



5G Wireless

A Comprehensive Introduction

Dr. William Stallings

5G Wireless: A Comprehensive Introduction

Table of Contents

Cover

Title Page

Copyright Page

Dedication

Contents at a Glance

Contents

Preface

Part I: Overview

Chapter 1: Cellular Networks: Concepts and Evolution

- 1.1 Evolution of Cellular Networks
- 1.2 Cellular Network Concepts

Cellular Organization

Network System Elements

Operation of Cellular Systems

- 1.3 First Generation (1G)
- 1.4 Second Generation (2G)

Time-Division Multiple Access

GSM Architecture

Radio Link Aspects

1.5 Third Generation (3G)

Code-Division Multiple Access

3G Architecture

1.6 Fourth Generation (4G)



E-UTRAN

LTE-Advanced Transmission Characteristics

Evolved Packet Core

1.7 Key Terms and Review Questions

Key Terms

Review Questions

Chapter 2: 5G Standards and Specifications

2.1 ITU-R and IMT-2020

International Mobile Telecommunications

Capabilities

Usage Scenarios

Use Cases

Evaluation

2.2 ITU-T and IMT-2020

Requirements

Network Slicing

Fixed Mobile Convergence

IMT-2020 Core Network Framework

2.3 3GPP

3GPP Releases

Detailed Requirements

2.4 Key Terms and Review Questions

Key Terms

Review Questions

2.5 References and Documents

References

Documents

Chapter 3: Overview of 5G Use Cases and Architecture

3.1 5G Use Cases

ITU-R

5G Americas

NGMA Alliance



3.2 NGMN 5G Architecture Framework

Layered Functionality

Network Slicing

3.3 3GPP 5G Architecture

5G Core Network Architecture

Radio Access Network Architecture

Session Establishment

3.4 Key Terms and Review Questions

Key Terms

Review Questions

3.5 References and Documents

References

Documents

Part II: Use Cases and Applications

Chapter 4: Enhanced Mobile Broadband

4.1 eMBB Deployment Scenarios

Indoor Hotspot

Dense Urban

Rural

4.2 eMBB Performance Characteristics

Data Rate Requirements

Spectral Efficiency Requirements

Latency Requirements

Mobility Requirements

System Requirements

- 4.3 Smart Office: An Indoor Hotspot Use Case
- 4.4 Dense Urban Information Society: A Dense Urban Use Case
- 4.5 Radiocommunication Systems Between Train and Trackside: A Rural eMBB

Use Case

Elements of RSTT

Applications of RSTT

Broadband Connectivity for Passengers



Linear Cell Architecture

4.6 Key Terms and Review Questions

Key Terms

Review Questions

4.7 References and Documents

References

Documents

Chapter 5: Massive Machine Type Communications

5.1 mMTC Performance Requirements

5.2 The Internet of Things

The Scope of the Internet of Things

Things on the Internet of Things

Components of IoT-Enabled Things

Constrained Devices

IoT and Cloud Context

5.3 Relationship Between mMTC and the IoT

5.4 Relationship Between mMTC and NB-IoT and eMTC

Comparison of NB-IoT and eMTC

Low-Power Wide Area (LPWA)

