

Contents

List of Figures	xix
List of Tables	xxv
About the Author	xxvii
Preface	xxix
Acknowledgements	xxxi
1 Introduction	1
1.1 Applications and Services of Satellite Networks	1
1.1.1 <i>Roles of Satellite Networks</i>	2
1.1.2 <i>Network Software and Hardware</i>	4
1.1.3 <i>Satellite Network Interfaces</i>	4
1.1.4 <i>Network Services</i>	5
1.1.5 <i>Applications</i>	5
1.2 ITU-R Definitions of Satellite Services	5
1.2.1 <i>Fixed Satellite Service (FSS)</i>	6
1.2.2 <i>Mobile Satellite Service (MSS)</i>	6
1.2.3 <i>Broadcasting Satellite Service (BSS)</i>	6
1.2.4 <i>Other Satellite Services</i>	6
1.3 ITU-T Definitions of Network Services	6
1.3.1 <i>Interactive Services</i>	7
1.3.2 <i>Distribution Services</i>	7
1.4 Internet Services and Applications	8
1.4.1 <i>World Wide Web (WWW)</i>	8
1.4.2 <i>File Transfer Protocol (FTP)</i>	9
1.4.3 <i>Telnet</i>	9
1.4.4 <i>Electronic Mail (email)</i>	10
1.4.5 <i>Multicast and Content Distribution</i>	10
1.4.6 <i>Voice over Internet Protocol (VoIP)</i>	10
1.4.7 <i>Domain Name System (DNS)</i>	11
1.5 Circuit-switching Network	11
1.5.1 <i>Connection Set Up</i>	12
1.5.2 <i>Signalling</i>	13

1.5.3	<i>Transmission Multiplexing Hierarchy based on FDM</i>	13
1.5.4	<i>Transmission Multiplexing Hierarchy based on TDM</i>	13
1.5.5	<i>Space Switching and Time Switching</i>	15
1.5.6	<i>Coding Gain of Forward Error Correction (FEC)</i>	16
1.6	<i>Packet-switching Networks</i>	17
1.6.1	<i>Connection-oriented Approach</i>	18
1.6.2	<i>Connectionless Approach</i>	19
1.6.3	<i>Relationship between Circuit-switching and Packet-switching</i>	20
1.6.4	<i>Considerations of Packet Network Designs</i>	20
1.6.5	<i>Packet Header and Payload</i>	21
1.6.6	<i>Complexity and Heterogeneous Networks</i>	21
1.6.7	<i>Performance of Packet Transmissions</i>	21
1.6.8	<i>Impact of Bit Level Errors on Packet Level</i>	22
1.7	<i>OSI/ISO Reference Model</i>	22
1.7.1	<i>Protocol Terminology</i>	23
1.7.2	<i>Layering Principle</i>	23
1.7.3	<i>Functions of the Seven Layers</i>	23
1.7.4	<i>Fading of the OSI/ISO Reference Model</i>	24
1.8	<i>The ATM Protocol Reference Model</i>	25
1.8.1	<i>Narrowband ISDN (N-ISDN)</i>	25
1.8.2	<i>Broadband ISDN (B-ISDN)</i>	25
1.8.3	<i>ATM Technology</i>	25
1.8.4	<i>Reference Model</i>	26
1.8.5	<i>Problems: Lack of Available Services and Applications</i>	26
1.9	<i>Internet Protocols Reference Model</i>	27
1.9.1	<i>Network Layer: IP Protocol</i>	27
1.9.2	<i>Network Technologies</i>	27
1.9.3	<i>Transport Layer: TCP and UDP</i>	28
1.9.4	<i>Application Layer</i>	28
1.9.5	<i>QoS and Control on Resources</i>	28
1.10	<i>Satellite Network</i>	28
1.10.1	<i>Access Network</i>	29
1.10.2	<i>Transit Network</i>	29
1.10.3	<i>Broadcast Network</i>	29
1.10.4	<i>Space Segment</i>	29
1.10.5	<i>Ground Segment</i>	31
1.10.6	<i>Satellite Orbits</i>	31
1.10.7	<i>Satellite Transmission Frequency Bands</i>	32
1.11	<i>Characteristics of Satellite Networks</i>	34
1.11.1	<i>Propagation Delay</i>	34
1.11.2	<i>Propagation Loss and Power Limited</i>	35
1.11.3	<i>Orbit Space and Bandwidth Limited for Coverage</i>	35
