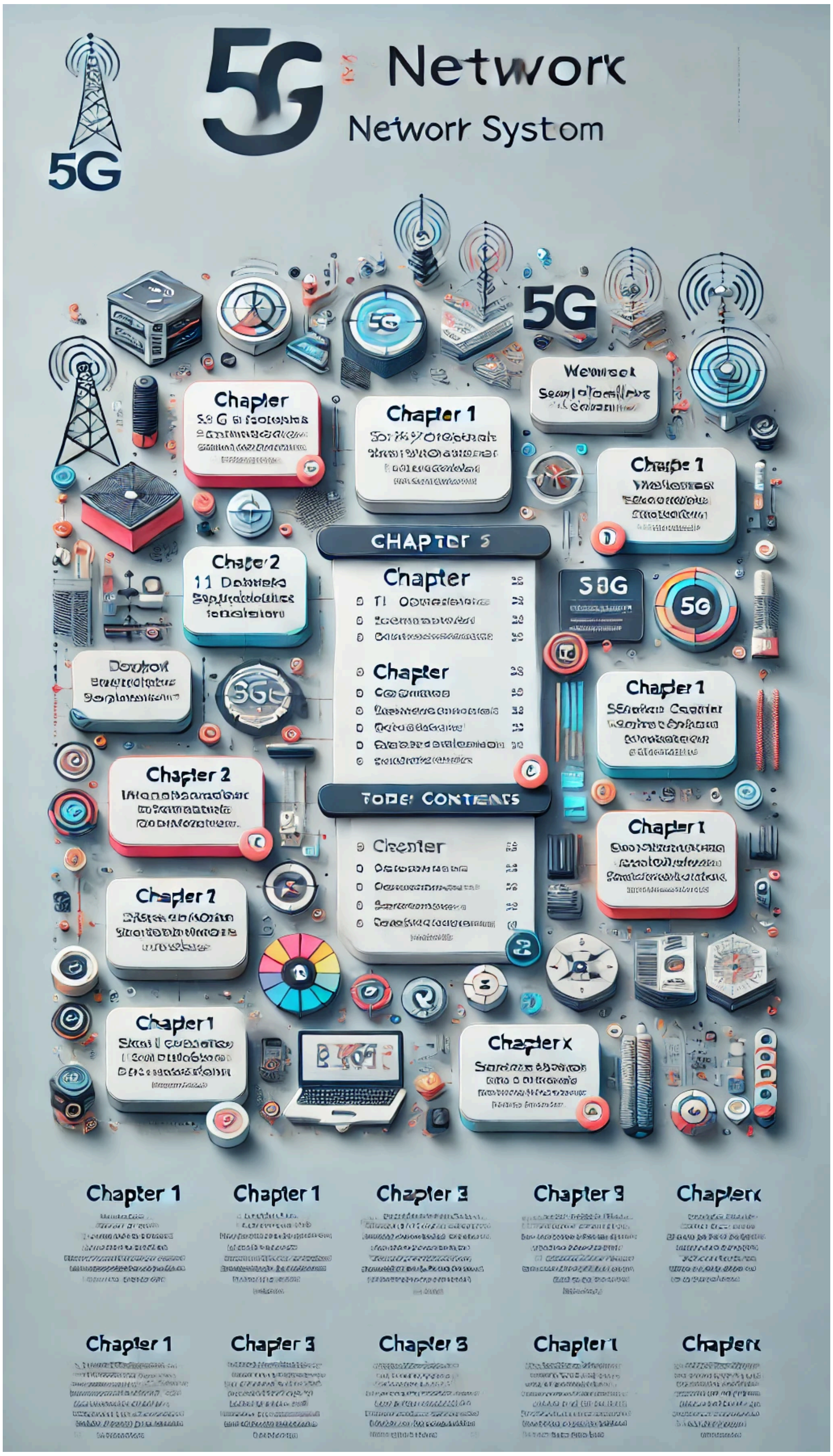
2. 5G Mobile Communication System Technical Specification



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Contents

Chapter 1: Overview

1.1 Purpose of This Document

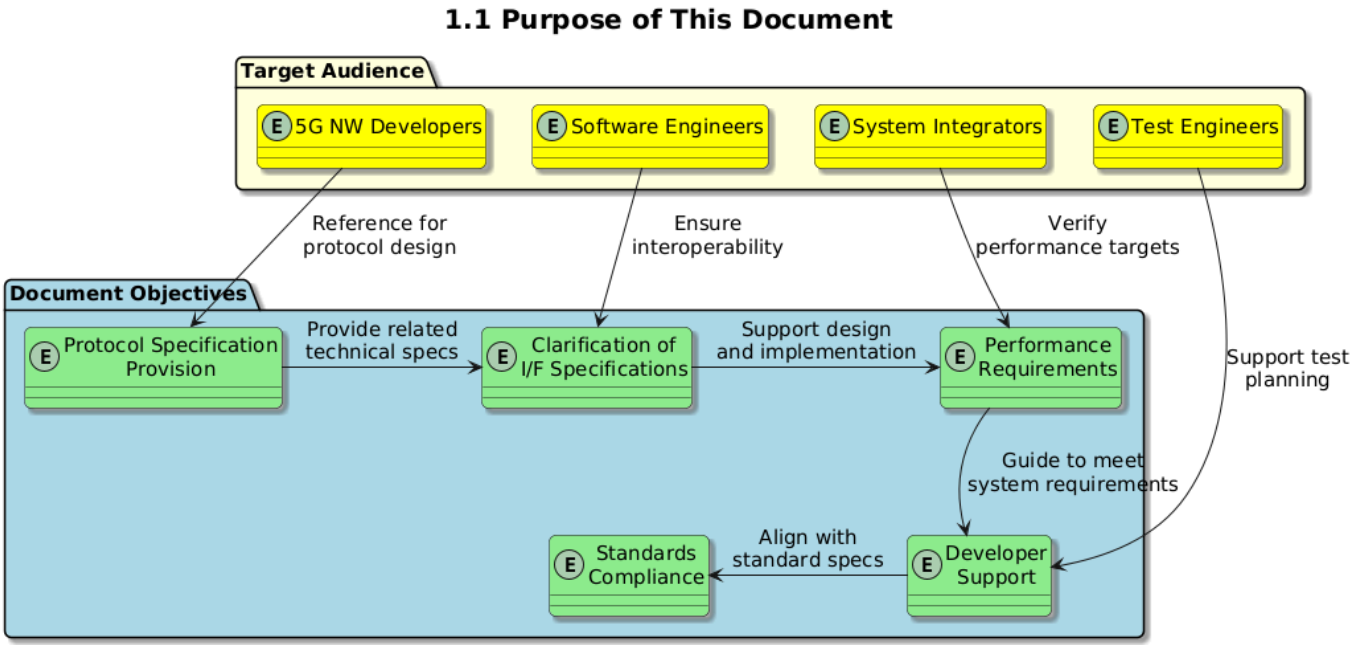
This document aims to provide detailed technical specifications required for the design and development of cutting-edge, high-performance 5G Mobile Communication System (MCS) systems. It is intended for engineers and developers working on advanced 5G systems, with a particular focus on the following aspects:

- **Detailed Protocol Specifications**
  Comprehensive information necessary for the design and implementation of each protocol layer, including PHY, MAC, RLC, PDCP, SDAP, RRC, 5GMM, and 5GSM.
- **Clarification of Interface (I/F) Specifications**
  Definitions of interface specifications such as NR-Uu, NG, Xn, N2/N3 to ensure interoperability between system components.
- **Provision of Performance Requirements**
  Description of technical requirements essential to maintain high performance in 5G networks, including frequency bands, beamforming, and QoS profiles.
- **Developer Support**
  Design guidelines and practical examples to assist in system development and implementation.
- **Promotion of Standards Compliance**
  Standard-compliant specifications based on 3GPP Release 16/17 to promote global compatibility.

