Contents

		Contents
law.		
or applicable copyright law		Preface xiii
e cop	1	Global System for Mobile Communications (GSM) 1
cabl	1.1	Circuit-Switched Data Transmission 1
ppli	1.1.1	Classic Circuit Switching 2
or a	1.1.2	Virtual Circuit Switching over IP 3
	1.2	Standards 4
er O	1.3	Transmission Speeds 5
pun	1.4	The Signaling System Number 7 6
tted	1.4.1	The Classic SS-7 Protocol Stack 7
ermi	1.4.2	SS-7 Protocols for GSM 9
න රැ	1.4.3	IP-Based SS-7 Protocol Stack 10
an A	1.5	The GSM Subsystems 12
fai	1.6	The Network Subsystem 12
cept	1.6.1	The Mobile Switching Center (MSC), Server and Gateway 13
ě,	1.6.2	The Visitor Location Register (VLR) 16
sher	1.6.3	The Home Location Register (HLR) 17
ubli	1.6.4	The Authentication Center 20
he p	1.6.5	The Short Messaging Service Center (SMSC) 22
om t	1.7	The Base Station Subsystem (BSS) and Voice Processing 24
n fr	1.7.1	Frequency Bands 24
ssio	1.7.2	The Base Transceiver Station (BTS) 26
ermi	1.7.3	The GSM Air Interface 27
ut p	1.7.4	The Base Station Controller (BSC) 35
itho	1.7.5	The TRAU for Voice Encoding 39
* #	1.7.6	Channel Coder and Interleaver in the BTS 43
, fo	1.7.7	Ciphering in the BTS and Security Aspects 45
a any	1.7.8	Modulation 49
ii	1.7.9	Voice Activity Detection 49
onpo	1.8	Mobility Management and Call Control 51
repro	1.8.1	Cell Reselection and Location Area Update 51
pe 1	1.8.2	The Mobile-Terminated Call 53
not	1.8.3	Handover Scenarios 56
/. Мау	1.9	The Mobile Device 58
filey.	1.9.1	Architecture of a Voice-Centric Mobile Device 58
용급 AN: 1570248	shing : eBook ; Martin Sau nu.main.ehost	: Academic Collection (EBSCOhost) - printed on 1/19/2023 2:35 PM via NTNU UNIVERSITY LIBRARY iter.; From GSM to LTE-Advanced Pro and 5G : An Introduction to Mobile Networks and Mobile Broadband

vi	Content	rs
	1.9.2	Architecture of a Smartphone 60
		The SIM Card 62
	1.11	The Intelligent Network Subsystem and CAMEL 66
	Quest	·
	-	ences 69
	2	General Packet Radio Service (GPRS) and EDGE 71
	2.1	Circuit-Switched Data Transmission over GSM 71
	2.2	Packet-Switched Data Transmission over GPRS 72
	2.3	The GPRS Air Interface 74
	2.3.1	GPRS vs. GSM Timeslot Usage on the Air Interface 74
	2.3.2	Mixed GSM/GPRS Timeslot Usage in a Base Station 77
	2.3.3	Coding Schemes 77
		Enhanced Datarates for GSM Evolution (EDGE) 78
		Mobile Device Classes 82
	2.3.6	Network Mode of Operation 83
	2.3.7	C
	2.4	The GPRS State Model 86
	2.5	
		The Packet Control Unit (PCU) 89
		The Serving GPRS Support Node (SGSN) 91
		The Gateway GPRS Support Node (GGSN) 93
	2.6	· · · · · · · · · · · · · · · · · · ·
	2.7	
		GPRS Mobility Management and Session Management (GMM/SM) 103
		Mobility Management Tasks 103
	2.8.2	GPRS Session Management 106
	Quest	
	Keiere	ences 109
	3	Universal Mobile Telecommunications System (UMTS) and High-Speed Packet Access (HSPA) 111
	3.1	Overview, History and Future 111
	3.1.1	·
	3.1.2	3GPP Release 4: Enhancements for the Circuit-Switched Core Network 115
	3.1.3	3GPP Release 5: High-Speed Downlink Packet Access 116
	3.1.4	3GPP Release 6: High-Speed Uplink Packet Access (HSUPA) 117
	3.1.5	3GPP Release 7: Even Faster HSPA and Continued Packet Connectivity 117
	3.1.6	3GPP Release 8: LTE, Further HSPA Enhancements and Femtocells 118
	3.1.7	3GPP Release 9: Digital Dividend and Dual-Cell Improvements 118
	3.1.8	3GPP Releases 10 and Beyond 119
	3.2	Important New Concepts of UMTS 119
	3.2.1	The Radio Access Bearer (RAB) 119
	3.2.2	The Access Stratum and Non-Access Stratum 120
	3.2.3	Common Transport Protocols for CS and PS 121
	3.3	Code Division Multiple Access (CDMA) 121