1.11.4	<i>Operational Complexity for LEO</i>	35
1.12	<i>Channel Capacity of Digital Transmissions</i>	35
1.12.1	<i>The Nyquist Formula for Noiseless Channels</i>	36
1.12.2	<i>The Shannon Theorem for Noise Channels</i>	36
1.12.3	<i>Channel Capacity Boundary</i>	36
1.12.4	<i>The Shannon Power Limit (-1.6 dB)</i>	36
1.12.5	<i>Shannon Bandwidth Efficiency for Large E_b/N_0</i>	37

1.13	Internetworking with Terrestrial Networks	38
1.13.1	<i>Repeaters at the Physical Layer</i>	38
1.13.2	<i>Bridges at the Link Layer</i>	38
1.13.3	<i>Switches at the Physical, Link and Network Layers</i>	39
1.13.4	<i>Routers for Interconnecting Heterogeneous Networks</i>	39
1.13.5	<i>Protocol Translation, Stacking and Tunnelling</i>	39
1.13.6	<i>Quality of Service (QoS)</i>	40
1.13.7	<i>End-user QoS Class and Requirements</i>	40
1.13.8	<i>Network Performance</i>	41
1.13.9	<i>QoS and NP for Satellite Networking</i>	42
1.14	Digital Video Broadcasting (DVB)	43
1.14.1	<i>The DVB Standards</i>	44
1.14.2	<i>Transmission System</i>	44
1.14.3	<i>Adaptation to Satellite Transponder Characteristics</i>	45
1.14.4	<i>Channel Coding</i>	46
1.14.5	<i>Reed–Solomon (RS) Outer Coding, Interleaving and Framing</i>	47
1.14.6	<i>Inner Convolutional Coding</i>	48
1.14.7	<i>Baseband Shaping and Modulation</i>	49
1.14.8	<i>Error Performance Requirements</i>	50
1.15	DVB-S Satellite Delivery	50
1.15.1	<i>MPEG-2 Baseband Processing</i>	51
1.15.2	<i>Transport Stream (TS)</i>	52
1.15.3	<i>Service Objectives</i>	52
1.15.4	<i>Satellite Channel Adaptation</i>	52
1.15.5	<i>DVB Return Channel over Satellite (DVB-RCS)</i>	53
1.15.6	<i>TCP/IP over DVB</i>	54
1.16	DVB Satellite – Second Generation (DVB-S2)	54
1.16.1	<i>Technology Novelty in the DVB-S2</i>	55
1.16.2	<i>Transmission System Architecture</i>	56
1.16.3	<i>Error Performance</i>	58
1.17	DVB Satellite Services to Handheld Devices (DVB-SH)	59
1.17.1	<i>Transmission System Architecture</i>	60
1.17.2	<i>Common Functions for both TDM and OFDM Modes</i>	61
1.17.3	<i>Functions for Single Carrier (TDM) Mode</i>	62
1.17.4	<i>Functions for Multi Carrier (OFDM) Mode</i>	65
1.17.5	<i>DVB-RCS2</i>	69
1.18	Historical Development of Computer and Data Networks	69
1.18.1	<i>Dawn of the Computer and Data Communications Age</i>	70
1.18.2	<i>Development of Local Area Networks (LANs)</i>	70
1.18.3	<i>Development of WANs and ISO/OSI</i>	70
1.18.4	<i>Birth of the Internet</i>	70
1.18.5	<i>Integration of Telephony and Data Networks</i>	70
1.18.6	<i>Development of Broadband Integrated Networks</i>	71
1.18.7	<i>The Killer Application WWW and Internet Evolutions</i>	71
1.19	Historical Development of Satellite Communications	71
1.19.1	<i>Start of Satellite and Space Eras</i>	71
1.19.2	<i>Early Satellite Communications: TV and Telephony</i>	72
1.19.3	<i>Development of Satellite Digital Transmission</i>	72
1.19.4	<i>Development of Direct-to-Home (DTH) Broadcast</i>	72

1.19.5	<i>Development of Satellite Maritime Communications</i>	72
1.19.6	<i>Satellite Communications in Regions and Countries</i>	72
1.19.7	<i>Satellite Broadband Networks and Mobile Networks</i>	73
