Understanding the 5G NR Protocol Stack

Concepts, Insights, and Key Learnings

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1 High-Level Overview of Mobile Generations

1.1 1G — Analog Voice

- Introduced in the 1980s
- Used FM modulation and FDMA
- Supported only voice communication
- No encryption or data support

1.2 2G — Digital Network Era

- GSM and CDMA introduced
- Voice became digital
- Supported SMS and MMS
- Basic data services using GPRS and EDGE

1.3 3G — Mobile Internet

- Introduced UMTS, WCDMA, and HSPA
- Enabled internet access and video calling
- Data speeds up to several Mbps

1.4 4G LTE — Mobile Broadband

- All-IP packet-based system
- Introduced OFDM, MIMO, and Carrier Aggregation
- Speeds up to 1 Gbps with very low latency

1.5 5G NR — Massive Connectivity

- Extremely high speeds (10+ Gbps)
- Ultra-low latency (around 1 ms)
- Massive IoT device support
- Technologies such as beamforming, mmWave, and network slicing

2 Role of 3GPP in 5G

3GPP produces global mobile communication standards. The key releases that shaped 5G are:

- Release 15: First 5G NR specifications
- Release 16: URLLC, V2X, and industrial IoT support
- Release 17: RedCap, satellite NR, and further enhancements

3GPP defines:

- Physical layer (PHY)
- MAC, RLC, PDCP, SDAP
- RRC procedures
- 5G Core architecture
- Spectrum and RF rules

3 Overview of 5G Basics, Components, and Deployment

3.1 5G Use Case Categories

- eMBB: High throughput for video streaming and AR/VR
- URLLC: Critical low-latency applications
- mMTC: Large-scale IoT deployments

3.2 5G Network Components

- gNB: Next-generation NodeB
- AMF: Access and Mobility Management Function
- SMF: Session Management Function
- UPF: User Plane Function
- UE: User Equipment

3.3 Deployment Options

- NSA: 5G NR with LTE anchor
- SA: Standalone 5G with 5G Core

4 Overview of 5G Concepts

4.1 Network Slicing

Multiple virtual networks are created on a single physical infrastructure.

4.2 Beamforming

Directional transmission using antenna arrays to improve coverage and capacity.

4.3 Massive MIMO

Uses dozens of antennas to significantly increase network capacity.

4.4 Flexible Numerology

Subcarrier spacing is given by:

$$\Delta f = 15 \times 2^n \text{ kHz}$$

4.5 Carrier Aggregation

Combines multiple carriers to increase throughput.

5 Layer 3: RRC (Radio Resource Control)

RRC is responsible for all signaling between the UE and the gNB.

5.1 RRC States

- Idle: UE camps on cell and receives paging
- Inactive: Reduced signaling load
- Connected: Dedicated resources allocated

5.2 RRC Functions

1. Connection establishment
2. Connection reconfiguration (DRBs, mobility, beam, security)
3. Mobility management (measurements, handover, reselection)
4. System information broadcast via MIB and SIBs
5. Security activation (ciphering and integrity)
6. Paging
7. Radio bearer control (SRB0, SRB1, SRB2, DRB)
8. QoS and layer configuration

6 Layer 2: SDAP, PDCP, RLC, MAC

Layer 2 interfaces higher layers with the physical layer and ensures QoS, security, and reliability.

6.1 SDAP

Maps QoS flows to DRBs using QoS Flow Identifier (QFI) and supports uplink and downlink QoS handling.

6.2 PDCP

Provides header compression (ROHC), ciphering, integrity protection, reordering, duplicate detection, and replay protection.

6.3 RLC

Supports:

- Acknowledged Mode (AM)
- Unacknowledged Mode (UM)

- Transparent Mode (TM)

Performs segmentation, reassembly, and reordering.

6.4 MAC

Handles scheduling, HARQ, buffer status reporting, logical channel prioritization, and synchronization with PHY.

6.5 Additional PHY Concepts

- OFDM: Flexible numerology and multipath robustness
- MIMO: Spatial multiplexing
- HARQ: FEC with retransmissions
- AMC: Adaptive modulation and coding

7 Design of PDCCH and PDSCH Channels

7.1 PDCCH Block Architecture

1. CRC attachment
2. Polar encoding
3. Rate matching
4. Scrambling
5. QPSK modulation
6. REG/CCE mapping
7. Mapping into CORESET

7.2 PDSCH Block Architecture

1. CRC attachment
2. LDPC encoding
3. Code block segmentation
4. Rate matching
5. Scrambling

6. Modulation (QPSK to 256QAM)
7. Layer mapping
8. Precoding
9. DMRS insertion
10. Resource mapping
11. OFDM signal generation

8 Reference Signals in 5G NR

8.1 SSB

Used for initial cell search and synchronization. Contains PSS, SSS, and PBCH.

8.2 DM-RS

UE-specific reference signal used for channel estimation and coherent demodulation.

8.3 CSI-RS

Used for channel quality measurement and CSI reporting.

8.4 PT-RS

Compensates phase noise at high frequencies.

8.5 SRS

Uplink reference signal for channel estimation, scheduling, and beam management.

9 Control Resource Set (CORESET)

CORESET defines the time-frequency resources for PDCCH transmission. It supports flexible placement, CCE aggregation, beam-based transmission, and efficient control signaling.

Weekly Task Report

HTML, CSS & Basic C Programming

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10 Objective

The objective of this weekly task report is to document the learning and practical implementation of HTML, CSS, and Basic C Programming concepts covered during the last whole week.

11 Day 1 – HTML Basics

11.1 Topics Covered

- Introduction to HTML
- Structure of HTML document
- Headings and paragraphs

11.2 Sample Code

[language=HTML] ¡!DOCTYPE html¿ ¡html¿ ¡head¿ ¡title¿Day 1¡/title¿ ¡/head¿ ¡body¿ ¡h1¿HTML Basics¡/h1¿ ¡p¿This is a simple HTML page.¡/p¿ ¡/body¿ ¡/html¿

12 Day 2 – HTML Lists and Links

12.1 Topics Covered

- Ordered and unordered lists
- Anchor tags
- Images

13 Day 3 – CSS Basics

13.1 Topics Covered

- Inline, internal, and external CSS
- Colors and fonts
- Background styling

13.2 Sample CSS Code

[language=CSS] body background-color: eef2f3; font-family: Arial; h1 color: darkblue;

14 Day 4 – CSS Box Model

14.1 Topics Covered

- Margin, padding, and border
- Width and height
- Basic layout design

15 Day 5 – C Programming Basics

15.1 Topics Covered

- Structure of C program
- Variables and data types
- printf and scanf

15.2 Sample C Program

[language=C] include ¡stdio.h¿ int main() int a; printf("Enter a number: "); scanf("printf("You entered: return 0;

16 Day 6 – C Operators and Conditions

16.1 Topics Covered

- Arithmetic operators
- if-else statements
- Relational operators

17 Day 7 – Revision and Practice

17.1 Activities

- Revised HTML and CSS concepts
- Practiced basic C programs
- Debugged simple errors

18 Learning Outcome

- Understood basic web page structure using HTML
- Applied styling concepts using CSS
- Developed simple programs using C language

19 Conclusion

The last whole week of practice strengthened my foundation in web development and programming concepts, preparing me for advanced topics in the coming weeks.

— End of Weekly Report —