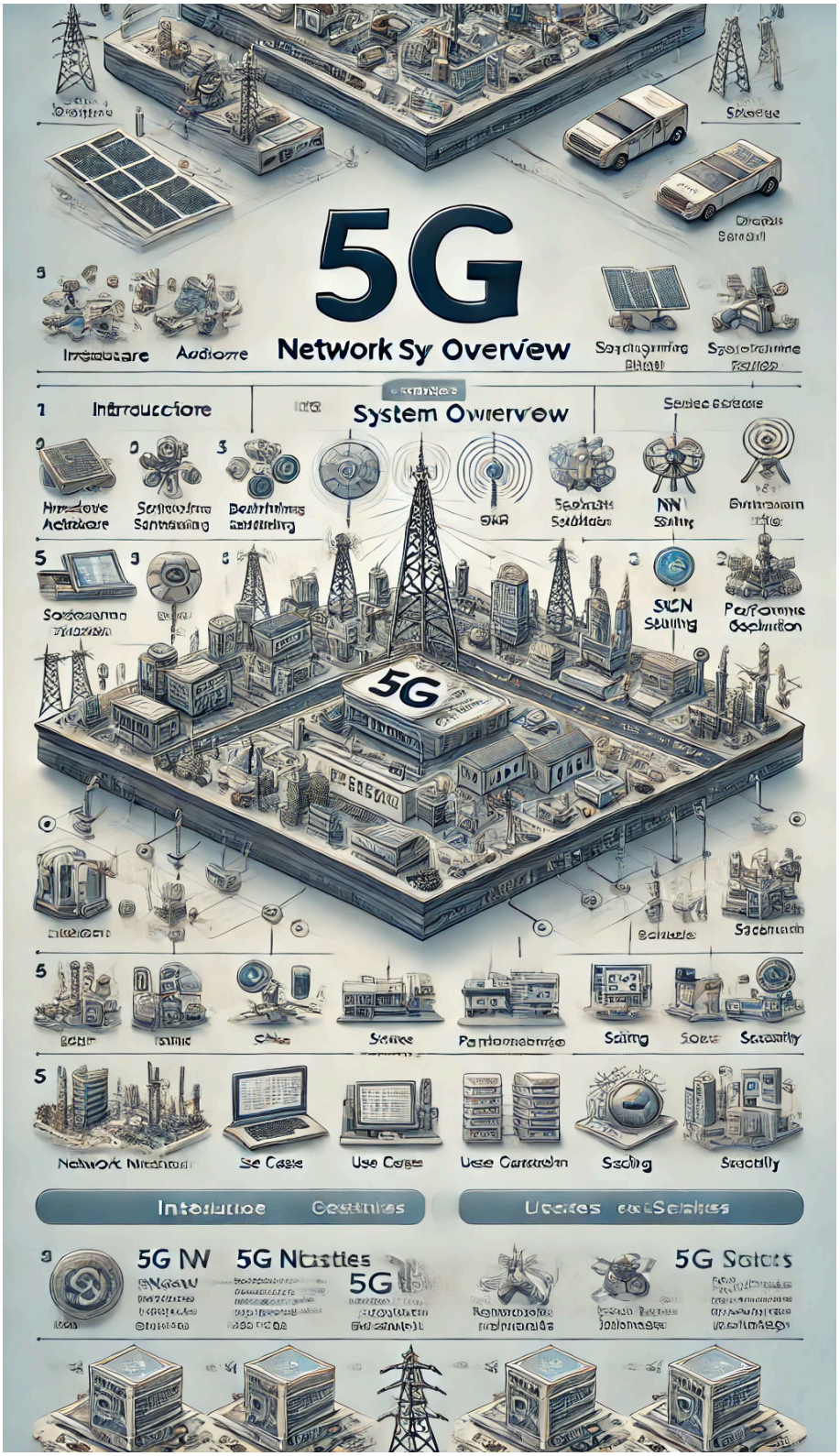
1. 5G Mobile Communication System Overview