This document is intended for the following audiences:

- Developers of 5G Mobile Communication System (including UE, gNB, and 5GC architects)
- 5G-related software engineers
- System integrators and test engineers

The following diagram groups and visualizes the elements that constitute the purpose of this document:



This diagram groups the five core elements of the document's objectives and illustrates their interrelationships. It also clarifies how these objectives align with the intended audience.

1.2 Scope of Application

This section defines the scope of the 5G MCS under development, including its system configuration, assumed operating environment, target users, applicable standards, as well as the content covered and limitations of this specification.

1.2.1 Scope Details

System Configuration

This specification applies to a 5G network composed of the following primary components:

- **UE (User Equipment):**
  High-performance and feature-rich devices such as smartphones, IoT devices, and industrial equipment.
- **gNB (Next Generation NodeB):**
  Base stations providing functionality from the physical layer up to the RRC layer.
- **5GC (5G Core Network):**
  A distributed network architecture implementing separation of control and user planes.

Assumed Operating Environment

- **Frequency Bands:**
  Supports both Sub-6 GHz and millimeter-wave (mmWave) spectrums.
- **Mobility:**
  Environments with high mobility (e.g., onboard trains, vehicles) and dense urban areas.
- **Traffic Characteristics:**
  Capable of handling a wide range of communication demands including high throughput, low latency, and low data-rate IoT use cases.

Target Users

- Network architects, developers, and operations administrators.
- Companies and researchers developing 3GPP-compliant products.

Standards and Reference Specifications

- Technologies based on 3GPP Releases 15 through 18.
- Interoperability requirements involving related standards from IETF, ETSI, and IEEE.

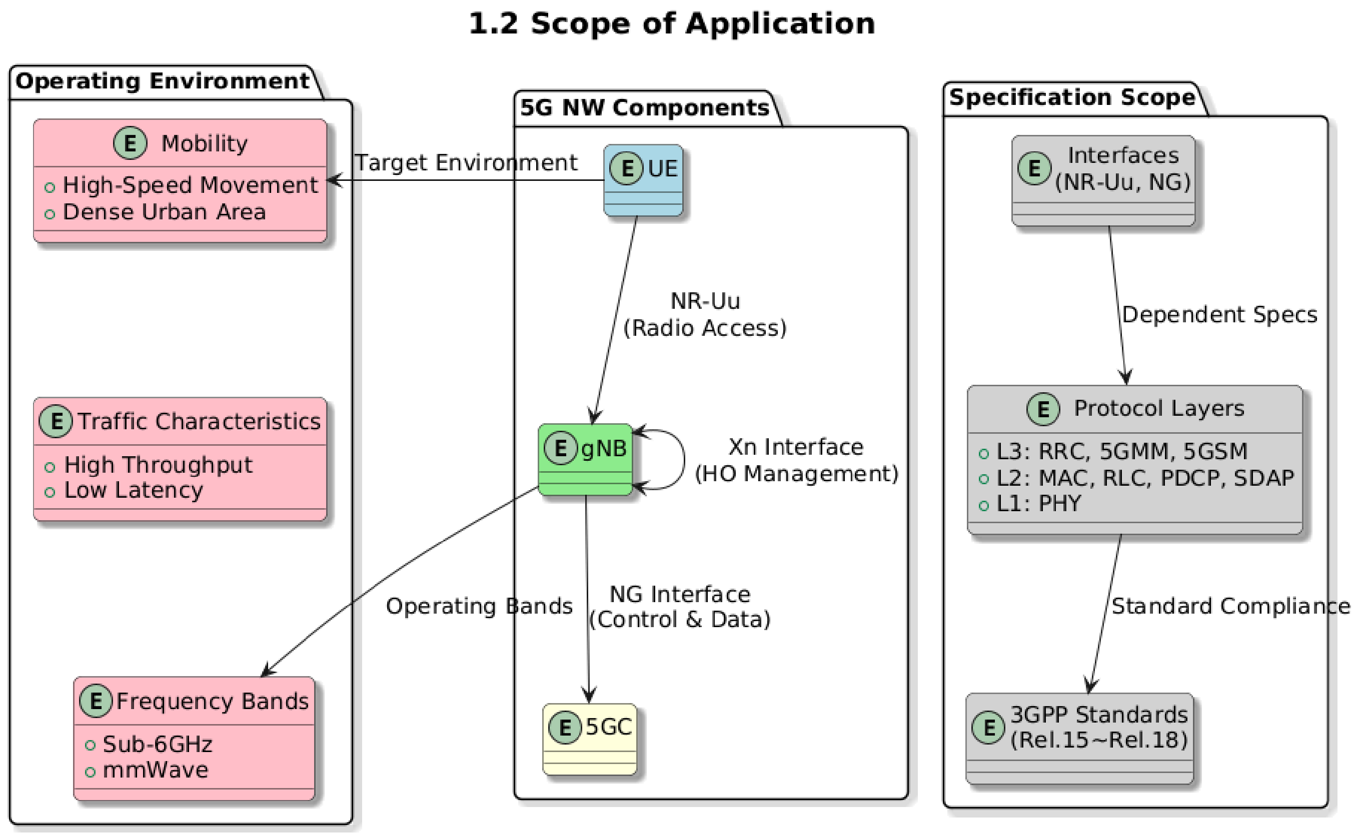
Covered Content

- Protocol specifications for each layer:
  - L1: PHY
  - L2: MAC, RLC, PDCP, SDAP
  - L3: RRC, 5GMM, 5GSM
- Detailed specifications of interfaces including NR-Uu, NG, Xn, and N2/N3.
- Advanced functions such as QoS management, beamforming, and network slicing.

Limitations

- Non-standard or proprietary features are not covered.
- Detailed hardware design is outside the scope of this document.

1.2.2 Diagram



This diagram visualizes the key elements covered in the scope—system composition, environment, and specification range—and illustrates their interrelations. Color coding reflects functional grouping.

1.3 Terminology and Abbreviations

This section provides key terms and abbreviations necessary for 5G MCS developers using this document. Each term includes a concise explanation and is categorized based on relevant components or functional groups.

1.3.1 Key Terms

UE (User Equipment)
5G terminal device used by end users.

gNB (Next Generation NodeB)
Base station in the 5G network.

5GC (5G Core)
Core network forming the backbone of 5G connectivity.

QoS (Quality of Service)
Quality control metrics for communication services.

NR (New Radio)
Radio access technology in 5G networks.

PDU (Protocol Data Unit)
Data unit handled by 5GSM during session management.