1.19.8	<i>Internet over Satellite Networks</i>	73
1.20	Convergence of Network Technologies and Protocols	73
1.20.1	<i>Convergence of Services and Applications in User Terminals</i>	73
1.20.2	<i>Convergence of Network Technologies</i>	74
1.20.3	<i>Convergence of Network Protocols</i>	75
1.20.4	<i>Satellite Network Evolution</i>	75
	Further Readings	77
	Exercises	78
2	Satellite Orbits and Networking Concepts	79
2.1	Laws of Physics	80
2.1.1	<i>Kepler's Three Laws</i>	80
2.1.2	<i>Newton's Three Laws of Motion and The Universal Law of Gravity</i>	80
2.1.3	<i>Kepler's First Law: Satellite Orbits</i>	81
2.1.4	<i>Kepler's Second Law: Area Swept by a Satellite Vector</i>	83
2.1.5	<i>Kepler's Third Law: Orbit Period</i>	83
2.1.6	<i>Satellite Velocity</i>	84
2.2	Satellite Orbit Parameters	85
2.2.1	<i>Semi-Major Axis (a)</i>	85
2.2.2	<i>Eccentricity (e)</i>	85
2.2.3	<i>Inclination of Orbit (i)</i>	85
2.2.4	<i>Right Ascension of the Node (Ω) and Argument of Perigee (ω)</i>	86
2.3	Useful Orbits	87
2.3.1	<i>Geosynchronous Earth Orbits</i>	87
2.3.2	<i>Geostationary Earth Orbits (GEOs)</i>	87
2.3.3	<i>High Elliptical Orbits (HEOs)</i>	88
2.3.4	<i>Notations of Low Earth Orbit (LEO) Satellite Constellations</i>	88
2.3.5	<i>Orbital Perturbations</i>	89
2.3.6	<i>Satellite Altitude and Coverage</i>	89
2.3.7	<i>Antenna Gain and Beam-width Angle</i>	90
2.3.8	<i>Coverage Calculations</i>	91
2.3.9	<i>Distance and Propagation Delay from Earth Station to Satellite</i>	92
2.4	Satellite Link Characteristics and Modulations for Transmissions	93
2.4.1	<i>Satellite Link Characteristics</i>	93
2.4.2	<i>Modulation Techniques</i>	95
2.4.3	<i>Phase Shift Keying (PSK) Schemes for Satellite Transmissions</i>	96
2.4.4	<i>Binary Phase Shift Keying (BPSK)</i>	96
2.4.5	<i>Quadrature PSK (QPSK)</i>	97
2.4.6	<i>Gaussian-filtered Minimum Shift Keying (GMSK)</i>	97
2.4.7	<i>Bit Error Rate (BER): the Quality Parameter of Modulation Schemes</i>	98
2.4.8	<i>Satellite Networking in the Physical Layer</i>	100
2.5	Forward Error Correction (FEC)	101
2.5.1	<i>Linear Block Codes</i>	101
2.5.2	<i>Cyclic Codes</i>	102
2.5.3	<i>Trellis Coding and Convolutional Codes</i>	102
2.5.4	<i>Concatenated Codes</i>	103
2.5.5	<i>Turbo Codes</i>	103
2.5.6	<i>Performance of FEC</i>	104

2.6	Multiple Access Techniques	105
2.6.1	<i>Frequency Division Multiple Access (FDMA)</i>	106
2.6.2	<i>Time Division Multiple Access (TDMA)</i>	106
2.6.3	<i>Code Division Multiple Access (CDMA)</i>	107
2.6.4	<i>Comparison of FDMA, TDMA and CDMA</i>	108
2.7	Bandwidth Allocation	108
2.7.1	<i>Fixed Assignment Access</i>	109
2.7.2	<i>Demand Assignment</i>	109
2.7.3	<i>Random Access</i>	109
2.8	Satellite Networking Issues	110
2.8.1	<i>Single-hop Satellite Connections</i>	110
2.8.2	<i>Multi-hop Satellite Connections</i>	110
2.8.3	<i>Inter-satellite Links (ISL)</i>	111
2.8.4	<i>Handovers</i>	112
2.8.5	<i>Satellite Intra-beam and Inter-beam Handovers</i>	114
2.8.6	<i>Earth Fixed Coverage versus Satellite Fixed Coverage</i>	114
2.8.7	<i>Routing within a Constellation of Satellite Networks</i>	115
2.8.8	<i>Internetworking</i>	116