Contents

1. Introduction

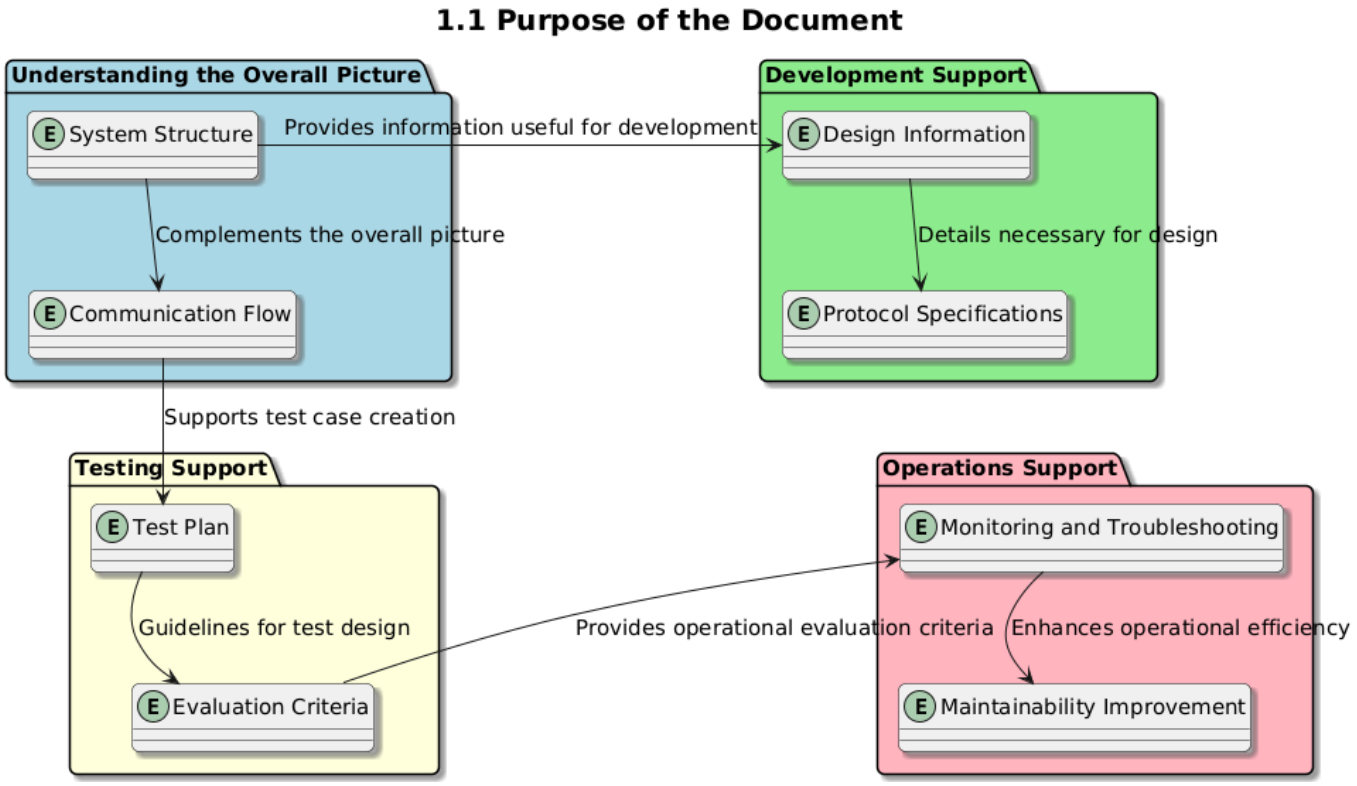
1.1 Purpose of This Document

This document aims to provide an overview of the entire 5G Mobile Communication System (UE, gNB, 5GC) system for developers, test engineers, and network operators. Specifically, it serves the following purposes:

1. **Enhancing Understanding of the 5G Mobile Communication System System**
    - Clarifies the roles and functions of each component (UE, gNB, 5GC).
    - Explains system-wide interactions and communication flows.
2. **Supporting Efficient Development and Integration**
    - Organizes essential information for developers working on system design and protocol stack implementation.
    - Describes interface (I/F) specifications and the application of standard regulations.
3. **Providing Guidelines for Testing and Debugging**
    - Assists test engineers in creating practical verification plans.
    - Defines criteria for system behavior analysis and performance evaluation.
4. **Optimizing Operations and Maintenance**
    - Helps network operators acquire fundamental knowledge of system monitoring and troubleshooting.
    - Shares key design considerations for maintainability and scalability.

This document serves as a comprehensive reference for all phases of 5G system design, implementation, and operation. It is structured to allow readers with diverse technical backgrounds to efficiently access the necessary information.

5. Diagram


1.1 Purpose of the Document
Understanding the Overall Picture
System Structure
Provides information useful for development
Complements the overall picture
Communication Flow
Development Support
Design Information
Details necessary for design
Protocol Specifications
Supports test case creation
Testing Support
Test Plan
Guidelines for test design
Evaluation Criteria
Provides operational evaluation criteria
Operations Support
Monitoring and Troubleshooting
Enhances operational efficiency
Maintainability Improvement

1.2 Target Audience

This document is intended for professionals in the following roles. By utilizing this document according to their responsibilities, readers can improve efficiency in the development, testing, and maintenance of the 5G Mobile Communication System system.

1.2.1 Categories of Target Audience

Developers

- Engineers involved in 5G Mobile Communication System software development
- Hardware designers
- Implementers of protocol stacks and device drivers

Test Engineers

- Technicians conducting unit tests, integration tests, and performance tests for 5G Mobile Communication System
- Developers of test automation scripts

Operations and Maintenance

- Engineers responsible for network operations and management
- Technicians handling network troubleshooting and optimization