HARQ (Hybrid Automatic Repeat Request)
Mechanism for error correction and retransmission, used in the PHY and MAC layers.

1.3.2 Protocol-Related Abbreviations

RRC (Radio Resource Control)
Definition: Protocol for radio resource management.
Role: Exchanges control signaling between UE and gNB; manages connection establishment, maintenance, and release.
Layer: L3

SDAP (Service Data Adaptation Protocol)
Definition: Protocol layer mapping QoS flows to DRBs (Data Radio Bearers).
Role: Data flow control based on QoS flow (5QI).
Layer: L2

PDCP (Packet Data Convergence Protocol)
Definition: Protocol for header compression and security management.
Role: Encryption, header compression, and reordering.
Layer: L2

RLC (Radio Link Control)
Definition: Protocol responsible for retransmission control.
Role: Provides AM (Acknowledged Mode), UM (Unacknowledged Mode), and TM (Transparent Mode).
Layer: L2

MAC (Medium Access Control)
Definition: Protocol for radio resource control.
Role: Handles HARQ, scheduling, and resource allocation.
Layer: L2
PHY (Physical Layer)
Definition: Layer managing physical data transmission.
Role: Modulation/demodulation, beamforming.
Layer: L1
5GMM (5G Mobility Management)
Definition: NAS layer function for mobility management.
Role: UE registration, tracking area update, connection state control via AMF.
Layer: NAS (L3)
5GSM (5G Session Management)
Definition: NAS layer function for session management.
Role: Manages PDU session establishment, modification, and release via SMF.
Layer: NAS (L3)

1.3.3 Interface-Related Abbreviations

NR-Uu
Radio interface between UE and gNB.
NG
Interface between gNB and 5GC.
Xn
Interface for inter-gNB communication.
N2/N3
Internal 5GC interfaces for signaling (N2) and user data (N3).

1.3.4 Frequency and Radio Technologies

FR1/FR2 (Frequency Range 1/2)
Frequency bands: Sub-6GHz (FR1) and mmWave (FR2).
MIMO (Multiple Input Multiple Output)
Communication technology using multiple antennas.
Beamforming
Technology for forming directional radio beams.

1.3.5 Network Management Terms

AMF (Access and Mobility Management Function)
Manages access and mobility.
UPF (User Plane Function)
Handles user data transfer in 5GC.
SMF (Session Management Function)
Controls session management.
PCF (Policy Control Function)
Manages QoS and charging policies.

NRF (Network Repository Function)

Handles NF registration and discovery; core of SBA architecture.

Diagram: Terminology Relationships

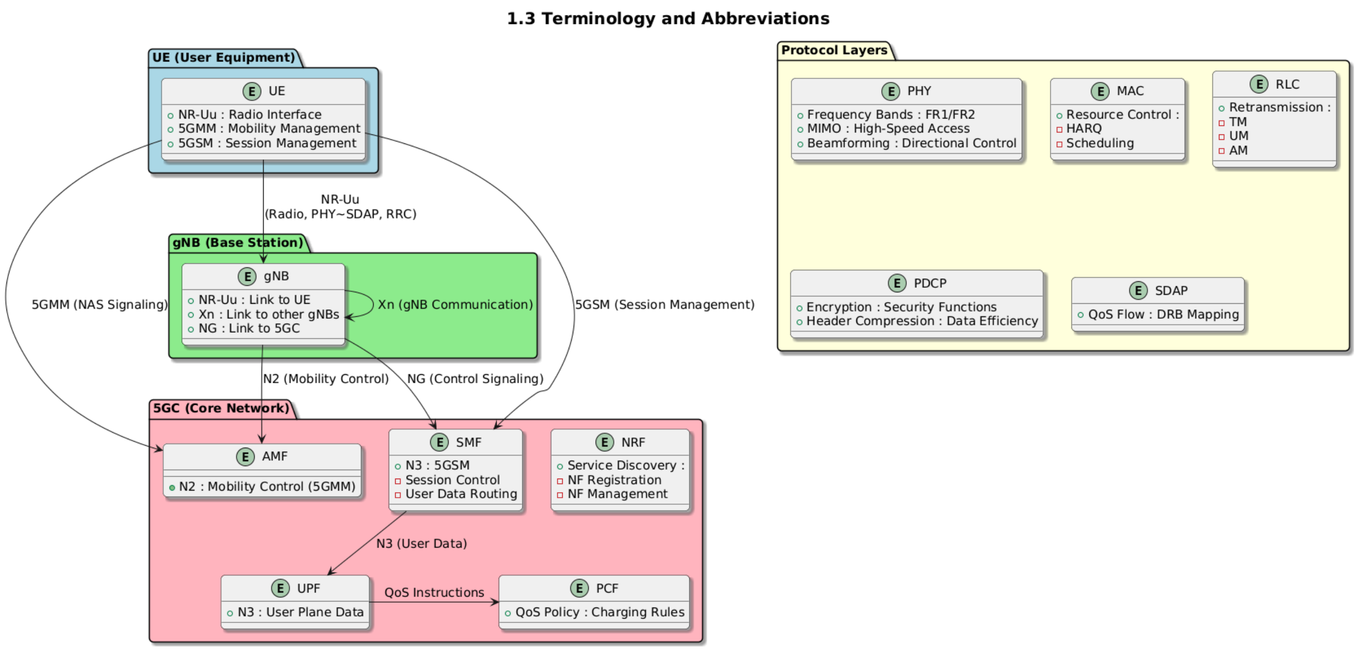


Diagram Description

Protocol Coordination

Illustrates the communication flow from UE to 5GC via NR-Uu, 5GMM, and 5GSM.

Protocol Layer Roles

Shows how each layer from PHY to SDAP supports data transmission through NR-Uu.

E2E Relationships

Clarifies end-to-end roles of UE, gNB, and 5GC components with functional associations. This diagram helps developers quickly understand major 5G network terms and their interrelationships.

1.4 Reference Documents

This section lists primary source documents used as the foundation for system design, protocol specifications, and requirements definition. The references are categorized as follows.

1.4.1 3GPP Standard Documents

3GPP TS 38.300: NR (New Radio) Overall Description
3GPP TS 38.331: RRC (Radio Resource Control) Specification
3GPP TS 38.321: MAC (Medium Access Control) Layer Specification
3GPP TS 23.501: 5G Core (5GC) Architecture
3GPP TS 23.502: 5GC Procedures

1.4.2 Technical References

IETF RFC 768: UDP (User Datagram Protocol) Specification
IETF RFC 791: IPv4 Specification
IETF RFC 8446: TLS 1.3 Security Protocol
IEEE 802.11ax: Wi-Fi 6 Standard

