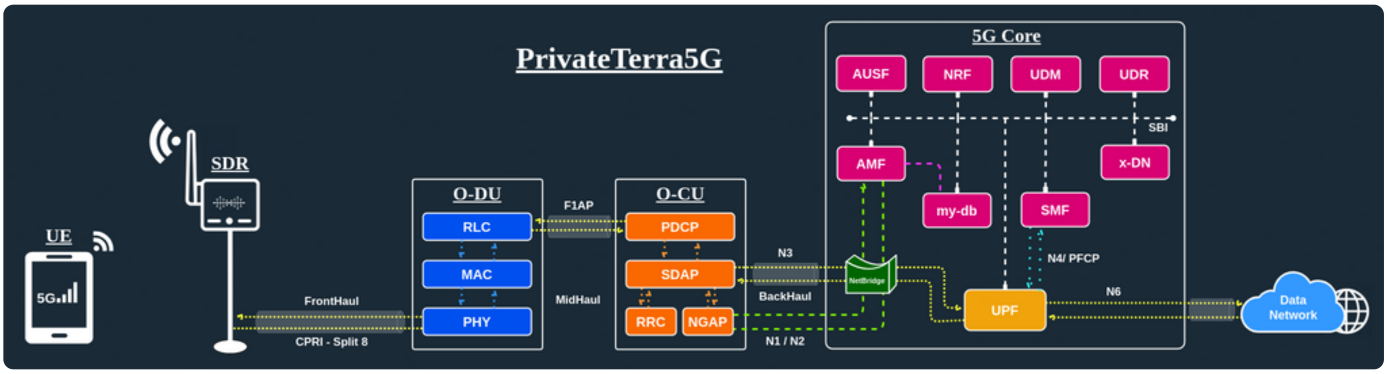

Figure 1: PrivateTerra5G 5G Solution

2.1.1 Salient Features

- Cloud-Native Architecture
- 3GPP Standards Compliance
- 5G-in-a-Box & Out-of-the-Box solution available
- Successfully tested with multiple SDR Models

- Web-based GUI for network management & monitoring
- Users can download real-time logs and PCAPs
- Integrated Testing Component for UPF Performance

2.1.2 Datasheet

Specifications	
Technology	5G NR SA
Standards	3GPP Release 16
Functional Split	Split 8
Frequency	FR1 (Sub-6GHz)
Frequency Bands	n78 (3300 - 3800 MHz)
Channel Bandwidth	100 MHz
Duplex Mode	Time Division Duplex (TDD)
Performance	
Max Throughput	400 Mbps
Max UEs	12 and more
Coverage	upto 100m (LoS) with external antennae (optional)
Hardware	
Antennae (MIMO)	1T1R, 2T2R, 4T4R (SDR tailored)
SDR	SDR B210, SDR X410, SDR N310
UEs	COTS UE, 5G UE QUECTEL RM500Q, One Plus 8T, Google Pixel 7

Table 1: PrivateTerra5G Datasheet

2.2 SDPack

SDPack is a comprehensive 5G solution (*CN5G+gNB*), characterised by its split 8 architecture, and operating in AF_PACKET mode, complemented by an optimized UPF that mirrors the capabilities of high-end software switching technologies.

2.10 SpeedTest

When conducting an online speed test for our products, be aware that your Internet connection's throughput might restrict the UE's maximum throughput. We recommend an Internet download speed of at least 1 Gbps to fully experience our products' capabilities. As an alternative, you can utilize iPerf for assessing the 5G network's maximum throughput, which is independent of your Internet speed. This ensures a reliable test of the 5G network's performance without the limitations of your existing Internet connection.

2.11 Dashboard

The CORAN Dashboard is a state-of-the-art, web-based platform engineered to streamline the configuration and monitoring of your 5G testbed. This user-friendly dashboard offers a suite of tools for real-time observation of both Core Network (CN) and Radio Access Network (RAN) metrics in 5G settings.

It features a selection of pre-configured, straightforward 5G scripts, which are easily accessible through intuitive navigation. This design ensures an efficient and practical experience for users conducting hands-on experiments with various 5G scenarios, enhancing the learning and research process in the field of 5G telecommunications.