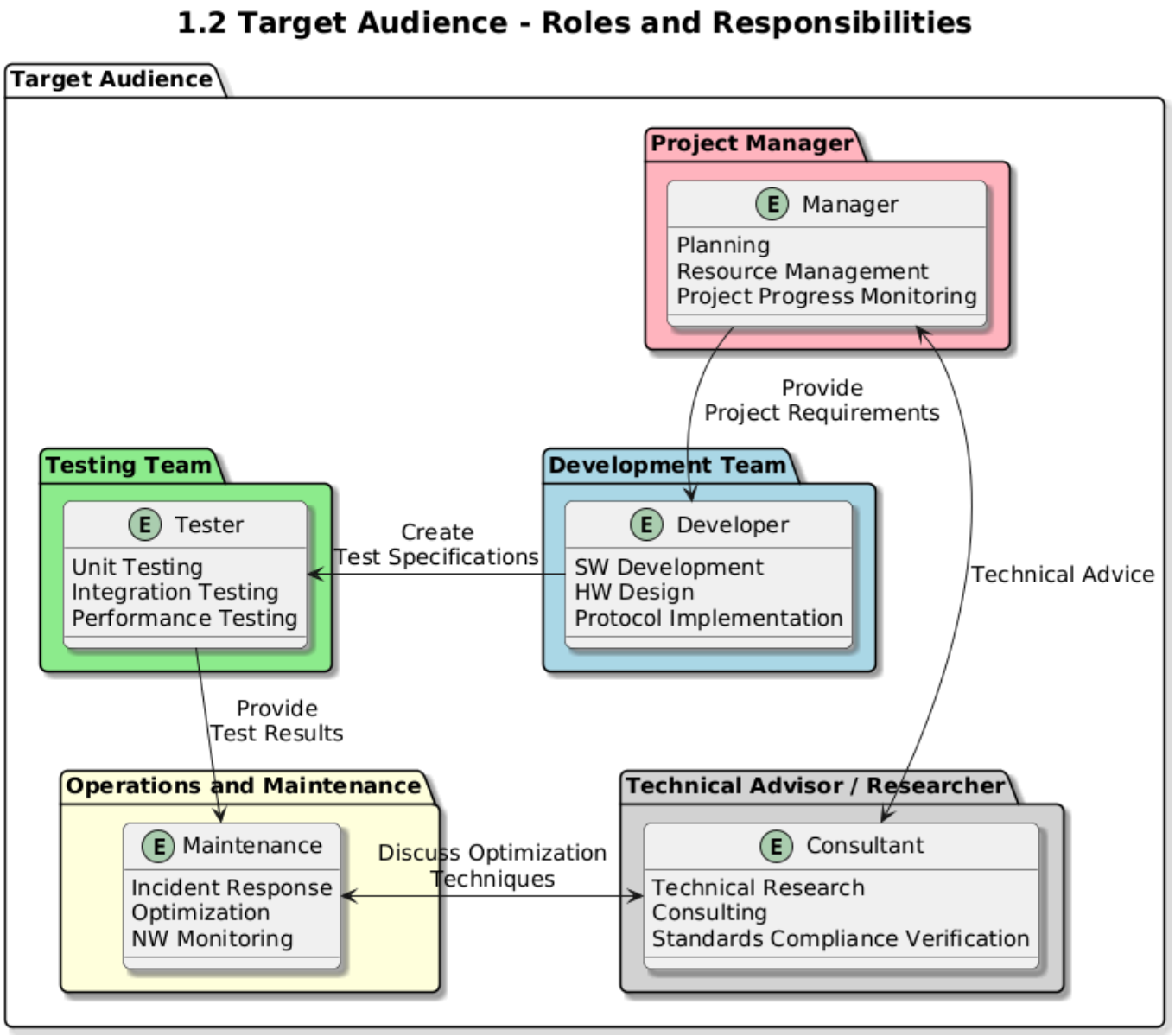
Project Managers

- Professionals overseeing project planning, resource management, and progress monitoring
- Coordinators facilitating communication between technical teams and customers

Technical Consultants / Researchers

- Experts conducting research and consulting for the adoption of emerging technologies
- Researchers involved in standards compliance verification and advanced technology development

1.2.2 Roles of Target Readers and Their Interrelationships



1.3 Glossary and Abbreviations

This section explains frequently used terms and abbreviations in 5G system development. The terms are categorized into major components, protocol layers, interfaces (I/F), technical aspects, security, and operations.

1.3.1 Major Components

UE (User Equipment)

- Definition: A terminal device that connects to the 5G system (e.g., smartphones, IoT devices, modems).
- Role: Connects to the 5GC via the gNB and facilitates communication between the user and the network.

gNB (Next Generation NodeB)

- Definition: A base station for 5G NR (New Radio).
- Role: Communicates with the UE via the wireless interface (NR-Uu) and exchanges data and signaling with the 5GC.

5GC (5G Core Network)

- Definition: The core part of the 5G network that provides user connectivity, control, and management.
- Role: Manages session control, mobility, QoS enforcement, and user plane data processing.

1.3.2 Protocol Layers

RRC (Radio Resource Control)

- Definition: A protocol for managing radio resources.
- Role: Handles control signal exchange between the UE and gNB, as well as connection establishment, maintenance, and release.

SDAP (Service Data Adaptation Protocol)

- Definition: A protocol layer that maps QoS flows to Data Radio Bearers (DRBs).
- Role: Manages data flows based on QoS requirements.

PDCP (Packet Data Convergence Protocol)

- Definition: A protocol responsible for encryption, header compression, and reordering of data.
- Role: Enhances data efficiency and security over the wireless interface.

RLC (Radio Link Control)

- Definition: A protocol layer that manages retransmissions and segmentation/reassembly of data.
- Role: Ensures reliable data transmission.

PHY (Physical Layer)

- Definition: The layer responsible for modulation, demodulation, and signal transmission.

- Role: Enables physical data communication using technologies such as beamforming and MIMO.

1.3.3 Interfaces (I/F)

NR-Uu

- Definition: The wireless interface between the UE and gNB.
- Role: Manages the transmission and reception of data and signaling.

NG-C (Next Generation Control Plane)

- Definition: The control plane interface between the gNB and AMF.
- Role: Facilitates the exchange of control signals (e.g., mobility and session management).

NG-U (Next Generation User Plane)

- Definition: The user plane interface between the gNB and UPF.
- Role: Transmits user data flows.

N2

- Definition: The interface used between the gNB and AMF.
- Role: Facilitates the exchange of control plane information.

N3

- Definition: The interface used between the gNB and UPF.
- Role: Handles user plane data transmission.

1.3.4 Technical Aspects

MIMO (Multiple Input Multiple Output)

- Definition: A communication technology that utilizes multiple transmitting and receiving antennas.
- Role: Enhances communication efficiency and increases throughput.

Beamforming

- Definition: A technology that generates directional wireless beams.
- Role: Optimizes signal quality and reduces interference.