2.8.9	<i>Satellite Availability and Diversity</i>	116
	Further Readings	118
	Exercises	118
3	B-ISDN ATM and Internet Protocols	119
3.1	ATM Protocol and Fundamental Concepts	119
3.1.1	<i>Packetisation Delay</i>	121
3.1.2	<i>Queuing Delay</i>	121
3.1.3	<i>Compromise Solution Between North America and Europe</i>	122
3.2	ATM Layer	123
3.2.1	<i>The GFC Field</i>	123
3.2.2	<i>The VPI and VCI Fields</i>	123
3.2.3	<i>The CLP Field</i>	125
3.2.4	<i>The PT Field</i>	126
3.2.5	<i>The HEC Field</i>	126
3.3	ATM Adaptation Layer (AAL)	126
3.3.1	<i>AAL1 for Class A</i>	127
3.3.2	<i>AAL2 for Class B</i>	129
3.3.3	<i>AAL3/4 for Classes C and D</i>	129
3.3.4	<i>AAL5 for Internet Protocol</i>	130
3.4	The Physical Layer	131
3.4.1	<i>The Physical Medium (PM) Sublayers</i>	131
3.4.2	<i>The Transmission Convergence (TC) Sublayer</i>	131
3.4.3	<i>ATM Cell Transmissions</i>	132
3.5	ATM Interfaces and ATM Networking	134
3.5.1	<i>User–Network Access</i>	134
3.5.2	<i>Network Node Interconnections</i>	135
3.5.3	<i>ATM DXI</i>	136
3.5.4	<i>B-ICI</i>	136
3.5.5	<i>Permanent Virtual Connections versus Switched Virtual Connections</i>	136
3.5.6	<i>ATM Signalling</i>	137
3.5.7	<i>ATM Addressing</i>	137
3.5.8	<i>Address Registration</i>	139

3.6	Network Traffic, QoS and Performance Issues	139
3.6.1	<i>Traffic Descriptors</i>	140
3.6.2	<i>QoS Parameters</i>	140
3.6.3	<i>Performance Issues</i>	140
3.7	Network Resource Management	141
3.7.1	<i>Connection Admission Control (CAC)</i>	142
3.7.2	<i>UPC and NPC</i>	142
3.7.3	<i>Priority Control and Congestion Control</i>	142
3.7.4	<i>Traffic Shaping</i>	143
3.7.5	<i>Generic Cell Rate Algorithm (GCRA)</i>	143
3.7.6	<i>Leaky Bucket Algorithm (LBA)</i>	143
3.7.7	<i>Virtual Scheduling Algorithm (VSA)</i>	146
3.8	Internet Protocols	146
3.8.1	<i>Internet Networking Basics</i>	147
3.8.2	<i>Protocol Hierarchies</i>	147
3.8.3	<i>Connectionless Network Layer</i>	148
3.8.4	<i>The IP Packet Format</i>	148
3.8.5	<i>IP Address</i>	150
3.8.6	<i>Mapping Between Internet and Physical Network Addresses</i>	151
3.8.7	<i>ARP, RARP and HDCP</i>	152
3.9	Internet Routing Protocols	152
3.9.1	<i>The Interior Gateway Routing Protocol (IGRP)</i>	152
3.9.2	<i>The Exterior Gateway Routing Protocol (EGRP)</i>	153
3.10	Transport Layer Protocols: TCP and UDP	153
3.10.1	<i>Transmission Control Protocol (TCP)</i>	153
3.10.2	<i>The TCP Segment Header Format</i>	154
3.10.3	<i>Connection Set Up and Data Transmission</i>	155
3.10.4	<i>Congestion and Flow Control</i>	156
3.10.5	<i>User Datagram Protocol (UDP)</i>	157
3.11	IP and ATM Internetworking	158
3.11.1	<i>Packet Encapsulation</i>	159
3.11.2	<i>IP and ATM Address Resolution</i>	160
	Further Readings	161
	Exercises	161
4	Satellite Internetworking with Terrestrial Networks	163
4.1	Networking Concepts	163
4.2	Networking Terminology	165
4.2.1	<i>Private Network</i>	165
4.2.2	<i>Public Network</i>	165
4.2.3	<i>Quality Aspects of Telephony Services</i>	166
4.2.4	<i>IP Based Network</i>	166
4.3	Network Elements and Connections	167
4.3.1	<i>Network Terminals</i>	167
4.3.2	<i>Network Nodes</i>	168
4.3.3	<i>Network Connections</i>	168