Spreading Factor, Chip Rate and Process Gain 125

3.3.2	The OVSF Code Tree 126
3.3.3	Scrambling in Uplink and Downlink Direction 127
3.3.4	UMTS Frequency and Cell Planning 128
3.3.5	The Near–Far Effect and Cell Breathing 129
3.3.6	Advantages of the UMTS Radio Network Compared to GSM 131
3.4	UMTS Channel Structure on the Air Interface 132
3.4.1	User Plane and Control Plane 132
3.4.2	Common and Dedicated Channels 132
3.4.3	Logical, Transport and Physical Channels 133
3.4.4	Example: Network Search 137
3.4.5	Example: Initial Network Access Procedure 139
3.4.6	The Uu Protocol Stack 141
3.5	The UMTS Terrestrial Radio Access Network (UTRAN) 146
3.5.1	Node-B, Iub Interface, NBAP and FP 146
3.5.2	The RNC, Iu, Iub and Iur Interfaces, RANAP and RNSAP 147
3.5.3	Adaptive Multirate (AMR) NB and WB Codecs for Voice Calls 152
3.5.4	Radio Resource Control (RRC) States 154
3.6	Core Network Mobility Management 159
3.7	Radio Network Mobility Management 160
3.7.1	Mobility Management in the Cell-DCH State 160
3.7.2	Mobility Management in Idle State 168
3.7.3	Mobility Management in Other States 170
3.8	UMTS CS and PS Call Establishment 172
3.9	UMTS Security 175
3.10	High-Speed Downlink Packet Access (HSDPA) and HSPA+ 177
3.10.1	HSDPA Channels 177
3.10.2	Shorter Delay Times and Hybrid ARQ (HARQ) 179
3.10.3	Node-B Scheduling 181
3.10.4	Adaptive Modulation and Coding, Transmission Rates and Multicarrier
	Operation 182
3.10.5	Establishment and Release of an HSDPA Connection 184
3.10.6	HSDPA Mobility Management 185
3.11	High-Speed Uplink Packet Access (HSUPA) 186
3.11.1	E-DCH Channel Structure 188
3.11.2	The E-DCH Protocol Stack and Functionality 191
3.11.3	E-DCH Scheduling 192
3.11.4	E-DCH Mobility 195
3.11.5	E-DCH-Capable Devices 195
3.12	Radio and Core Network Enhancements: CPC and One Tunnel 196
3.12.1	A New Uplink Control Channel Slot Format 196
3.12.2	CQI Reporting Reduction and DTX and DRX 197
3.12.3	HS-SCCH Discontinuous Reception 198
3.12.4	HS-SCCH-less Operation 198
3.12.5	Enhanced Cell-FACH and Cell/URA-PCH States 199
3.12.6	Radio Network Enhancement: One Tunnel 201
3.13	HSPA Performance in Practice 202
3.13.1	Throughput in Practice 202