1.4.3 Industry Guidelines

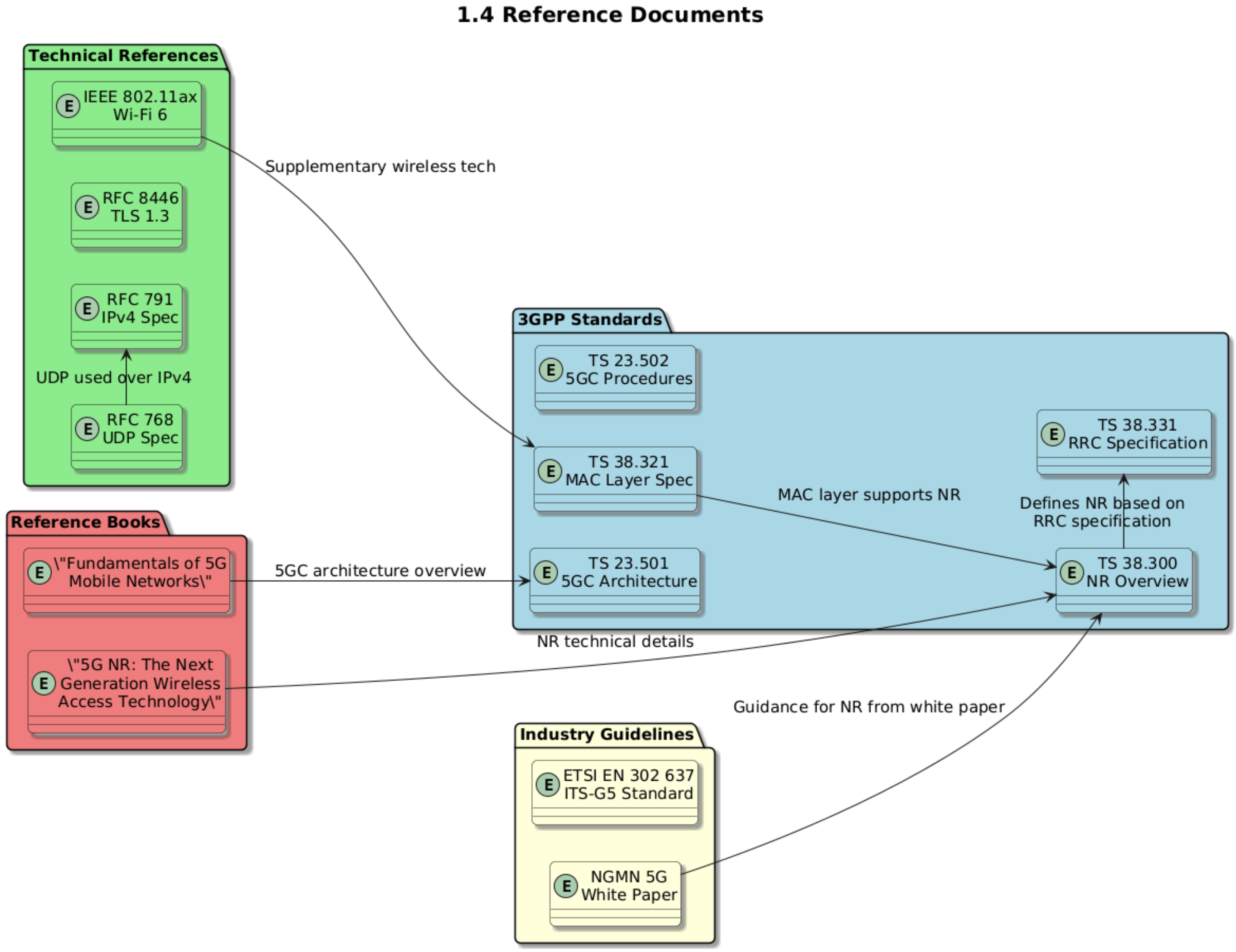
NGMN 5G White Paper: 5G Performance Requirements and Use Cases
ETSI EN 302 637: ITS-G5 Standard (Vehicle Communication)

1.4.4 Reference Books and Materials

"5G NR: The Next Generation Wireless Access Technology" by Erik Dahlman et al.
"Fundamentals of 5G Mobile Networks" by Jonathan Rodriguez

1.4.5 Other References

Technical documents from international organizations (e.g., ITU, GSMA)
Government guidelines on national frequency regulations
Diagram: Relationship of Reference Documents



Explanation:

This diagram visualizes the classification and interrelation of reference documents. Each colored package groups related documents, while directional arrows indicate dependency or supplementary relationships. This helps developers easily understand how different documents are connected and where to refer for deeper technical insights.

Chapter 2: System Overview

2.1 Overview of 5G Network Architecture

The 5G network (5G NW) is a next-generation communication infrastructure that offers both high performance and flexibility. As defined by 3GPP, it consists of the following three primary components:

2.1.1 User Equipment (UE)

- Includes various types of devices such as smartphones, IoT devices, and vehicle communication systems
- Equipped with a 5G modem and communicates with gNB via NR (New Radio)
- Supports mobility, handover (HO), and high throughput communication

2.1.2 Base Station (gNB: gNodeB)

- Communicates with UEs via the NR-Uu interface
- Incorporates advanced technologies such as Massive MIMO and Beamforming
- Distributes service data and connects to the 5G Core (5GC) via N2/N3 interfaces

2.1.3 5G Core Network (5GC)

- Cloud-native, modular architecture
- Composed of subsystems such as AMF, SMF, and UPF
- Provides application-specific communication through Network Slicing (eMBB, mMTC, URLLC)

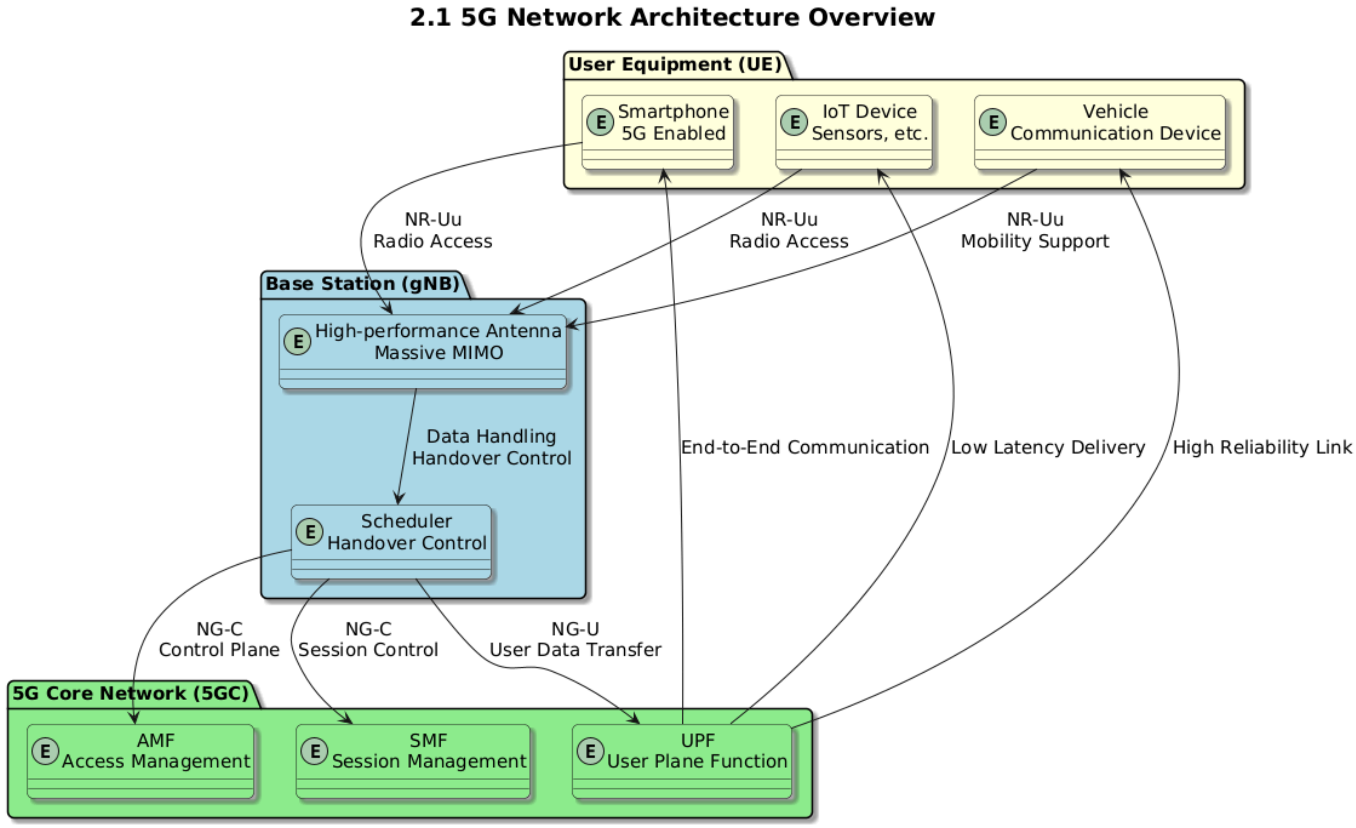
2.1.4 Interfaces and Communication Protocols