QoS (Quality of Service)

- Definition: A mechanism for ensuring communication quality.
- Role: Improves user experience by managing latency, bandwidth, and priority.

1.3.5 Security and Operations

AMF (Access and Mobility Management Function)

- Definition: The mobility management function in the 5GC.
- Role: Manages UE registration, connection, and tracking area updates.

UPF (User Plane Function)

- Definition: A function that processes user plane data in the 5GC.
- Role: Handles user data flow and connects to external networks such as the internet.

SUPI (Subscription Permanent Identifier)

- Definition: A unique identifier for a user.
- Role: Used for authentication during UE registration.

KDF (Key Derivation Function)

- Definition: An algorithm used to generate encryption keys for secure communication.
- Role: Generates security keys to ensure data protection.

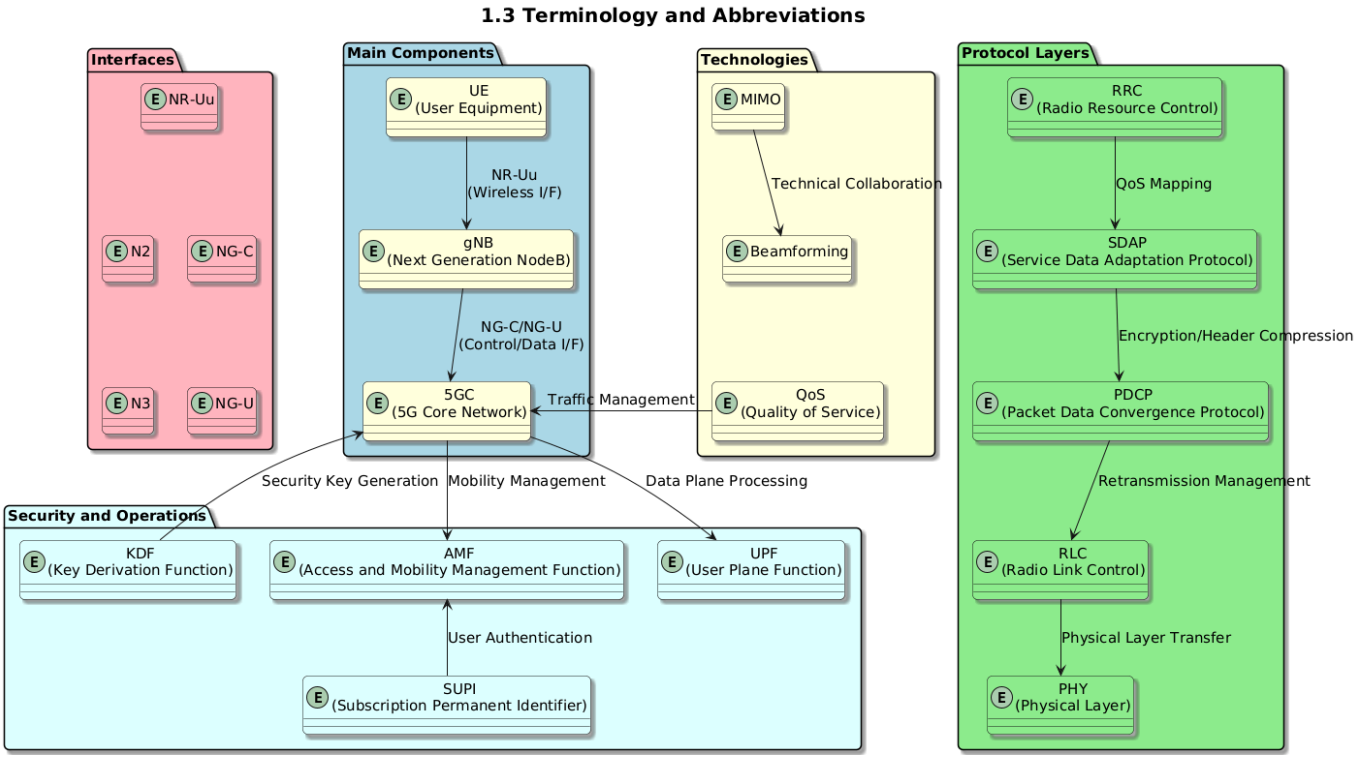


Diagram Description

Key Components:

- The UE connects to the 5GC via the gNB to enable communication.
- The gNB connects to the UE via NR-Uu and to the 5GC via NG-C/NG-U for control and user plane communication, respectively.

Protocol Layers:

- RRC is responsible for radio resource management, with each protocol layer playing a hierarchical role.
- The diagram illustrates the relationships between protocols, showing how data flows from upper layers to lower layers.

Interfaces (I/F):

- Covers wireless communication (NR-Uu), control plane (NG-C), user plane (NG-U), and internal interfaces (N2/N3).

Technical Aspects:

- MIMO and Beamforming work together to enhance transmission efficiency.
- QoS is a core function of the 5GC, ensuring traffic management and service differentiation.

Security and Operations:

- SUPI-based authentication and KDF-driven encryption establish a secure communication framework.

This diagram helps 5G system developers systematically understand key components, protocol layers, interfaces, technical aspects, and security functions.