The dashboard continuously updates to incorporate the latest features and improvements. Consequently, images in the manual may not always reflect the most current version of the dashboard interface.

2.11.1 Login Page

The CORAN Dashboard is accessible through any web browser via https://dashboard.coranlabs.com.

The signup process is streamlined, requiring just an institutional email address for registration. Once registered, users from the same institution can be automatically linked to the institution's account, with manual assignments available for different email accounts. After completing the email verification, users can gain full access to the dashboard. This process ensures a secure, user-friendly experience, enabling seamless interaction with our 5G solutions for all registered members of an institution.

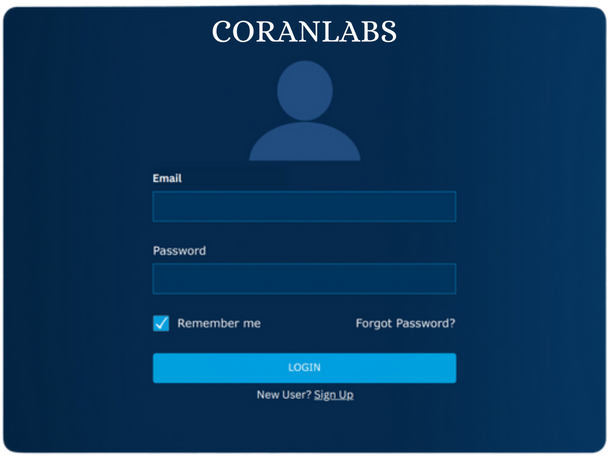

Figure 14: Dashboard Login Page

2.11.2 Home Page

The homepage of our dashboard is intuitively designed to provide a comprehensive view of your 5G network setup. It also features separate sections dedicated to the 5G Core, RAN, and UE, allowing users to monitor and configure each component individually.

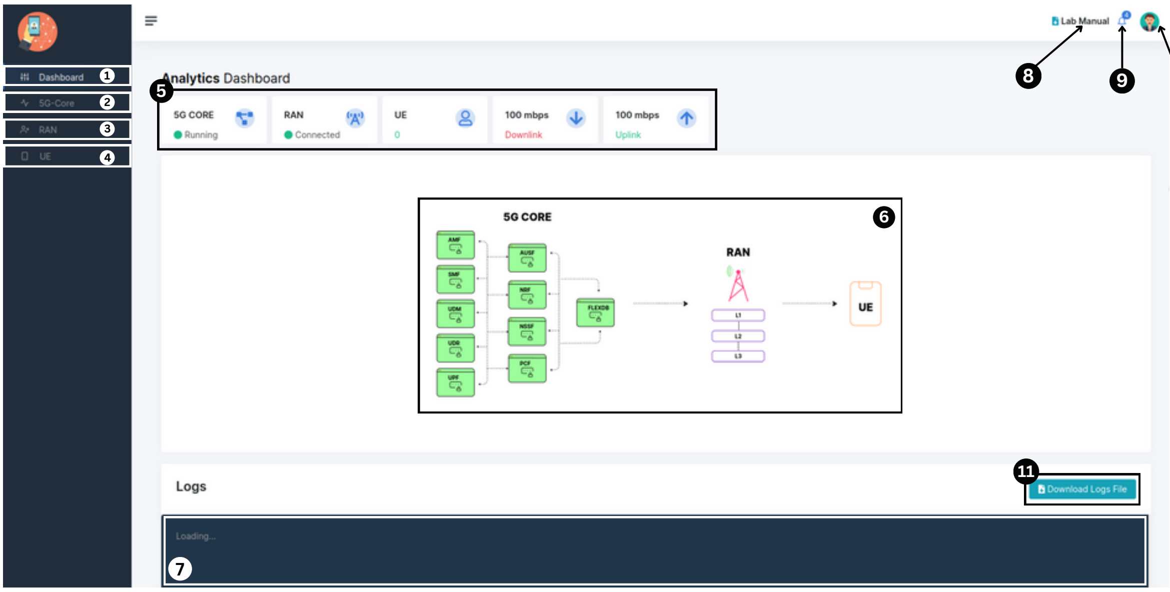

Figure 15: Dashboard Home Page

Each marked portion is explained below:

1 ➤ Displays the dashboard's main interface.