Cell Reselection between LTE and GSM/UMTS 275

RRC Connection Release with Redirect between LTE and GSM/UMTS 276

4.9.1 4.9.2

4.9.3	Handover from LTE to UMTS 277	
4.10	Interworking with CDMA2000 Networks 278	
4.10.1	Cell Reselection between LTE and CDMA2000 Networks 279	
4.10.2	RRC Connection Release with Redirect between LTE and CDMA2000	279
4.10.3	Handover between LTE and CDMA2000 279	
4.11	Carrier Aggregation 280	
4.11.1	CA Types, Bandwidth Classes and Band Combinations 281	
4.11.2	CA Configuration, Activation and Deactivation 283	
4.12	Network Planning Aspects 285	
4.12.1	Single Frequency Network 286	
4.12.2	Cell-Edge Performance 286	
4.12.3	Self-Organizing Network Functionality 287	
4.13	CS-Fallback for Voice and SMS Services with LTE 288	
4.13.1		
4.13.2		
4.14	Voice in Combined LTE and CDMA2000 Networks (SV-LTE) 293	
4.15	Network Sharing – MOCN and MORAN 293	
4.15.1	National Roaming 293	
4.15.2	MOCN (Multi-Operator Core Network) 294	
4.15.3	MORAN (Mobile Operator Radio Access Network) 295	
4.16	From Dipoles to Active Antennas and Gigabit Backhaul 296	
4.17	YD 64 34 141 37 1	
4.17.1		
4.17.2	IPv6 and International Roaming 301	
4.17.3	IPv6 and Tethering 301	
4.17.4	IPv6-Only Connectivity 303	
4.18	Network Function Virtualization 304	
4.18.1	Virtualization on the Desktop 304	
4.18.2	Running an Operating System in a Virtual Machine 305	
4.18.3	Running Several Virtual Machines Simultaneously 306	
4.18.4	Virtual Machine Snapshots 306	
4.18.5	Cloning a Virtual Machine 307	
4.18.6	Virtualization in Data Centers in the Cloud 307	
4.18.7	Managing Virtual Machines in the Cloud 308	
4.18.8	Network Function Virtualization 308	
4.18.9	Virtualizing Routers 310	
4.18.10	Software-Defined Networking 310	
4.19	Machine Type Communication and the Internet of Things 311	
4.19.1	LTE Cat-1 Devices 312	
4.19.2	LTE Cat-0 Devices and PSM 313	
4.19.3	LTE Cat-M1 Devices 313	
4.19.4	LTE NB1 (NB-IoT) Devices 313	
4.19.5	NB-IoT – Deployment Options 314	
4.19.6	NB-IoT – Air Interface 314	
4.19.7	NB-IoT – Control Channels and Scheduling 315	
4.19.8	NB-IoT Multicarrier Operation 316	

4.19.9

NB-IoT Throughput and Number of Devices per Cell 317

x	Contents		
	4.19.10	NB-IoT Power Consumption Considerations 317	
	4.19.11	NB-IoT – High Latency Communication 318	
	4.19.12	NB-IoT – Optimizing IP-Based and Non-IP-Based Data Transmission	319
	4.19.13		
	4.20	Other Features of LTE-Advanced and LTE-Advanced Pro 321	
	4.20.1	8×8 Downlink and 4×4 Uplink MIMO 322	
	4.20.2	Relays 322	
	4.20.3	HetNets, ICIC and eICIC 322	
	4.20.4	Coordinated Multipoint Operation 324	
	4.21	From LTE to 5G 325	
	4.21.1	New Radio for 5G 326	
	4.21.2	Radio Network Evolution for 5G 329	
	4.21.3	Core Network Evolution for 5G 330	
	Question	ns 330	
	Reference	ces 331	
	5	VoLTE, VoWifi and Mission Critical Communication 335	
	5.1	Overview 335	
	5.2	The Session Initiation Protocol (SIP) 336	
	5.3	The IP Multimedia Subsystem (IMS) and VoLTE 340	
	5.3.1	Architecture Overview 340	
	5.3.2	Registration 342	
	5.3.3	VoLTE Call Establishment 344	
	5.3.4	LTE Bearer Configurations for VoLTE 346	
	5.3.5	Dedicated Bearer Setup with Preconditions 348	
	5.3.6	Header Compression and DRX 349	
	5.3.7	Speech Codec and Bandwidth Negotiation 350	
	5.3.8	Alerting Tone, Ringback Tone and Early Media 353	
	5.3.9	Port Usage 354	
	5.3.10	Message Filtering and Asserted Identities 354	
	5.3.11	DTMF Tones 355	
	5.3.12	SMS over IMS 356	
	5.3.13	e e	
	5.3.14	Single Radio Voice Call Continuity 359	
	5.3.15	Radio Domain Selection, T-ADS and VoLTE Interworking with GSM and UMTS 362	
	5.3.16	VoLTE Emergency Calls 364	
	5.4	VoLTE Roaming 365	
	5.4.1	Option 1: VoLTE Local Breakout 367	
	5.4.2	Option 2: VoLTE S8-Home Routing 367	
	5.5	Voice over WiFi (VoWifi) 369	
	5.5.1	VoWifi Network Architecture 370	
	5.5.2	VoWifi Handover 372	
	5.5.3	Wi-Fi-Preferred vs. Cellular-Preferred 373	
	5.5.4	SMS, MMS and Supplementary Services over Wi-Fi 373	
	5.5.5	VoWifi Roaming 374	
	5.6	VoLTE Compared to Fixed-Line IMS in Practice 375	

