

Contents at a Glance

Preface	xxi
PART I MODERN NETWORKING	3
CHAPTER 1 Elements of Modern Networking	4
CHAPTER 2 Requirements and Technology	38
PART II SOFTWARE DEFINED NETWORKS	75
CHAPTER 3 SDN: Background and Motivation	76
CHAPTER 4 SDN Data Plane and OpenFlow	92
CHAPTER 5 SDN Control Plane	112
CHAPTER 6 SDN Application Plane	144
PART III VIRTUALIATION	175
CHAPTER 7 Network Functions Virtualization: Concepts and Architecture	176
CHAPTER 8 NFV Functionality	198
CHAPTER 9 Network Virtualization	230
PART IV DEFINING AND SUPPORTING USER NEEDS	265
CHAPTER 10 Quality of Service	266
CHAPTER 11 QoE: User Quality of Experience	300
CHAPTER 12 Network Design Implications of QoS and QoE	322
PART V MODERN NETWORK ARCHITECTURE: CLOUDS AND FOG	347
CHAPTER 13 Cloud Computing	348
CHAPTER 14 The Internet of Things: Components	372
CHAPTER 15 The Internet of Things: Architecture and Implementation ..	394
PART VI RELATED TOPICS	433
CHAPTER 16 Security	434
CHAPTER 17 The Impact of the New Networking on IT Careers	466
Appendix A: References	492
Glossary	498
Index	510

Table of Contents

Preface	xxi
PART I MODERN NETWORKING	3
Chapter 1: Elements of Modern Networking	4
1.1 The Networking Ecosystem	5
1.2 Example Network Architectures	7
A Global Network Architecture	7
A Typical Network Hierarchy	9
1.3 Ethernet	11
Applications of Ethernet	11
Standards	14
Ethernet Data Rates	14
1.4 Wi-Fi	19
Applications of Wi-Fi	19
Standards	21
Wi-Fi Data Rates	21
1.5 4G/5G Cellular	23
First Generation	23
Second Generation	23
Third Generation	24
Fourth Generation	24
Fifth Generation	25
1.6 Cloud Computing	25
Cloud Computing Concepts	26
The Benefits of Cloud Computing	27
Cloud Networking	28
Cloud Storage	28

1.7	Internet of Things.	28
	Things on the Internet of Things	28
	Evolution	29
	Layers of the Internet of Things	29
1.8	Network Convergence	30
1.9	Unified Communications	33
1.10	Key Terms	37
1.11	References.	37

Chapter 2: Requirements and Technology 38

2.1	Types of Network and Internet Traffic	39
	Elastic Traffic	39
	Inelastic Traffic	40
	Real-Time Traffic Characteristics.	43
2.2	Demand: Big Data, Cloud Computing, and Mobile Traffic	45
	Big Data	45
	Cloud Computing	48
	Mobile Traffic	51
2.3	Requirements: QoS and QoE.	53
	Quality of Service	53
	Quality of Experience	54
2.4	Routing.	55
	Characteristics.	55
	Packet Forwarding	56
	Routing Protocols	57
	Elements of a Router.	59
2.5	Congestion Control.	60
	Effects of Congestion	60
	Congestion Control Techniques	64

2.6	SDN and NFV	67
	Software-Defined Networking	67
	Network Functions Virtualization	69
2.7	Modern Networking Elements	71
2.8	Key Terms	72
2.9	References	73

PART II SOFTWARE DEFINED NETWORKS 75

Chapter 3: SDN: Background and Motivation 76

3.1	Evolving Network Requirements	77
	Demand Is Increasing	77
	Supply Is Increasing	77
	Traffic Patterns Are More Complex	78
	Traditional Network Architectures are Inadequate	79
3.2	The SDN Approach	80
	Requirements	80
	SDN Architecture	81
	Characteristics of Software-Defined Networking	85
3.3	SDN- and NFV-Related Standards	85
	Standards-Developing Organizations	87
	Industry Consortia	89
	Open Development Initiatives	89
3.4	Key Terms	91
3.5	References	91

Chapter 4: SDN Data Plane and OpenFlow 92

4.1	SDN Data Plane	93
	Data Plane Functions	93
	Data Plane Protocols	95

4.2	OpenFlow Logical Network Device	95
	Flow Table Structure	98
	Flow Table Pipeline	102
	The Use of Multiple Tables	106
	Group Table	107
4.3	OpenFlow Protocol	109
4.4	Key Terms	111