2 3 4 ➤ Direct access to individual pages for 5G Core, RAN, and UE.

5 ➤ Details the status of 5G components (Core, RAN, UE), indicating their operational state (up or down), the number of connected gNBs and UEs, and also displays current UL/DL speeds.

6 ➤ Uses color codes (green for ready or up, red for down) to visually represent the status of each 5G network element.

7 ➤ Provides access to RAN logs, facilitating the identification and troubleshooting of connection issues or errors.

8 ➤ Option to download a detailed lab manual for user guidance.

9 ➤ Area for receiving dashboard-related alerts.

10 ➤ Profile section, allows users to update personal information.

11 ➤ Enables downloading of RAN logs for analysis.

2.11.3 Section: 5G Core

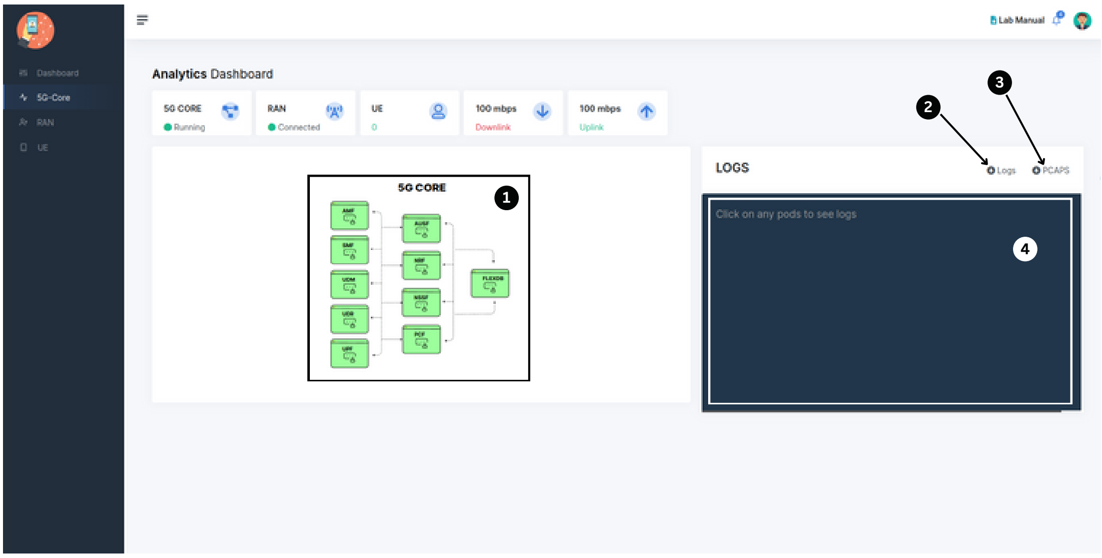

Figure 16: Dashboard 5G Core Section

Each marked portion is explained below:

1. ➤ Visual indicators display the operational status of each network function; green signifies active and healthy, while red denotes inactive.
2. ➤ Users have the option to download detailed logs for individual network functions, aiding in diagnostics and analysis.
3. ➤ Facilitates the downloading of PCAP files for each network function, providing valuable data for troubleshooting and network performance assessment.
4. ➤ A dedicated space for users to view real-time logs associated with selected network functions, enhancing monitoring and troubleshooting capabilities.