4.3.4	<i>End-to-End Paths</i>	169
4.3.5	<i>Reference Configurations</i>	169
4.4	Network Traffic and Signalling	170
4.4.1	<i>User Traffic and Network Services</i>	170
4.4.2	<i>Signalling Systems and Signalling Traffic</i>	171

4.4.3	<i>In-band Signalling</i>	172
4.4.4	<i>Out-of-Band Signalling</i>	173
4.4.5	<i>Associated and Disassociated Channel Signalling</i>	173
4.4.6	<i>Network Management</i>	174
4.4.7	<i>Network Operation Systems and Mediation Functions</i>	175
4.5	<i>Access and Transit Transmission Networks</i>	176
4.5.1	<i>Analogue Telephony Networks</i>	177
4.5.2	<i>Telephony Network Traffic Engineering Concept</i>	177
4.5.3	<i>Access to Satellite Networks in the Frequency Domain</i>	178
4.5.4	<i>On-Board Circuit Switching</i>	179
4.6	<i>Digital Telephony Networks</i>	180
4.6.1	<i>Digital Multiplexing Hierarchy</i>	180
4.6.2	<i>Satellite Digital Transmission and On-Board Switching</i>	181
4.6.3	<i>Plesiochronous Digital Hierarchy (PDH)</i>	181
4.6.4	<i>Limitations of PDH</i>	181
4.7	<i>Synchronous Digital Hierarchy (SDH)</i>	182
4.7.1	<i>Development of SDH</i>	183
4.7.2	<i>The SDH Standards</i>	183
4.7.3	<i>Mapping from PDH to SDH</i>	184
4.7.4	<i>The Benefits of SDH</i>	185
4.7.5	<i>Synchronous Operation</i>	185
4.7.6	<i>Synchronous Optical Network (SONET)</i>	187
4.7.7	<i>SDH Over Satellite – The Intelsat Scenarios</i>	188
4.8	<i>Hypothetical References for Satellite Networks</i>	189
4.8.1	<i>ITU-T Hypothetical Reference Connection (HRX)</i>	189
4.8.2	<i>ITU-R Hypothetical Reference Digital Path (HRDP) for Satellite</i>	190
4.8.3	<i>Performance Objectives</i>	191
4.9	<i>Satellites and MANET</i>	191
4.9.1	<i>Networking Scenarios</i>	193
4.10	<i>Interworking with Heterogeneous Networks</i>	197
4.10.1	<i>Services</i>	197
4.10.2	<i>Addressing</i>	198
4.10.3	<i>Routing</i>	198
4.10.4	<i>Evolution</i>	198
	<i>Further Readings</i>	199
	<i>Exercises</i>	200
5	B-ISDN ATM over Satellite Networks	201
5.1	<i>Background</i>	201
5.1.1	<i>Networking Issues</i>	202
5.1.2	<i>Satellite Services in the B-ISDN Networking Environment</i>	202
5.2	<i>Design Issues of Satellite B-ISDN ATM Systems</i>	204
5.2.1	<i>Propagation Delay</i>	204
5.2.2	<i>Attenuation and Constraints</i>	205
5.3	<i>The GEO Satellite B-ISDN ATM Networking Architecture</i>	206
5.3.1	<i>Ground Segment</i>	206
5.3.2	<i>Space Segment</i>	207
5.3.3	<i>Satellite Bandwidth Resource Management</i>	207
5.3.4	<i>Connection Admission Control (CAC)</i>	209
5.3.5	<i>Network Policing Functions</i>	209
5.3.6	<i>Reactive Congestion Control</i>	209

5.4	Advanced Satellite B-ISDN ATM Networks	210
5.4.1	<i>Radio Access Layer</i>	210
5.4.2	<i>On-Board Processing (OBP) Characteristics</i>	211
5.4.3	<i>B-ISDN ATM On-Board Switch</i>	211
5.4.4	<i>Multibeam Satellites</i>	214
5.4.5	<i>LEO/MEO Satellite Constellations</i>	215
5.4.6	<i>Inter-Satellite Links (ISL)</i>	215
5.4.7	<i>Mobility Management</i>	216
5.4.8	<i>Use of Higher Frequency Spectrum</i>	216
5.5	B-ISDN ATM Performance	217
5.5.1	<i>Layered Model of Performance for B-ISDN</i>	217
5.5.2	<i>Network Performance Parameters</i>	218