- NR-Uu: Interface between UE and gNB
- NG-C/N: Control and user plane interfaces between gNB and 5GC
- Xn: Interface for inter-gNB communication

2.1.5 Architectural Characteristics

- Modularity: Flexible combination of functional components
- Scalability: Supports increasing traffic loads
- Low Latency: Enables ultra-reliable low-latency communications (URLLC)

Diagram: 5G Network Architecture Overview



Explanation:

This diagram categorizes each component by function and visualizes the communication flow. Different colors are used to clearly distinguish the roles of UE, gNB, and 5GC. It also illustrates the roles and interconnections of major interfaces (NR-Uu, NG-C/N, NG-U), allowing intuitive understanding of the overall 5G network structure.

2.2 Fundamental Requirements

The 5G network must meet the following essential requirements to ensure reliable, high-performance, and future-proof operations.

1. Reliability

- Guarantees 99.999% network availability
- Automatic recovery mechanisms upon network failure
- Ensures ultra-low latency (<1ms) communication for real-time applications such as autonomous driving

2. Performance

- Maximum data rate of 10 Gbps between UE and gNB
- Minimum guaranteed speed of 100 Mbps per user device
- Support for URLLC (Ultra-Reliable Low Latency Communication)
- High-capacity connectivity enabling up to 1 million devices per km^2 (mMTC: Massive Machine-Type Communication)

3. Interoperability

- Compliance with 3GPP Release 17/18 specifications
- Seamless integration with existing 4G/LTE networks (Non-Standalone mode)
- Interoperability across multi-vendor environments

4. Security

- End-to-end data encryption using AES-256
- Dedicated security profiles for each Network Slice
- Protection against cyber threats including DDoS and strengthened authentication

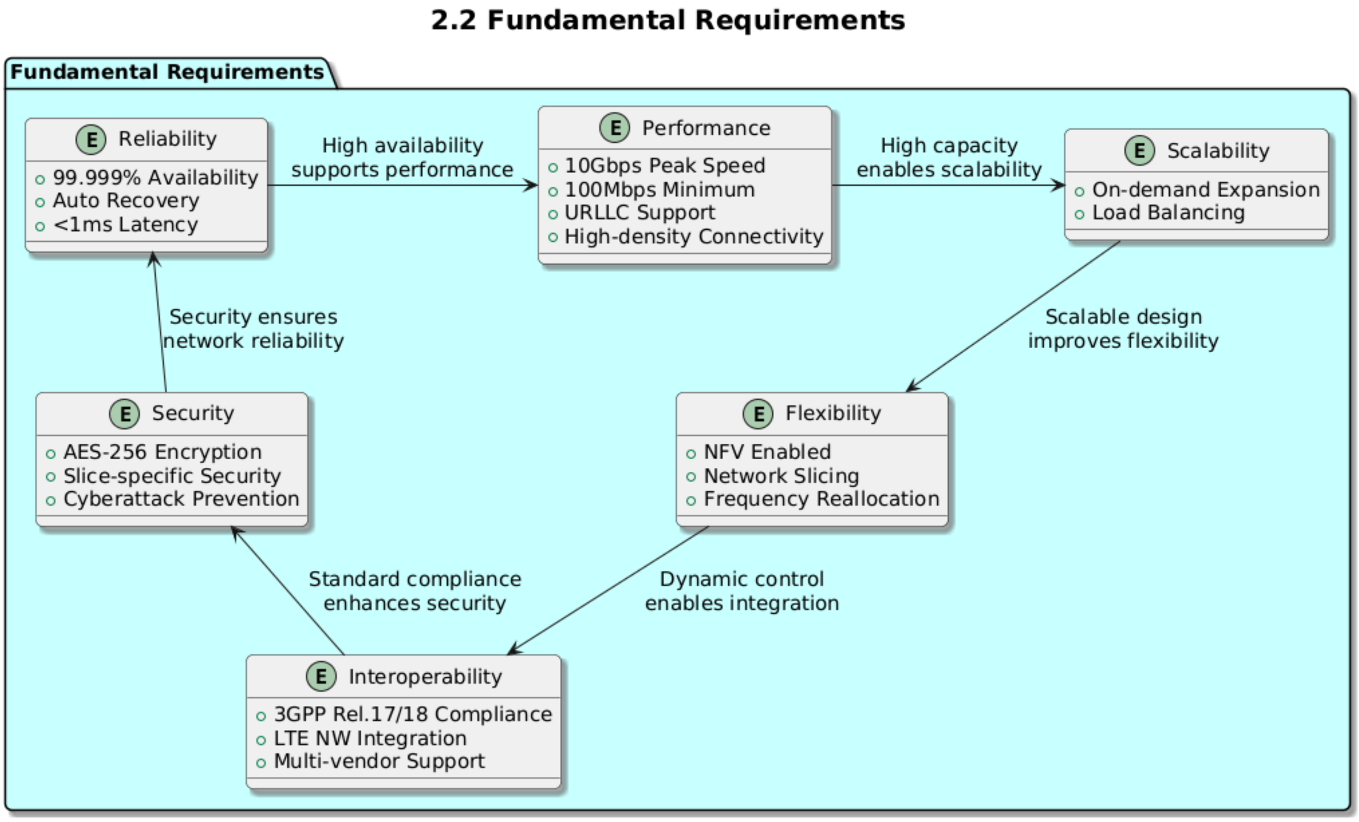
5. Scalability

- On-demand expansion of network resources in response to user growth
- Load balancing mechanisms for multi-cell and multi-user environments

6. Flexibility

- Software-based network control through NFV (Network Function Virtualization)
- Support for diverse use cases (e.g., IoT, AR/VR, cloud gaming) via Network Slicing
- Dynamic frequency reallocation and Carrier Aggregation (CA)

Diagram: Elements and Relationships of Fundamental Requirements



Explanation

- Reliability → Performance:
  A highly reliable network serves as the foundation for consistent high-speed and low-latency communication.
- Performance → Scalability:
  Achieving high throughput and capacity supports the growth of connected devices and services.
- Scalability → Flexibility:
  Scalable architecture allows dynamic resource allocation, leading to increased operational flexibility.
- Flexibility → Interoperability:
  Flexible network control facilitates integration across different technologies and standards.
- Interoperability → Security:
  Standard-based integration allows for uniform and robust security policies.
- Security → Reliability:
  A secure network environment ensures the overall reliability of the system.