2.11.4 Section: RAN

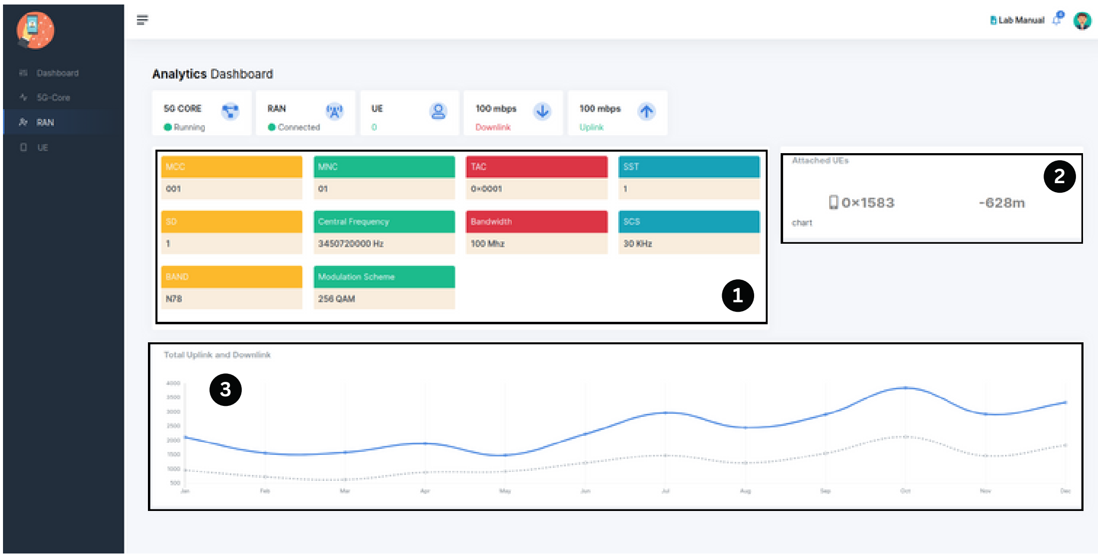

Figure 17: Dashboard 5G Core Section

Each marked portion is explained below:

1. ➤ Displays customizable settings for the gNB configuration, including Frequency Band, channel bandwidth, SCS and modulation scheme, along with their current values.
2. ➤ Shows UE-related data, with the left side indicating the RNTI and the right side showing the RSSI value for each connected device.
3. ➤ Presents a dynamic graph depicting the uplink and downlink bitrate, offering immediate insights into network performance.

2.11.5 Section: UE

The UE section highlights the number of UEs connected, showing each UE's IMSI. It features dynamic, real-time graphs displaying UE KPIs and metrics such as RSSI, RSRP, RSRQ, SINR, SNR, PHR, CQI, etc. This provides a detailed view of network performance and individual UE statuses, enabling effective monitoring and analysis.

2.12 UE Metrics and KPIs

KPIs (*Key Performance Indicators*) are crucial metrics for evaluating how effectively a network serves its users. These KPIs are integral for defining system requirements, verifying network functionality, and comparing performances across vendors or technologies. Our dashboard prominently displays these KPIs, providing users with valuable insights into network performance and aiding in efficient network management and optimization.

2.12.1 RNTI

RNTI (*Radio Network Temporary Identifier*) is a 16-bit identifier used to distinguish between connected UE in a cell, specific radio channels, groups of UEs during paging, and for power control commands issued by the gNB. It also identifies system information transmitted to all UEs by the gNB.

As per **3GPP TS 38.321**, a comprehensive list of RNTIs for New Radio (NR) is shown in **Table 7**. Additionally, **Table 8** presents the corresponding hex and decimal values assigned to each RNTI type, offering a detailed reference for their identification and usage in 5G networks.

RNTI	Usage	Transport Channel	Logical Channel
P-RNTI	Paging and System Information change notification	PCH	PCCH
SI-RNTI	Broadcast of System Information	DL-SCH	BCCH
RA-RNTI	Random Access Response	DL-SCH	N/A
Temporary C-RNTI	Contention Resolution (when no valid C-RNTI is available)	DL-SCH	CCCH
Temporary C-RNTI	Msg3 transmission	UL-SCH	CCCH, DCCH, DTCH
C-RNTI, MCS-C-RNTI	Dynamically scheduled unicast transmission	UL-SCH	DCCH, DTCH
C-RNTI	Dynamically scheduled unicast transmission	DL-SCH	CCCH, DCCH, DTCH
MCS-C-RNTI	Dynamically scheduled unicast transmission	DL-SCH	DCCH, DTCH
C-RNTI	Triggering of PDCCH ordered random access	N/A	N/A
CS-RNTI	Configured scheduled unicast transmission (activation, reactivation and retransmission)	DL-SCH, UL-SCH	DCCH, DTCH
CS-RNTI	Configured scheduled unicast transmission (deactivation)	N/A	N/A
TPC-PUCCH-RNTI	PUCCH power control	N/A	N/A
TPC-PUSCH-RNTI	PUSCH power control	N/A	N/A
TPC-SRS-RNTI	SRS trigger and power control	N/A	N/A
INT-RNTI	Indication pre-emption in DL	N/A	N/A
SFI-RNTI	Slot Format Indication on the given cell	N/A	N/A
SP-CSI-RNTI	Activation of Semi-persistent CSI reporting on PUSCH	N/A	N/A
NOTE: The usage of MCS-C-RNTI is equivalent to that of C-RNTI in MAC procedures (except for the C-RNTI MAC CE).			