5.5.3	<i>Impact of Satellite Burst Errors on the ATM Layer</i>	220
5.5.4	<i>Impact of Burst Errors on AAL Protocols</i>	221
5.5.5	<i>Error Control Mechanisms</i>	221
5.5.6	<i>Enhancement Techniques for Broadband Satellite Networks</i>	222
5.6	Evolution of Broadband Satellite Systems	224
	Further Readings	225
	Exercises	225
6	Internet Protocol (IP) over Satellite Networks	227
6.1	Different Viewpoints of Satellite Networking	227
6.1.1	<i>Protocol-centric Viewpoint of Satellite IP Network</i>	228
6.1.2	<i>Satellite-centric Viewpoint of Global Networks and the Internet</i>	229
6.1.3	<i>Network-centric Viewpoint of Satellite Networks</i>	230
6.2	IP Packet Encapsulation	231
6.2.1	<i>Basic Concepts</i>	231
6.2.2	<i>High-level Data Link Control (HDLC) Protocol</i>	232
6.2.3	<i>Point-to-Point Protocol (PPP)</i>	232
6.2.4	<i>Media Access Control</i>	233
6.2.5	<i>IP Over Satellite</i>	233
6.3	Satellite IP Networking	233
6.3.1	<i>Routing On-Board Satellites</i>	235
6.3.2	<i>IP Mobility in Satellite Networks</i>	235
6.3.3	<i>Address Resolution</i>	237
6.4	IP Multicast Over Satellite	237
6.4.1	<i>IP Multicast Concepts</i>	238
6.4.2	<i>IP Multicast Addressing</i>	239
6.4.3	<i>Multicast Group Management</i>	239
6.4.4	<i>IP Multicast Routing</i>	240
6.4.5	<i>IP Multicast Scope</i>	241
6.4.6	<i>IGMP Behaviour in Satellite Environments</i>	241
6.4.7	<i>Multicast Routing Protocols in Satellite Environments</i>	243
6.4.8	<i>Reliable Multicast Protocols Over Satellites</i>	243
6.5	Basic Network Security Mechanisms	245
6.5.1	<i>Security Approaches</i>	245
6.5.2	<i>Single-direction Hashing Functions</i>	246
6.5.3	<i>Symmetrical Codes (With Secret Keys)</i>	246
6.5.4	<i>Asymmetrical Codes (With Public/Private Keys)</i>	247

6.6	Satellite Networking Security	248
6.6.1	<i>IP Security (IPsec)</i>	248
6.6.2	<i>Firewall and VPN</i>	249
6.6.3	<i>IP Multicast Security</i>	250
6.7	Internet Quality of Service (IP QoS)	250
6.7.1	<i>Layered Model of Performance for IP Service</i>	251
6.7.2	<i>IP Packet Transfer Performance Parameters</i>	252
6.7.3	<i>IP Network Performance Objectives for QoS Classes</i>	253
6.7.4	<i>Guidance on IP QoS Class Usage</i>	254
6.8	Integrated Services (Intserv) Architectures for QoS	254
6.8.1	<i>Integrated Services Architecture (ISA) Principles</i>	255
6.8.2	<i>Resource Reservation Protocol (RSVP)</i>	256
6.8.3	<i>Intserv Service Classes</i>	257
6.9	Differentiated Services (Diffserv) for QoS	258
6.9.1	<i>Diffserv Architecture</i>	258
6.9.2	<i>Traffic Classification</i>	260
6.9.3	<i>Traffic Conditioning</i>	261
6.9.4	<i>Diffserv Per Hop Behaviour (PHB)</i>	261
6.9.5	<i>Supporting Intserv Across the Satellite Network Diffserv Domain</i>	263
6.10	DVB Over Satellite	264
6.10.1	<i>MPEG-2 Source Coding and Multiplexing DVB-S Streams</i>	265
6.10.2	<i>DVB-S System</i>	266
6.10.3	<i>DVB Security</i>	268
6.10.4	<i>Conditional Access in DVB-S</i>	268
6.10.5	<i>DVB-RCS Interactive Service and IP over DVB</i>	270
6.10.6	<i>DVB-RCS Security</i>	271
6.10.7	<i>IP Multicast Security</i>	271
6.11	DVB-S and DVB-RCS Network Architecture	272