2.3 System Architecture

The 5G MCS (Mobile Communication System) consists of the following three primary components:

UE (User Equipment)

Role:
Acts as the user device, performing network access and data communication.
Key Functions:

- 5G protocol stack (NR Layer 1, 2, and 3)
- Application layer processing
- RF frontend and antenna control
- Security authentication and encryption

Examples:
Smartphones, IoT devices, AR/VR terminals

gNB (Next Generation Node B)

Role:
Provides the 5G Radio Access Network (RAN) and acts as an intermediary between UE and 5GC.
Key Functions:

- Radio Resource Management (RRM)
- Beamforming and scheduling
- Data encoding/decoding
- Interface connections via F1 and Xn

Component Structure:

- CU (Central Unit): Centralized control and data processing (RRC/RRM, PDCP, SDAP)
- DU (Distributed Unit): Local processing for MAC, RLC, and PHY layers
- RU (Radio Unit): RF signal transmission/reception and antenna control

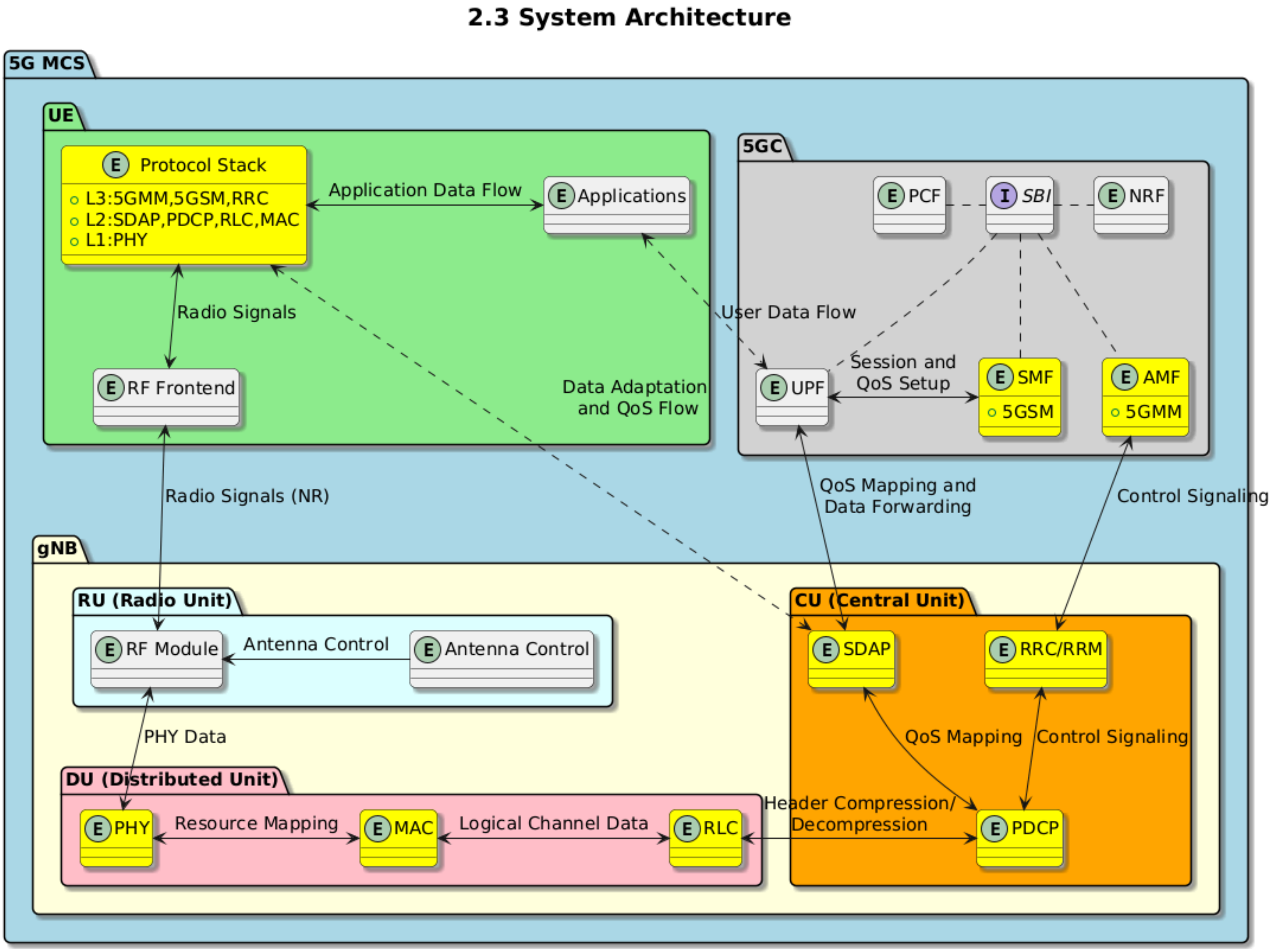
5GC (5G Core Network)

Role:
Manages session control, mobility, and data transfer.
Key Functions:

- UPF (User Plane Function): User data processing and forwarding
- AMF (Access and Mobility Management Function): UE authentication and mobility management
- SMF (Session Management Function): Session establishment and control
- NRF (Network Repository Function): NF registration and discovery
- PCF (Policy Control Function): QoS and charging policy management

Diagram: System Architecture Overview

The following diagram illustrates the overall architecture of the 5G MCS and the relationships between its components.



Description of the Diagram

System Overview:

This diagram represents the basic architecture of the 5G system, including key functional blocks and their interactions.

UE:

Acts as the user terminal and communicates via the NR protocol stack:

- L3: 5GMM (Mobility), 5GSM (Session), RRC
- L2: SDAP, PDCP, RLC, MAC
- L1: PHY

The application layer generates and consumes user data.

gNB:

Provides the 5G radio interface and is divided into:

- CU: Manages RRC/RRM, PDCP, SDAP for control and QoS
- DU: Handles data plane processing with RLC, MAC, and PHY
- RU: Controls RF transmission and antenna operations

5GC:

Manages core functions for user and control planes:

- AMF: Handles mobility (5GMM)
- SMF: Controls sessions (5GSM)
- UPF: Forwards user data
- NRF: Registers and discovers network functions
- PCF: Applies QoS and policy rules
- SBI (Service-Based Interface): Enables standard communication between core functions

Data Flow:

User data generated at the UE application layer passes through the protocol stack, is assigned QoS via SDAP, and is transmitted through gNB to UPF, where it is forwarded to external networks.