Chapter 5: SDN Control Plane 112

5.1	SDN Control Plane Architecture	113
	Control Plane Functions	113
	Southbound Interface	116
	Northbound Interface	117
	Routing	119
5.2	ITU-T Model	120
5.3	OpenDaylight	122
	OpenDaylight Architecture	122
	OpenDaylight Helium	124
5.4	REST	128
	REST Constraints	128
	Example REST API	130
5.5	Cooperation and Coordination Among Controllers	133
	Centralized Versus Distributed Controllers	133
	High-Availability Clusters	134
	Federated SDN Networks	135
	Border Gateway Protocol	136
	Routing and QoS Between Domains	137
	Using BGP for QoS Management	138
	IETF SDNi	140
	OpenDaylight SNDi	141

5.6	Key Terms	143
5.7	References	143
Chapter 6: SDN Application Plane		144
6.1	SDN Application Plane Architecture	145
	Northbound Interface	146
	Network Services Abstraction Layer	146
	Network Applications	147
	User Interface	147
6.2	Network Services Abstraction Layer	147
	Abstractions in SDN	147
	Frenetic	150
6.3	Traffic Engineering	153
	PolicyCop	153
6.4	Measurement and Monitoring	157
6.5	Security	157
	OpenDaylight DDoS Application	157
6.6	Data Center Networking	162
	Big Data over SDN	163
	Cloud Networking over SDN	164
6.7	Mobility and Wireless	168
6.8	Information-Centric Networking	168
	CCNx	169
	Use of an Abstraction Layer	170
6.9	Key Terms	173

PART III VIRTUALIATION **175**

Chapter 7: Network Functions Virtualization: Concepts and Architecture **176**

7.1	Background and Motivation for NFV	177
7.2	Virtual Machines	178
	The Virtual Machine Monitor	179

Architectural Approaches	180
Container Virtualization	183
7.3 NFV Concepts	184
Simple Example of the Use of NFV	188
NFV Principles	189
High-Level NFV Framework	190
7.4 NFV Benefits and Requirements	191
NFV Benefits	191
NFV Requirements	192
7.5 NFV Reference Architecture	193
NFV Management and Orchestration	194
Reference Points	195
Implementation	196
7.6 Key Terms	197
7.7 References	197

Chapter 8: NFV Functionality 198

8.1 NFV Infrastructure	199
Container Interface	199
Deployment of NFVI Containers	203
Logical Structure of NFVI Domains	204
Compute Domain	205
Hypervisor Domain	208
Infrastructure Network Domain	209
8.2 Virtualized Network Functions	213
VNF Interfaces	213
VNFC to VNFC Communication	215
VNF Scaling	216
8.3 NFV Management and Orchestration	217
Virtualized Infrastructure Manager	217

Virtual Network Function Manager	218
NFV Orchestrator	219
Repositories	219
Element Management	220
OSS/BSS	220
8.4 NFV Use Cases	221
Architectural Use Cases	222
Service-Oriented Use Cases	223
8.5 SDN and NFV	225
8.6 Key Terms	228
8.7 References	229

Chapter 9: Network Virtualization 230

9.1 Virtual LANs	231
The Use of Virtual LANs	234
Defining VLANs	235
Communicating VLAN Membership	236
IEEE 802.1Q VLAN Standard	237
Nested VLANs	239
9.2 OpenFlow VLAN Support	240
9.3 Virtual Private Networks	241
IPsec VPNs	241
MPLS VPNs	243
9.4 Network Virtualization	247
A Simplified Example	248
Network Virtualization Architecture	250
Benefits of Network Virtualization	252
9.5 OpenDaylight’s Virtual Tenant Network	253
9.6 Software-Defined Infrastructure	257
Software-Defined Storage	259

SDI Architecture	261
9.7 Key Terms	263
9.8 References	263

PART IV DEFINING AND SUPPORTING USER NEEDS 265

Chapter 10: Quality of Service 266

10.1 Background	267
10.2 QoS Architectural Framework	268
Data Plane	269
Control Plane	271
Management Plane	272
10.3 Integrated Services Architecture	273
ISA Approach	273
ISA Components	274
ISA Services	276
Queuing Discipline	277
10.4 Differentiated Services	279
Services	281
DiffServ Field	282
DiffServ Configuration and Operation	284
Per-Hop Behavior	286
Default Forwarding PHB	287
10.5 Service Level Agreements	291
10.6 IP Performance Metrics	293
10.7 OpenFlow QoS Support	296
Queue Structures	296
Meters	297
10.8 Key Terms	299
10.9 References	299