Table 7: Types of RNTIs

RNTI Types	Decimal Value	Hex Value
SI-RNTI	65535	0xFFFF
P-RNTl	65534	0xFFFE
Reserved	65520 - 65533	0xFFF0 - 0xFFFD
TC-RNTI	00001 - 65519	0x0001 - 0xFFEF
C-RNTI		
CS-RNTI		
MCS-C-RNTI		
TPC-PUCCH-RNTI		
TPC-PUSCH-RNTI		
TPC-SRS-RNTI		
INT-RNTI		
SP-CSI-RNTI		
SFI-RNTI		

Table 8: RNTI Values

2.12.2 RSSI

RSSI (*Received Signal Strength Indicator*) measures the linear average of the total received power (in Watt) observed only in certain OFDM symbols of measurement time resource, in the measurement bandwidth, over N_{RB} (*No. of Resource Blocks*) from all sources, including co-channel serving and non-serving cells, adjacent channel interference, thermal noise etc. (defined **as per 3GPP TS 38.215**). In Simple terms, RSSI is the total power UE observes across the whole band.

RSSI = Wideband Power = Noise + Serving Cell Power + Interference Power

Mathematical Expression:

$$RSSI = \frac{1}{N_{sym}} \sum_{l=1}^{N_{sym}} . \sum_{r=1}^{N_{RB}} . \sum_{k=1}^{N_{SC}^{RB}} . \left| S_{l,r,k} \right|^2$$

$$RSSI_{dBm} = 10 \, log_{10} \left(\frac{RSSI\,[W]}{10^{-3}} \right)$$

N_{sym} = No. of OFDM Symbols
N_{SC}^{RB} = No. of SCs per RB
N_{RB} = No. of RBs
$S_{l,r,k}$ = Signal Power in lth OFDM Symbol, rth RB, kth SC

2.12.3 RSRP

RSRP (*Reference Signal Received Power)* is the linear average of reference signal power (*in Watts*) measured over a specified bandwidth (*in the number of REs*). This is the most important measurement UE has to do for cell selection, re-selection, and handover.

In 4G, RSRP is associated with CRS (*Cell Specific Reference Signal*) whereas in 5G, it is defined through two specific reference signals: SS-RSRP (*Synchronisation Signal RSRP*) and CSI-RSRP (*Channel State Information RSRP*).

Pre-Lab

BACKGROUND

3. Pre-Lab Background

3.1 RAN Protocol Stack

The NR RAN protocol stack is organized into two distinct stacks based on the type of data processed: the Control Plane (C-Plane) for signaling messages and the User Plane (U-Plane) for user data. Both planes share the PHY, MAC, RLC, and PDCP layers but differ at the upper layers. The U-Plane incorporates the SDAP layer, connecting directly to the UPF for data handling. Conversely, the C-Plane is topped by the RRC and NAS layers, managing signaling and session functions, with the NAS layer linking to the AMF for seamless connectivity and control.

Each layer provides the services to the layers above and consumes the services of the layers below.