7	Bluetooth and Bluetooth Low Energy 453
TOTOTOI.	100
Referen	
Questic	
6.8	IEEE 802.11e and WMM – Quality of Service 444
6.7.8	Wi-Fi-Protected Setup (WPS) 442
6.7.7	WPA and WPA2 Encryption 441
6.7.6	WPA and WPA2 Enterprise Mode Authentication – EAP-SIM 439
6.7.5	WPA and WPA2 Enterprise Mode Authentication – EAP-PEAP 438
6.7.4	WPA and WPA2 Enterprise Mode Authentication – EAP-TTLS 437
6.7.3	WPA and WPA2 Enterprise Mode Authentication – EAP-TLS 435
6.7.2	WPA and WPA2 Personal Mode Authentication 434
6.7.1	Wired Equivalent Privacy (WEP) 432
6.7	Wireless LAN Security 432
6.6.6	IEEE 802.11ad – Gigabit Wireless at 60 GHz 428
6.6.5	IEEE 802.11 ac – Gigabit Wireless 424
6.6.4	IEEE 802.11n with up to 600 Mbits/s 415
6.6.3	IEEE 802.11a with up to 54 Mbit/s 415
6.6.2	IEEE 802.11 g with up to 54 Mbit/s 413
6.6.1	IEEE 802.11b – 11 Mbit/s 411
6.6	The Physical Layer and MAC Extensions 410
6.5.2	The MAC Header 409
6.5.1	Air Interface Access Control 406
6.5	The MAC Layer 406
6.4	Management Operations 400
6.3.2	SSID and Frequency Selection 399
6.3.1	Ad Hoc, BSS, ESS and Wireless Bridging 396
6.3	WLAN Configurations: From Ad Hoc to Wireless Bridging 396
6.2	Transmission Speeds and Standards 393
6.1	Wireless LAN Overview 393
6 6 1	Wireless Local Area Network (WLAN) 393
6	Wireless Local Area Network (WLAN) 202
Referen	nces 390
Questio	
5.7.11	Priority and Quality of Service 389
5.7.10	eMBMS for MCPTT 386
5.7.9	MCPTT Configuration and Provisioning 385
5.7.8	MCPTT Group Call Types 385
5.7.7	MCPTT Floor Control 384
5.7.6	MCPTT Group Call Establishment 383
5.7.5	Mission Critical Push To Talk (MCPTT) – Overview 381
5.7.4	Network Operation Models 380
5.7.3	Challenges of Mission Critical Communication for LTE 378
5.7.2	Advantages of LTE for Mission Critical Communication 377
5.7.1	Overview 376
5.7	Mission Critical Communication (MCC) 376

7.2	Physical Properties 454
7.3	Piconets and the Master/Slave Concept 457
7.4	The Bluetooth Protocol Stack 459
7.4.1	The Baseband Layer 460
7.4.2	The Link Controller 465
7.4.3	The Link Manager 468
7.4.4	The HCI Interface 469
7.4.5	The L2CAP Layer 470
7.4.6	The Service Discovery Protocol 473
7.4.7	The RFCOMM Layer 474
7.4.8	Overview of Bluetooth Connection Establishment 476
7.5	Bluetooth Security 476
7.5.1	Pairing up to Bluetooth 2.0 477
7.5.2	Pairing with Bluetooth 2.1 and Above (Secure Simple Pairing) 479
7.5.3	Authentication 480
7.5.4	Encryption 481
7.5.5	Authorization 482
7.5.6	Security Modes 483
7.6	Bluetooth Profiles 484
7.6.1	Basic Profiles: GAP, SDP and the Serial Profile 484
7.6.2	Object Exchange Profiles: FTP, Object Push and Synchronize 486
7.6.3	Headset, Hands-Free and SIM Access Profile 489
7.6.4	High-Quality Audio Streaming 492
7.6.5	The Human Interface Device (HID) Profile 495
7.7	Bluetooth Low Energy 495
7.7.1	Introduction 495
7.7.2	The Lower BLE Layers 497
7.7.3	BLE SMP, GAP and Connection Establishment 499
7.7.4	BLE Authentication, Security and Privacy 500
7.7.5	BLE ATT and GATT 501
7.7.6	Practical Example 503
7.7.7	BLE Beacons 504
7.7.8	BLE and IPv6 Internet Connectivity 505
Quest	
Refere	ences 508

Index *511*