5.5 Smart Agriculture

Model of IoT Deployment

Use Cases

Precision Crop Management

Network Performance Requirements

5.6 Smart Cities

Smart City Use Cases

ICT Architecture for Smart Cities

Network Performance Requirements

5.7 Key Terms and Review Questions

Key Terms

Review Questions

5.8 References and Documents



References

Documents

Chapter 6: Ultra-Reliable and Low-Latency Communications

6.1 URLLC Performance Requirements

Latency

Mobility

Reliability

NGMN Definitions

6.2 URLLC Use Cases in Emerging Mission-Critical Applications

Industrial Automation

Ground Vehicles, Drones, and Robots

Tactile Interaction

Augmented Reality and Virtual Reality

Emergencies, Disasters, and Public Safety

Urgent Healthcare

Intelligent Transportation

6.3 URLLC Applications Based on Performance Requirements

Higher Reliability and Lower Latency

Higher Reliability, Higher Availability, and Lower Latency

Very Low Latency

Higher Accuracy Positioning

Higher Availability

Mission-Critical Services

6.4 Industry 4.0

Factory Automation Architecture

Application Areas

Use Cases

Performance Requirements

6.5 Unmanned Aircraft System Traffic Management

UTM Architecture

5G Performance Requirements for UTM

6.6 Key Terms and Review Questions



Key Terms

Review Questions

6.7 References and Documents

References

Documents

Part III: 5G NextGen Core Network

Chapter 7: Software-Defined Networking

7.1 Evolving Network Requirements

7.2 The SDN Approach

Modern Network Requirements

SDN Architecture

Characteristics of Software-Defined Networking

7.3 SDN Data Plane

Data Plane Functions

Data Plane Protocols

7.4 OpenFlow

Flow Table Structure

Flow Table Pipeline

The Use of Multiple Tables

Group Table

OpenFlow Protocol

7.5 SDN Control Plane

Control Plane Functions

Southbound Interface

Northbound Interface

Eastbound Interface

Westbound Interface

7.6 SDN Application Plane

Application Plane Architecture

Northbound Interface

Network Services Abstraction Layer

Network Applications



User Interface

7.7 Key Terms and Review Questions

Key Terms

Review Questions

7.8 References and Documents

References

Documents

Chapter 8: Network Functions Virtualization

8.1 Background and Motivation for NFV

8.2 Virtual Machines and Containers

Hypervisor

Architectural Approaches

Container Virtualization

8.3 NFV Concepts

Simple Example of the Use of NFV

NFV Principles

High-Level NFV Framework

8.4 NFV Benefits and Requirements

NFV Benefits

NFV Requirements

8.5 NFV Reference Architecture

NFV Management and Orchestration

Reference Points

8.6 NFV Infrastructure

Container Interface

Deployment of NFVI Containers

Logical Structure of NFVI Domains

Compute Domain

Hypervisor Domain

Infrastructure Network Domain

8.7 Virtualized Network Functions

VNF Interfaces



VNFC-to-VNFC Communication

VNF Scaling

8.8 SDN and NFV

8.9 Key Terms and Review Questions

Key Terms

Review Questions

8.10 References and Documents

References

Documents

Chapter 9: Core Network Functionality, QoS, and Network Slicing

9.1 Core Network Requirements

Network Operational Requirements

Basic Network Requirements

9.2 Core Network Functional Architecture

Tunneling

PDU Session Establishment

Policy Control Function

9.3 Quality of Service

QoS Capabilities

QoS Architectural Framework

QoS Classification, Marking, and Differentiation

3GPP QoS Architecture

QoS Parameters

QoS Characteristics

Standardized 5QI-to-QoS Characteristic Mapping

9.4 Network Slicing

Network Slicing Concepts

Requirements for Network Slicing

Identifying and Selecting a Network Slice

Functional Aspects of Network Slicing

Generic Slice Template

9.5 SDN and NFV Support for 5G



9.6 Key Terms and Review Questions

Key Terms

Review Questions

9.7 References and Documents

References

Documents

Chapter 10: Multi-Access Edge Computing

10.1 MEC and 5G

10.2 MEC Architectural Concepts

10.3 ETSI MEC Architecture

Design Principles