3.1.1 Control Plane Protocol Stack

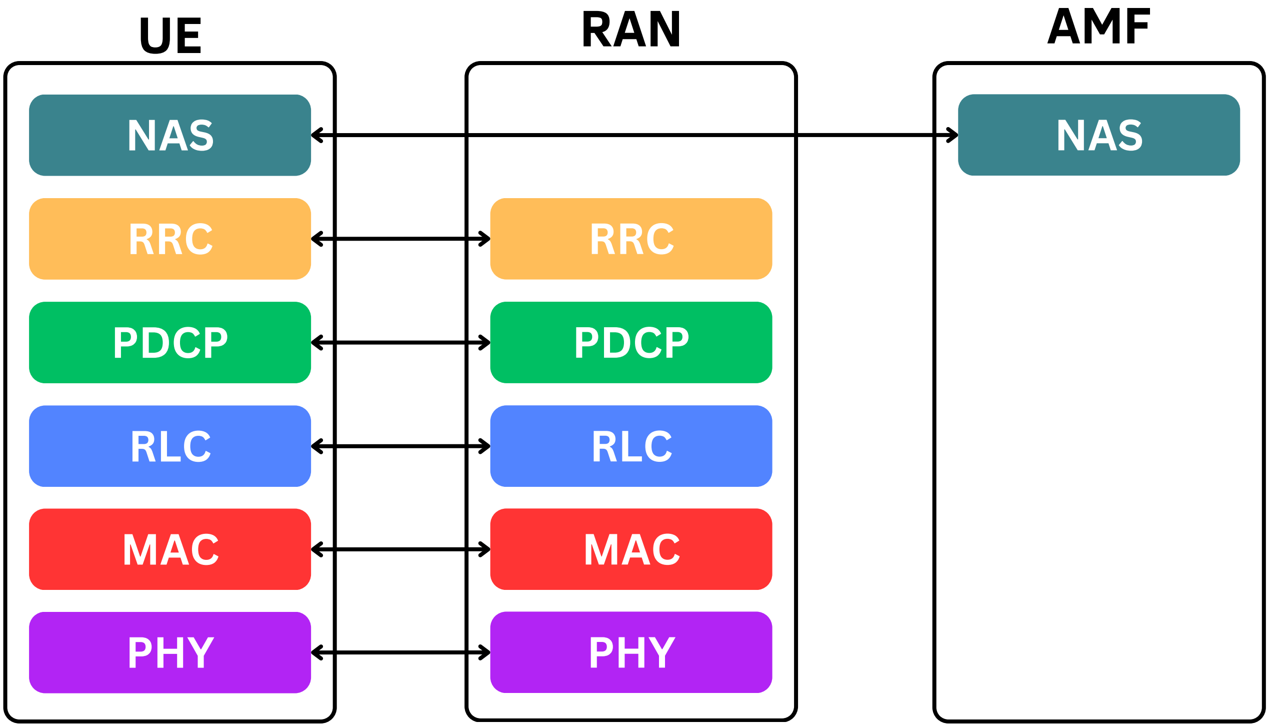

Figure 23: Control Plane Protocol Stack

- **PHY Layer**: Manages the mapping of data onto transport blocks, channel coding for noise and interference protection, modulation/demodulation to determine bits per resource element, measures channel quality, and performs error correction.
- **MAC Layer**: Handles prioritization of data streams, HARQ for error detection and retransmission, schedules resources, and manages multiplexing/demultiplexing of data flows.
- **RLC Layer**: Offers robust error detection, segmentation, and reassembly of data packets, retransmits data as needed, and ensures data packet reordering.
- **PDCP Layer**: Compresses/decompresses headers for efficiency and security, adds sequence numbers for order, and checks for and removes duplicates.
- **RRC Layer**: Oversees RAN control plane procedures like system information broadcasting for cell discovery, paging message transmission, radio bearer setup for message exchange, and measurement configurations for the UE.

- **NAS Layer**: Manages communication between the core network's AMF and the UE, covering authentication, security, and IDLE mode processes, including paging and IP address allocation.