Chapter 11: QoE: User Quality of Experience	300
11.1 Why QoE?	301
Online Video Content Delivery	302
11.2 Service Failures Due to Inadequate QoE Considerations	304
11.3 QoE-Related Standardization Projects	304
11.4 Definition of Quality of Experience.	305
Definition of Quality	306
Definition of Experience	306
Quality Formation Process	307
Definition of Quality of Experience.	308
11.5 QoE Strategies in Practice	308
The QoE/QoS Layered Model	308
Summarizing and Merging the QoE/QoS Layers	310
11.6 Factors Influencing QoE	311
11.7 Measurements of QoE	312
Subjective Assessment.	312
Objective Assessment	314
End-User Device Analytics	315
Summarizing the QoE Measurement Methods.	316
11.8 Applications of QoE	317
11.9 Key Terms	319
11.10 References.	320
Chapter 12: Network Design Implications of QoS and QoE	322
12.1 Classification of QoE/QoS Mapping Models	323
Black-Box Media-Based QoS/QoE Mapping Models	323
Glass-Box Parameter-Based QoS/QoE Mapping Models.	325
Gray-Box QoS/QoE Mapping Models.	326
Tips for QoS/QoE Mapping Model Selection	327

12.2	IP-Oriented Parameter-Based QoS/QoE Mapping Models	327
	Network Layer QoE/QoS Mapping Models for Video Services	328
	Application Layer QoE/QoS Mapping Models for Video Services	328
12.3	Actionable QoE over IP-Based Networks	330
	The System-Oriented Actionable QoE Solution	330
	The Service-Oriented Actionable QoE Solution	331
12.4	QoE Versus QoS Service Monitoring.	332
	QoS Monitoring Solutions.	334
	QoE Monitoring Solutions.	335
12.5	QoE-Based Network and Service Management.	341
	QoE-Based Management of VoIP Calls	341
	QoE-Based Host-Centric Vertical Handover.	341
	QoE-Based Network-Centric Vertical Handover	342
12.6	Key Terms	344
12.7	References.	344

PART V MODERN NETWORK ARCHITECTURE: CLOUDS AND FOG 347

Chapter 13: Cloud Computing 348

13.1	Basic Concepts	349
13.2	Cloud Services	351
	Software as a Service	352
	Platform as a Service	353
	Infrastructure as a Service	354
	Other Cloud Services	355
	XaaS.	357
13.3	Cloud Deployment Models.	358
	Public Cloud	359
	Private Cloud	359
	Community Cloud	360
	Hybrid Cloud	360

13.4	Cloud Architecture	361
	NIST Cloud Computing Reference Architecture	361
	ITU-T Cloud Computing Reference Architecture	365
13.5	SDN and NFV	368
	Service Provider Perspective	369
	Private Cloud Perspective	369
	ITU-T Cloud Computing Functional Reference Architecture	369
13.6	Key Terms	371

Chapter 14: The Internet of Things: Components 372

14.1	The IoT Era Begins	373
14.2	The Scope of the Internet of Things	374
14.3	Components of IoT-Enabled Things	377
	Sensors	377
	Actuators	380
	Microcontrollers	381
	Transceivers	386
	RFID	387
14.4	Key Terms	393
14.5	References	393

Chapter 15: The Internet of Things: Architecture and Implementation 394

15.1	IoT Architecture	395
	ITU-T IoT Reference Model	395
	IoT World Forum Reference Model	401
15.2	IoT Implementation	409
	IoTivity	409
	Cisco IoT System	420
	ioBridge	427
15.3	Key Terms	431
15.4	References	431

PART VI RELATED TOPICS	433
Chapter 16: Security	434
16.1 Security Requirements	435
16.2 SDN Security	436
Threats to SDN	436
Software-Defined Security	440
16.3 NFV Security	441
Attack Surfaces	441
ETSI Security Perspective	444
Security Techniques	446
16.4 Cloud Security	446
Security Issues and Concerns	449
Cloud Security Risks and Countermeasures	450
Data Protection in the Cloud	452
Cloud Security as a Service	453
Addressing Cloud Computer Security Concerns	456
16.5 IoT Security	458
The Patching Vulnerability	459
IoT Security and Privacy Requirements Defined by ITU-T	459
An IoT Security Framework	462
Conclusion	465
16.6 Key Terms	465
16.7 References	465
Chapter 17: The Impact of the New Networking on IT Careers	466
17.1 The Changing Role of Network Professionals	467
Changing Responsibilities	467
Impact on Job Positions	469
Bottom Line	470

17.2	DevOps	470
	DevOps Fundamentals	471
	The Demand for DevOps	475
	DevOps for Networking	476
	DevOps Network Offerings	478
	Cisco DevNet	479
	Conclusion on the Current State of DevOps	479
17.3	Training and Certification	480
	Certification Programs	480
	IT Skills	488
17.4	Online Resources	489
17.5	References	491
	Appendix A: References	492
	Glossary	498
	Index	510