1.4 References and Related Documents

1.4.1 Standards and Technical Specifications

3GPP Technical Specifications

- TS 38.211: General specifications for NR physical layer
- TS 38.331: RRC protocol specification
- TS 38.401: NG-RAN architecture

ITU-R Recommendations

- M.2083: Vision for IMT-2020
- M.2150: 5G radio interface

1.4.2 Reference Books and White Papers

Books

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

White Papers

- Latest technical reports from major vendors (e.g., Qualcomm, Ericsson, Nokia)

1.4.3 Development and Testing Tool Documentation

Simulation Tools

- Official manuals for Ns-3 and OMNet++

Protocol Analysis Tools

- Wireshark for 5G official guide

Debugging Tools

- Reference guides for JTAG/ETM tools

1.4.4 API References

UE Modem API

- Qualcomm Snapdragon API documentation
- Usage guide for Modem Link Manager (MLM)

5GC API

- Network Function Service API specifications (3GPP TS 29 series)
- Details on NF interfaces (e.g., N1, N2, N3)

1.4.5 Open Source Resources

- Open5GS (Open Source 5G Core) official documentation
- srsRAN (formerly srsLTE) official reference guide

2. Overview of 5G Mobile Communication System

2.1 Basic Concepts and Key Features of 5G

Basic Concepts

5G is designed as the next-generation mobile communication system, offering significantly enhanced performance compared to 4G LTE. Its primary objectives are as follows:

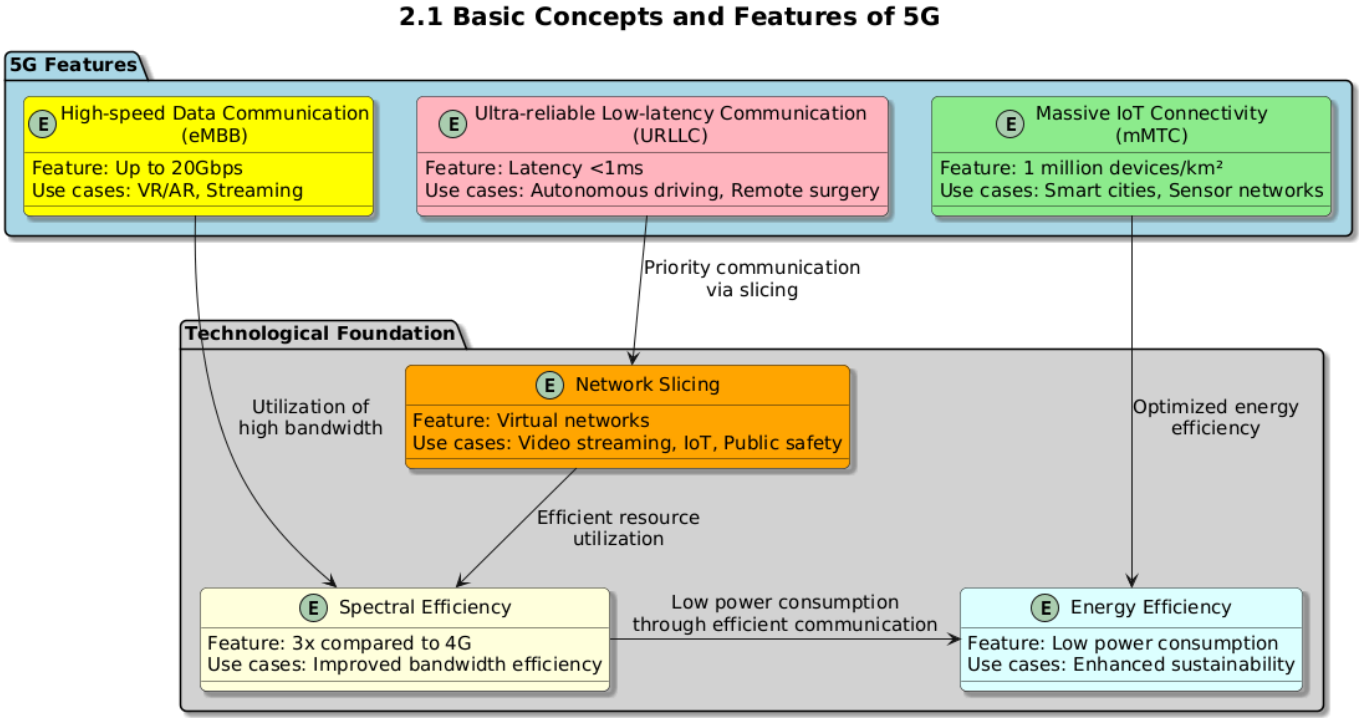
- High-speed data communication (eMBB: Enhanced Mobile Broadband)
- Massive IoT connectivity (mMTC: Massive Machine-Type Communication)
- Ultra-low latency communication (URLLC: Ultra-Reliable Low-Latency Communication)

These capabilities enable a flexible and efficient communication infrastructure that supports a wide range of use cases.

Key Features

1. **High Speed and Large Capacity**
    - Supports a maximum download speed of up to 20 Gbps.
    - Improves spectral efficiency to approximately three times that of 4G.
    - Enables flexible bandwidth utilization with carrier aggregation (CA) up to 400 MHz.
2. **Low Latency**
    - Achieves end-to-end latency of less than 1 millisecond.
    - Supports real-time applications such as autonomous driving and remote surgery.
3. **Scalability for Massive Connectivity**
    - Connects up to one million devices per square kilometer.
    - Facilitates the deployment of smart cities and industrial IoT.
4. **Network Slicing**
    - Uses virtualization technology to create logical networks tailored for specific use cases and applications.
    - Examples include slices for video streaming, IoT applications, and public safety networks.
5. **Energy Efficiency**
    - Aims to reduce power consumption, minimizing energy usage during idle states.
    - Adopts green communication technologies for sustainable network operations.

Diagram: Basic Concepts and Features of 5G



2.2 Components of the 5G Mobile Communication System

The 5G mobile communication system consists of the following key components. These components work together to enable high-speed, low-latency, and massive connectivity.