Control Flow:

Control signaling from 5GMM, 5GSM, and RRC flows through gNB CU and reaches AMF/SMF for authentication and session control.

QoS and Data Adaptation:

SDAP and UPF cooperate to apply QoS policies and ensure high-quality service delivery.

Key Characteristics:

- Distributed Architecture: Separation into CU, DU, RU allows flexible deployment
- Standardized Interfaces: Based on 3GPP specifications (e.g., SBI, F1, Xn) for high interoperability and scalability
- End-to-End QoS: SDAP enables QoS flow control; UPF ensures service quality throughout the path

2.4 Key Technical Specifications and Performance Indicators

2.4.1 Core Technical Specifications

Network Architecture

- UE: Assumes modern mobile and IoT devices; supports both 5G Standalone (SA) and Non-Standalone (NSA) modes.
- gNB: Compliant with 3GPP Release 17, supporting:
    - mmWave and sub-6GHz bands
    - Massive MIMO and Beamforming
    - Separation of Central Unit (CU) and Distributed Unit (DU)
- 5GC:
    - Service-Based Architecture (SBA)
    - Support for Network Slicing
    - URLLC, eMBB, and mMTC services

Communication Performance

- Data Rates:
    - Downlink: up to 20 Gbps
    - Uplink: up to 10 Gbps
- Latency:
    - U-Plane (URLLC): less than 1 ms
    - C-Plane: less than 10 ms
- Connection Density:
    - Up to 1 million devices per square kilometer

Quality of Service (QoS)

- Based on 5QI (5G QoS Identifier)
- Configurable per service: priority, bandwidth, latency, and packet loss rate

2.4.2 Performance Indicators

Capacity

- Maximum throughput per cell: 50 Gbps

Spectral Efficiency

- Downlink: 30 bps/Hz
- Uplink: 15 bps/Hz

Reliability and Availability

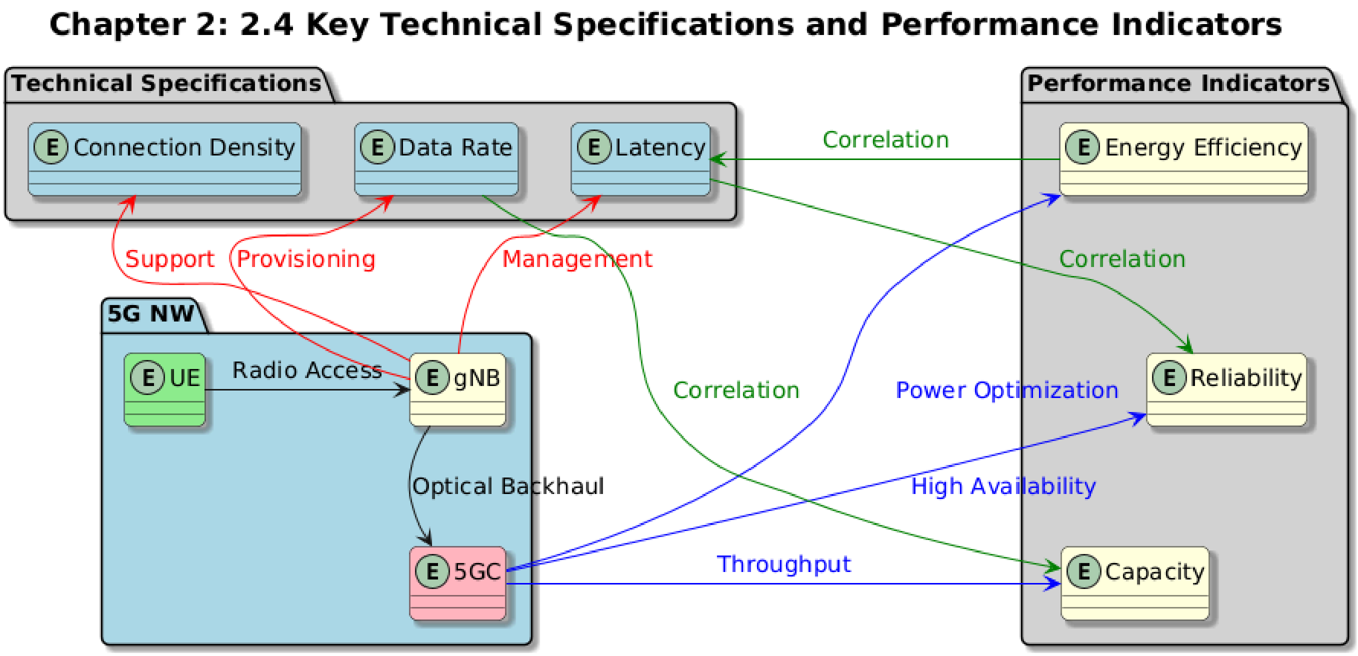
- Network availability: 99.999%
- Packet success rate (URLLC): 99.999%

Energy Efficiency

- Power consumption per bit: < 1 μJ/bit
- Energy-saving mechanisms: automatic sleep modes and small cell deployment

Diagram

The following diagram illustrates the relationship between technical specifications and key performance indicators:



This diagram highlights the interdependencies between network entities (UE, gNB, 5GC), technical specifications, and performance indicators. Each arrow denotes how specific components contribute to or correlate with key metrics.

Chapter 3: 3GPP-Compliant Protocol Specifications

3.1 Overview of Protocol Layers

3.1.1 Structure of the Protocol Stack

The protocol layers of the 5G system are designed in accordance with 3GPP specifications. The control plane (C-Plane) and user plane (U-Plane) adopt distinct protocol stacks, enabling the flexible and extensible communication characteristic of 5G.

Protocol Layer Classification:

- **Physical Layer (PHY Layer):**
  Responsible for radio signal transmission and reception, modulation/demodulation, encoding/decoding, and beamforming.
  Shared by both C-Plane and U-Plane.
- **MAC Layer (Medium Access Control):**
  Handles scheduling, HARQ, and resource management.
  Provides interface between PHY and RLC layers.
- **RLC Layer (Radio Link Control):**
  Implements transmission modes (TM/UM/AM) and reliable data transfer.
- **PDCP Layer (Packet Data Convergence Protocol):**
  Manages security (encryption/decryption), header compression, and duplicate packet elimination.
- **SDAP Layer (Service Data Adaptation Protocol):**
  Maps QoS flows to data bearers based on service priority.
- **RRC Layer (Radio Resource Control):**
  Control-plane exclusive. Manages connection state, cell selection/reselection, and initial security setup.
- **5GMM (5G Mobility Management):**
  Handles mobility procedures such as registration, tracking, updates, and handover.
  Communication is established between UE and AMF.
- **5GSM (5G Session Management):**
  Manages session lifecycle including PDU session establishment, modification, and release.
  Handles QoS parameters and traffic rules between UE and SMF.