MEC System Reference Architecture

Related Elements

10.4 MEC in NFV

MEC Components Implemented as VNFs

MEC Components Replaced by NFV Components

MEC System-Level Components

10.5 MEC Support for Network Slicing

10.6 MEC Use Cases

Consumer-Oriented Services

Operator and Third-Party Services

Network Performance and QoS Improvements

10.7 3GPP Architecture for Enabling Edge Applications

FDGFAPP Functional Architecture

Synergized Mobile Edge Cloud Architecture

10.8 Key Terms and Review Questions

Key Terms

Review Questions

10.9 References and Documents

References

Documents

Part IV: 5G NR Air Interface and Radio Access Network



Chapter 11: Wireless Transmission

11.1 Channel Capacity

Nyquist Bandwidth

Shannon Capacity Formula

11.2 Line-of-Sight Transmission

Refraction

Optical and Radio Line of Sight

11.3 Line-of-Sight Transmission Impairments

Attenuation

Free Space Loss

Path Loss Exponent in Practical Cellular Systems

Noise

The Expression Eb/N0

Atmospheric Absorption

Multipath

Refraction

11.4 Fading in the Mobile Environment

Multipath Propagation

The Effects of Multipath Propagation

Types of Fading

The Fading Channel

11.5 Millimeter Wave Transmission for 5G

Propagation Impairments

Implications for 5G

11.6 Key Terms and Review Questions

Key Terms

Review Questions

11.7 References

ANNEX 11A: Decibels and Signal Strength

Chapter 12: Antennas

12.1 Channel Correction Mechanisms

Adaptive Equalization



Diversity Techniques

Adaptive Modulation and Coding

Forward Error Correction

12.2 Introduction to Antennas

Radiation Patterns

Antenna Types

Antenna Gain

12.3 Multiple-Input/Multiple-Output (MIMO) Antennas

MIMO Principles

Multiple-User MIMO

12.4 Advanced Cellular Antennas

Evolution of Cellular Antennas

Beamforming

Active Antenna Systems

Massive MIMO

12.5 Key Terms and Review Questions

Key Terms

Review Questions

12.6 References

Chapter 13: Air Interface Physical Layer

13.1 Modulation Schemes

Modulation

Amplitude-Shift Keying

Frequency-Shift Keying

Phase-Shift Keying

Quadrature Amplitude Modulation

p/2-BPSK

13.2 OFDM, OFDMA, and SC-FDMA

Orthogonal Frequency-Division Multiplexing

OFDM Implementation

Difficulties of OFDM

Orthogonal Frequency-Division Multiple Access



Single-Carrier FDMA

13.3 Waveforms and Numerologies

Numerology

CP-OFDM

DFT-S-OFDM

13.4 Key Terms and Review Questions

Key Terms

Review Questions

13.5 References and Documents

References

Documents

ANNEX 13A: Multiplexing and Multiple Access

Multiplexing

Multiple Access

Chapter 14: Air Interface Channel Coding

14.1 Transmission Errors

Error Burst

Data Transmission Channels

14.2 Forward Error Correction

Block Error Correction

Hamming Distance

14.3 Parity-Check Matrix Codes

Encoding

Error Detection

Error Correction

14.4 Low-Density Parity-Check Codes

Code Construction

Error Correction

Encoding

14.5 Polar Coding

Polar Encoder

Synthetic Channels



Decoding

14.6 3GPP Channel Coding Specification

Quasi-Cyclic Low-Density Parity-Check Codes

Polar Coding with CRC

14.7 Hybrid Automatic Repeat Request

14.8 Key Terms and Review Questions

Key Terms

Review Questions

14.9 References and Documents

References

Documents

Chapter 15: 5G Radio Access Network

15.1 Overall RAN Architecture

15.2 RANCore Functional Split

RAN Functional Areas

Core Functional Areas

15.3 RAN Channel Structure

Logical Channel

Transport Channels

Physical Channels

15.4 RAN Protocol Architecture

Air Interface Protocol Architecture

Channel Structure

RANCore Network Interface Protocol Architecture

Xn Interface Protocol Architecture

15.5 NG RAN Transport Network

15.6 Integrated Access and Backhaul

IAB Architecture

Parent/Child Relationship

IAB Protocol Architecture

15.7 Key Terms and Review Questions

Key Terms



Review Questions

15.8 References and Documents

References

Documents

Part V: Appendixes

Appendix A: Review Questions and Solutions

Appendix B: Glossary

Appendix C: Acronyms

Index