1. UE: User Equipment

Role:

- A terminal device that initiates or receives communication for end users.

Main Functions:

- Wireless Communication: Communicates with the gNB via the NR-Uu interface.
- Security: Performs authentication using a SIM card or encryption module.
- Application Processing: Supports various 5G services, such as IoT, AR/VR, and eMBB.

2. gNB: Next Generation Node B

Role:

- The core of the RAN, responsible for controlling communication with the UE.

Main Functions:

- NR-Uu Interface Management: Handles communication with the UE over New Radio (NR).
- Beamforming and MIMO: Enables high-throughput communication.
- Protocol Processing: Manages data across PHY, MAC, RLC, PDCP, and SDAP layers.
- Connectivity with 5GC: Uses N2 (control plane) and N3 (user plane) interfaces to connect with the 5G Core.

3. 5GC: 5G Core Network

Role:

- Manages session control, traffic routing, authentication, and network slicing.

Main Components:

- AMF: Manages mobility and connections.
- SMF: Establishes and controls PDU sessions.
- UPF: Handles user data forwarding and QoS management.
- NRF: Registers and discovers Network Functions (NF).
- PCF: Manages policy control.
- AUSF: Provides authentication functions.

4. External Networks

Role:

- Provides external connectivity for the 5G network, such as the internet and cloud services.

Primary Use Cases:

- Data Transmission: Sends user data to the internet via the UPF.
- Cloud Computing: Utilizes edge and cloud computing resources.

5. Multi-access Edge Computing (MEC)

Role:

- Handles computing at the network edge to reduce latency and improve data processing efficiency.

Main Functions:

- Local Data Processing: Processes data at the edge to reduce cloud dependency.
- Content Caching: Stores videos and AR/VR content locally for faster access.
- AI and Machine Learning: Supports real-time control for beamforming and QoS optimization.

Connectivity:

- Integration with gNB: MEC is located close to the gNB to provide data processing and caching services.
- Integration with 5GC: Works with UPF for data forwarding and session management.

6. Internal Interfaces in gNB

Key Interfaces:

- F1 Interface:
  - Definition: Connects CU (Centralized Unit) and DU (Distributed Unit).
  - Protocols: F1-C (control plane), F1-U (user plane).
  - Specification: 3GPP TS 38.470.
- E1 Interface:
  - Definition: Connects DU and RU (Radio Unit).
  - Protocols: eCPRI, IEEE 1914.1.
  - Purpose: Digital fronthaul communication.
- S1 Interface:
  - Definition: Used for communication between gNB and MEC via proprietary or extended protocols.
  - Purpose: Enables coordination of edge data processing.

7. Operations, Administration, and Maintenance (OAM) System

Role:

- Manages network configuration, monitoring, and troubleshooting.

Main Functions:

- Network Monitoring:
  - Monitors network status in real-time and detects anomalies.
  - Primarily uses SNMP (Simple Network Management Protocol).
- Configuration Management:
  - Manages device configurations and modifications.
  - Configurations are changed via GUI or CLI.
- Fault Management:
  - Identifies root causes using troubleshooting tools.

- Collects and analyzes system logs.

8. gNB and 5GC Integration

Key Interfaces:

- NG-C (N2):
  - Role: Used for control plane communication.
  - Protocol: NGAP (Next Generation Application Protocol).
  - Specification: 3GPP TS 38.413.
- NG-U (N3):
  - Role: Supports user data transfer (user plane).
  - Protocol: GTP-U (GPRS Tunneling Protocol).
  - Specification: 3GPP TS 38.414.

9. MEC and gNB Integration

Main Connectivity:

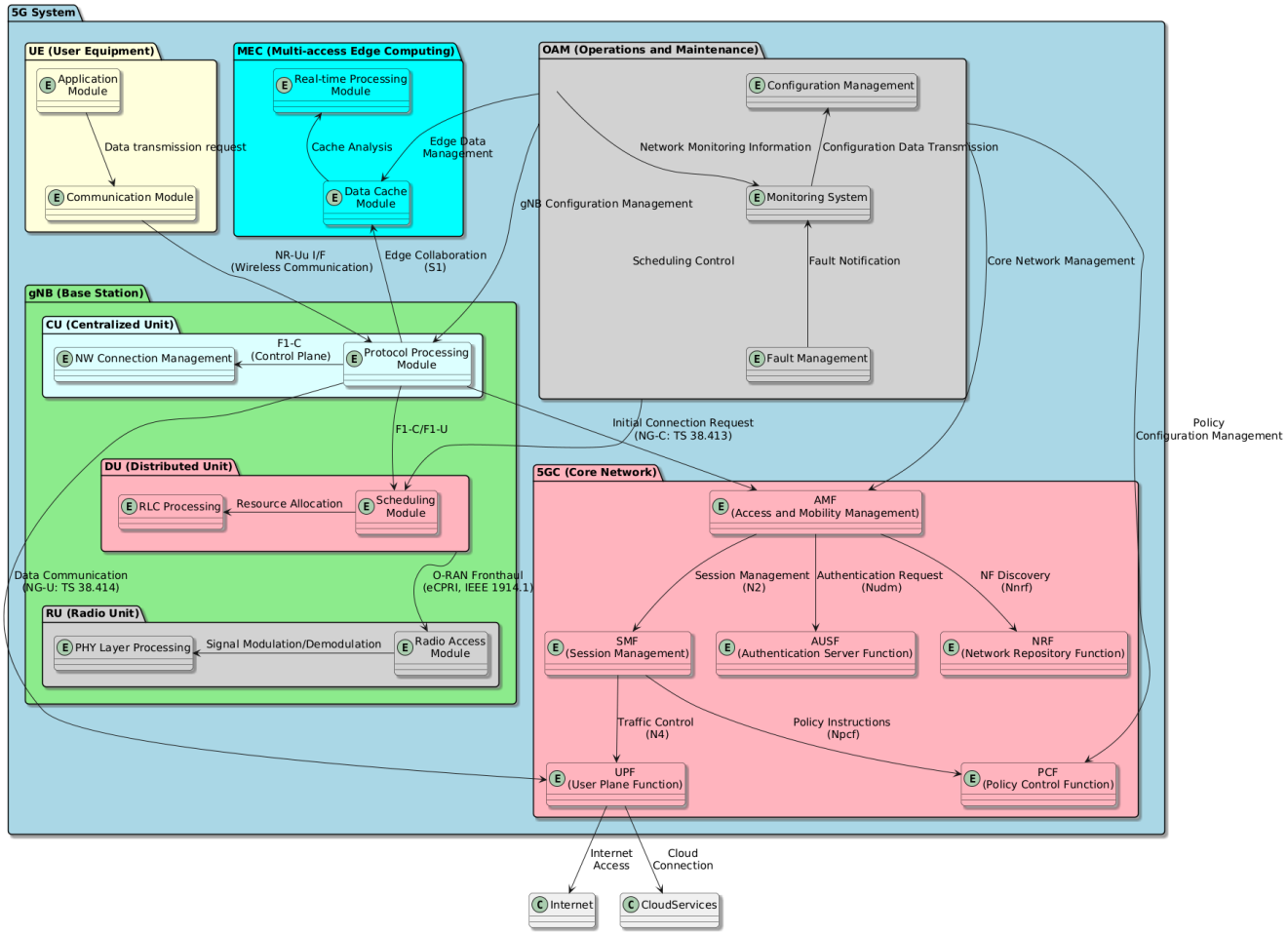
- Interface:
  - S1 (or proprietary extended interfaces).
- Role:
  - Handles local data processing and content caching from the gNB.
- Protocol:
  - Uses HTTP/2 or custom protocols.

10. Implementation of Monitoring and Maintenance Systems (OAM)

Integrated Management:

- Monitoring and Alerts:
  - Monitors network status in real-time and sends alerts in case of failures.
- Configuration Management:
  - Allows remote configuration changes via CLI or GUI.
- Traffic Analysis:
  - Visualizes traffic patterns for network optimization.

2.2 Components of the 5G Mobile Communication System



2.3 Standards and Releases (3GPP)

2.3.1 Overview of 3GPP

3GPP is an international standardization organization responsible for developing communication standards.
The 5G standards began with 3GPP Release 15 and have continued evolving beyond Release 17.

2.3.2 Key Releases and Their Features

- Release 15:
  - The first 5G NR specification.
  - Focuses on Enhanced Mobile Broadband (eMBB).
  - Defines both Non-Standalone (NSA) and Standalone (SA) architectures.
- Release 16:
  - Enhancements to 5G NR (including URLLC and mMTC).
  - Support for Time-Sensitive Networking (TSN).
  - Introduction of 5G V2X (vehicle-to-vehicle communication).
- Release 17:
  - Support for IoT and emerging industries (low-power features, satellite communications).
  - Enhancements for remote control and industrial IoT applications.

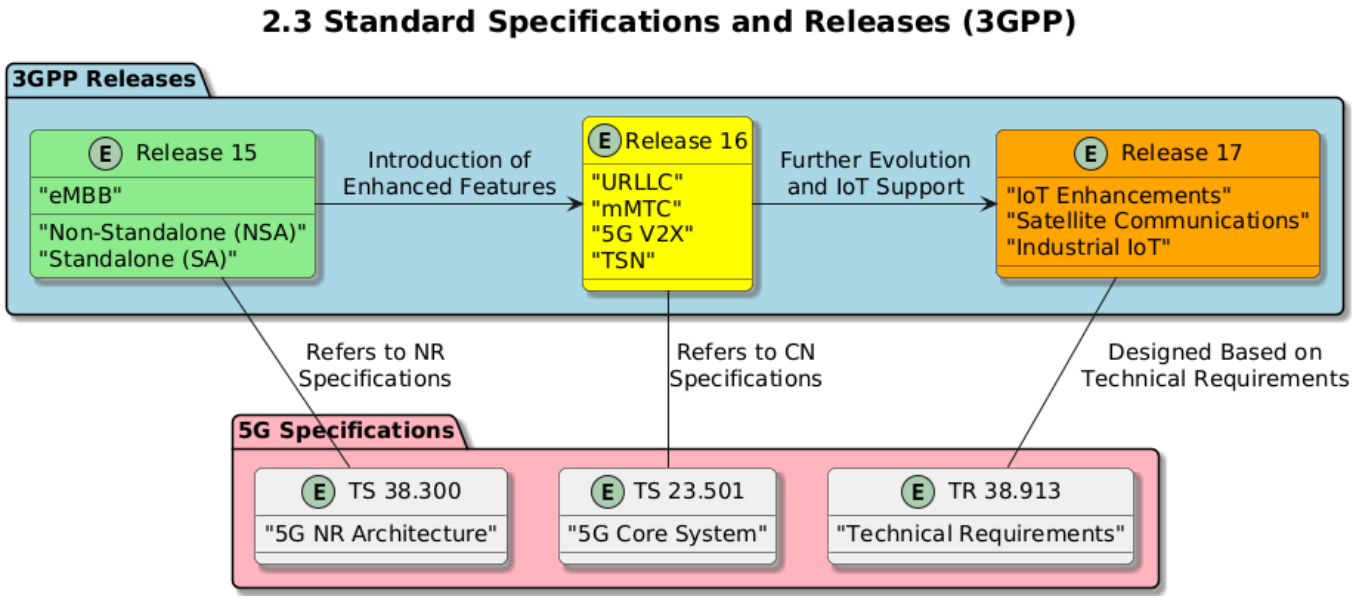
2.3.3 Structure of 3GPP Specifications

- TS (Technical Specifications): Technical documents defining the standards.
  - TS 38.300: 5G NR architecture.
  - TS 23.501: 5G Core system architecture.
- TR (Technical Reports): Reports providing technical analysis.
  - TR 38.913: Technical requirements for 5G.