3.1.2 Key Functions of the Protocol Stack

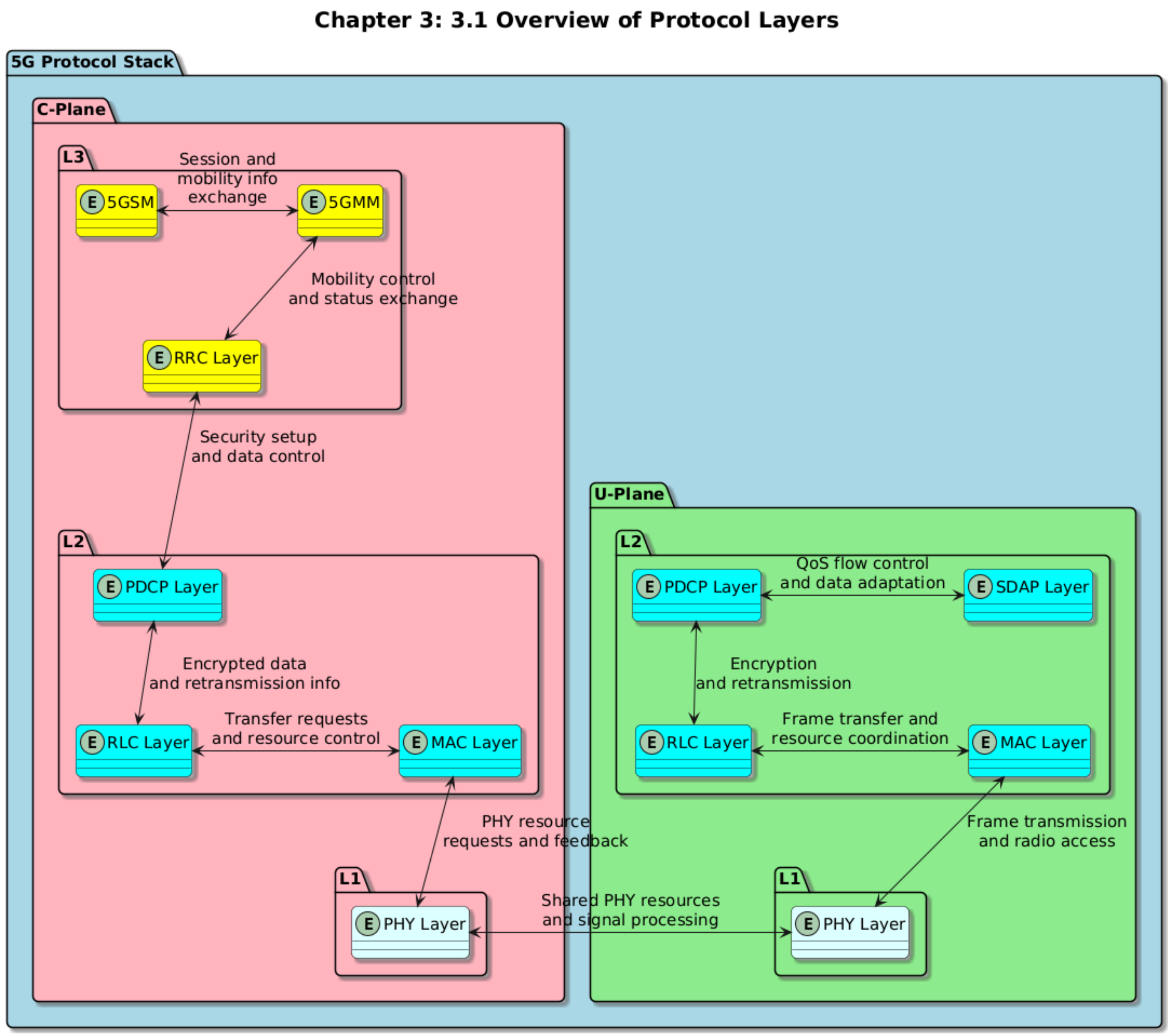
U-Plane Protocol Stack:

- Application Layer:
  Supports eMBB (enhanced Mobile Broadband), URLLC (Ultra-Reliable Low Latency Communication), and mMTC (massive Machine Type Communication).
- SDAP:
  Performs QoS flow classification and mapping.
- PDCP:
  Encrypts data and eliminates duplicates.
- RLC:
  Controls retransmissions and data sequencing.
- MAC:
  Executes scheduling and resource allocation.
- PHY:
  Handles physical transmission and reception of radio signals.

C-Plane Protocol Stack:

- RRC:
  Manages connections, initializes security, and performs cell (re)selection.
- 5GMM:
  Manages UE registration, tracking, and handover.
- 5GSM:
  Controls session-related procedures, including QoS and traffic management.
- Other Layers (PDCP, RLC, MAC, PHY):
  Operate under the control of RRC and 5GMM/5GSM to transmit and receive control data.

Protocol Stack Diagram



Detailed Explanations

Control Plane (C-Plane):

- 5GSM ↔ 5GMM:
  Manages the session lifecycle (establishment, maintenance, release).
  When mobility events affect sessions, both layers exchange notifications.
- 5GMM ↔ RRC:
  RRC provides cell selection and connection state updates to 5GMM.
  5GMM sends mobility control commands to RRC.
- RRC ↔ PDCP_Control:
  RRC provides PDCP with security keys and initialization data.
  PDCP reports encryption results and errors back to RRC.
- PDCP_Control ↔ RLC_Control:
  PDCP passes encrypted data to RLC and receives information on retransmissions and ordering.

- RLC_Control ↔ MAC_Control:
  Coordinates scheduling and resource requests.
- MAC_Control ↔ PHY_Control:
  MAC requests resource allocation from PHY and receives feedback on availability.

User Plane (U-Plane):

- SDAP ↔ PDCP_User:
  SDAP classifies packets by QoS flow and sends them to PDCP.
  PDCP reports compression and duplicate elimination results.
- PDCP_User ↔ RLC_User:
  PDCP encrypts data and passes it to RLC, which manages retransmissions.
- RLC_User ↔ MAC_User:
  RLC requests frame transfer; MAC provides resource assignment status.
- MAC_User ↔ PHY_User:
  MAC controls PHY radio resources and receives data transmission results.

Shared Layer (PHY_Control ↔ PHY_User):

The PHY layer is shared by both planes, enabling integrated signal processing and physical data transfer.

Indirect Relationship Between 5GSM and RRC

In 5G architecture, 5GSM does not directly communicate with the RRC layer. Instead, it interacts indirectly through 5GMM. The reasons and relationships are as follows:

Role Separation Between 5GMM and 5GSM:

- 5GMM:
  Manages mobility (e.g., UE registration, handover, authentication).
  Communicates directly with the RRC layer for mobility-related control.
- 5GSM:
  Manages session lifecycle (e.g., QoS configuration, PDU session procedures).
  Interfaces with the 5GC (AMF/SMF) to control sessions.
  When radio resource allocation or QoS settings are required, 5GSM uses 5GMM to reach the RRC.

Indirect Interaction:

- 5GSM → 5GMM → RRC:
  5GSM sends QoS or session configuration requests to 5GMM, which forwards them to RRC for radio resource allocation.
- RRC → 5GMM → 5GSM:
  RRC reports network state or resource availability to 5GMM, which updates 5GSM for session management.

Supplementary Note:

This modular interaction pattern enhances the architectural flexibility of the 5G protocol. By separating mobility and session management and enabling inter-layer coordination via 5GMM, the system achieves robust integration across functional layers.