3.1.2 User Plane Protocol Stack

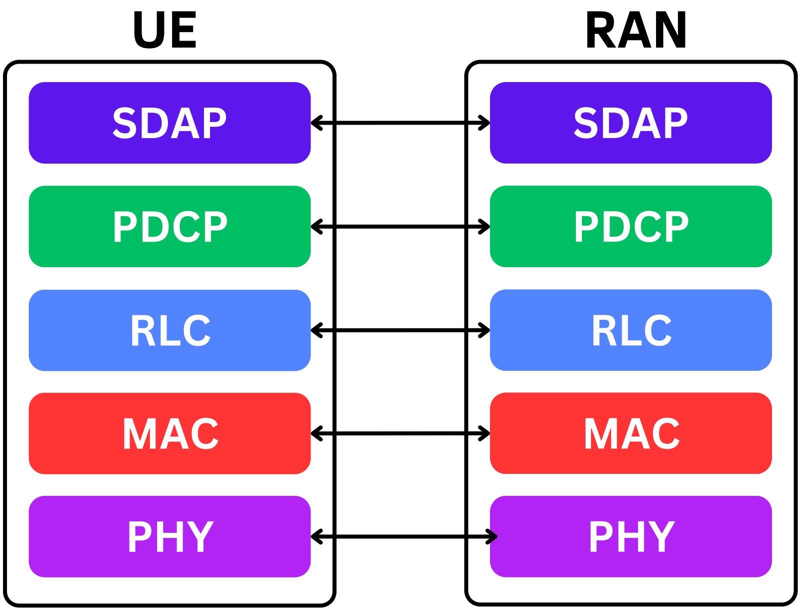

Figure 24: User Plane Protocol Stack

The User Plane protocol stack in 5G NR includes the PHY, MAC, RLC, and PDCP layers, same as in the Control Plane. However, it uniquely incorporates the **SDAP** layer on top. This additional layer is specifically tasked with mapping QoS flows to the appropriate radio bearers, ensuring that data transmission meets the required quality of service standards.

3.2 Frame Structure

Data(UL/DL) is transmitted in the form of radio frames in the air. Radio Frames are of a duration of 10ms which consists of 10 subframes each having a duration of 1ms. Subframes inside a radio frame are serialized as SF0, SF1, SF2, SF3, …., and SF9. A subframe is made up of a Resource Grid which is a (m x n) matrix of Resource Elements where 'm' defines the number of Sub-carriers and 'n' defines the number of OFDM Symbols.

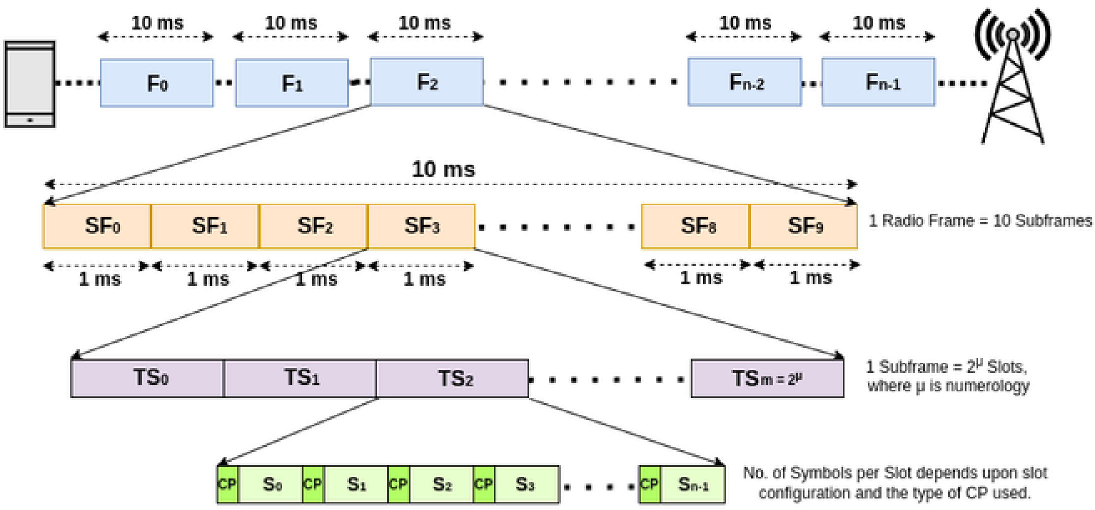

Figure 25: NR Frame Structure

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