2.3.4 Relationships Between Standards in 5G Mobile Communication System

- Defines the interoperability of protocols and interfaces between UE, gNB, and 5GC.
- Analyzes the impact of changes and enhancements introduced in each release.

Diagram: Structure and Relationships of 3GPP Releases



Explanation

Color Coding and Grouping:

- Each 3GPP release is color-coded:
  - Release 15: Green
  - Release 16: Yellow
  - Release 17: Orange
- Related specifications are placed in separate packages (Pink).

Arrows and Descriptions:

- Arrows indicate the evolutionary relationships between releases and dependencies on related specifications.
- Descriptions are added to the arrows to clearly explain the advancements made.

Practicality:

- Helps developers easily understand the features of each release and grasp their specific interrelations.
- Provides a visual representation of the priority and references for relevant specifications.

This structure allows for an efficient understanding of 3GPP release evolution and standard relationships. Additionally, it enables easy incorporation of supplementary information as needed.

2.4 Use Cases and Applications

This section describes specific use cases of the 5G Mobile Communication System and provides implementation examples of related 5G features and applications for each scenario. The 5G Mobile Communication System is designed to support a wide range of use cases and applications. Below are the key use cases and their characteristics.

2.4.1 Enhanced Mobile Broadband (eMBB)

Overview:

Enables high-speed downloads, streaming, and immersive AR/VR experiences.

Application Examples:

- 4K/8K video streaming
- Virtual reality (VR) gaming and immersive learning

2.4.2 Ultra-Reliable Low-Latency Communications (URLLC)

Overview:

Supports communications that require extremely low latency and high reliability.

Application Examples:

- Autonomous vehicles
- Remote medical surgery
- Industrial IoT robot control

2.4.3 Massive Machine-Type Communications (mMTC)

Overview:

Allows simultaneous connectivity of a large number of IoT devices with low power consumption.

Application Examples:

- Smart city infrastructure (smart meters, traffic management)
- Agricultural IoT (smart irrigation, soil sensors)

2.4.4 Network Slicing

Overview:

Provides independent virtual networks for different users and services.

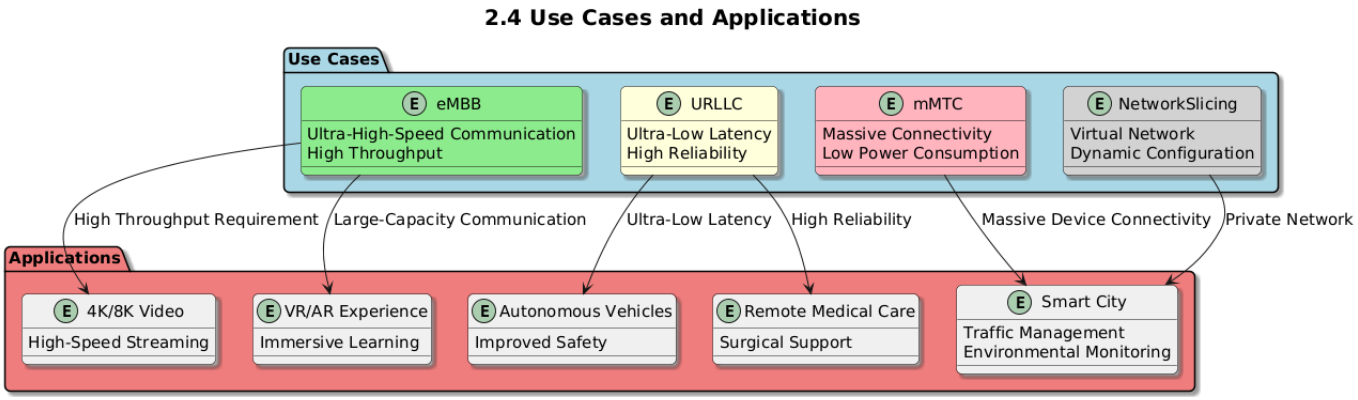
Application Examples:

- Private networks for enterprises
- Public safety networks

2.4.5 Other Use Cases

- Cloud gaming: Requires high throughput and low latency.
- Smart factories: Supports robotic control and AI-based monitoring systems.
- Education: Enables remote learning and AR-based educational experiences.

Diagram


2.4 Use Cases and Applications
Use Cases
eMBB
Ultra-High-Speed Communication
High Throughput
URLLC
Ultra-Low Latency
High Reliability
mMTC
Massive Connectivity
Low Power Consumption
NetworkSlicing
Virtual Network
Dynamic Configuration
High Throughput Requirement
Large-Capacity Communication
Ultra-Low Latency
High Reliability
Massive Device Connectivity
Private Network
Applications
4K/8K Video
High-Speed Streaming
VR/AR Experience
Immersive Learning
Autonomous Vehicles
Improved Safety
Remote Medical Care
Surgical Support
Smart City
Traffic Management
Environmental Monitoring