6.11.1	<i>On-Board Processor (OBP)</i>	273
6.11.2	<i>Management Station (MS)</i>	274
6.11.3	<i>Regenerative Satellite Gateway (RSGW)</i>	274
6.11.4	<i>Return Channel Satellite Terminal (RCST)</i>	275
6.11.5	<i>Network Interface</i>	275
6.11.6	<i>Network System Characteristics</i>	276
6.12	Network Protocol Stack Architecture	276
6.13	The Physical Layer (PHY)	277
6.13.1	<i>Up-link (DVB-RCS Compliant)</i>	277
6.13.2	<i>Time Slots</i>	278
6.13.3	<i>Frames</i>	278
6.13.4	<i>Superframes</i>	280
6.13.5	<i>Carrier Type and Frame Composition</i>	280
6.13.6	<i>Uplink MF-TDMA Channel Frequency Plan</i>	281
6.13.7	<i>Downlink (DVB-S Compliant)</i>	282
6.13.8	<i>RCS Terminal (RCST) Transmission</i>	283
6.14	Satellite MAC (SMAC) Layer	284
6.14.1	<i>Transport Mechanisms</i>	284
6.14.2	<i>MPEG-2, DVB-S and DVB-RCS Tables</i>	285
6.15	Multi Protocol Encapsulation (MPE)	288

6.16	Satellite Link Control Layer	290
6.16.1	<i>Session Control</i>	290
6.16.2	<i>Resource Control</i>	293
6.16.3	<i>Capacity Request Categories</i>	294
6.16.4	<i>Connection Control</i>	294
6.17	Quality of Service (QoS)	297
6.17.1	<i>Traffic Classes</i>	297
6.17.2	<i>Flow Classification</i>	298
6.17.3	<i>Link Layer Connection QoS Adaptation</i>	298
6.18	Network Layer	299
6.18.1	<i>IP Routing and Address Resolution</i>	301
6.18.2	<i>IP Multicast – Star and Mesh Configurations</i>	303
	Further Readings	305
	Exercises	305
7	Impact of Satellite Networks on Transport Layer Protocols	307
7.1	Introduction	308
7.1.1	<i>Application Characteristics</i>	308
7.1.2	<i>Client and Server Host Parameters</i>	309
7.1.3	<i>Satellite Network Configurations</i>	309
7.1.4	<i>TCP and Satellite Channel Characteristics</i>	310
7.1.5	<i>TCP Flow Control, Congestion Control and Error Recovery</i>	311
7.2	TCP Performance Analysis	313
7.2.1	<i>First TCP Segment Transmission</i>	313
7.2.2	<i>TCP Transmission in the Slow-start Stage</i>	314
7.2.3	<i>TCP Transmission in the Congestion Avoidance Stage</i>	314
7.3	Slow-start Enhancement for Satellite Networks	315
7.3.1	<i>TCP for Transactions</i>	316
7.3.2	<i>Slow-start and Delayed Acknowledgement (ACK)</i>	316
7.3.3	<i>Larger Initial Window</i>	317
7.3.4	<i>Terminating Slow-start</i>	317
7.4	Loss Recovery Enhancement	318
7.4.1	<i>Fast Retransmission and Fast Recovery</i>	318
7.4.2	<i>Selective Acknowledgement (SACK)</i>	319
7.4.3	<i>SACK Based Enhancement Mechanisms</i>	319
7.4.4	<i>ACK Congestion Control</i>	320
7.4.5	<i>ACK Filtering</i>	320
7.4.6	<i>Explicit Congestion Notification</i>	321
7.4.7	<i>Detecting Corruption Loss</i>	322
7.4.8	<i>Congestion Avoidance Enhancement Policy</i>	322
7.5	Enhancements for Satellite Networks Using Interruptive Mechanisms	323
7.5.1	<i>TCP Spoofing</i>	323
7.5.2	<i>Cascading TCP or Split TCP</i>	324
7.5.3	<i>Other Considerations for Satellite Networking</i>	325
7.6	Impacts on Applications	325
7.6.1	<i>Bulk Data Transfer</i>	325
7.6.2	<i>Interactive Applications</i>	326
7.6.3	<i>Distributed Caching for Internet Services and Applications</i>	326
7.6.4	<i>Web Caching in Satellite Networks</i>	327

7.7	Real-time Transport Protocol (RTP)	328
7.7.1	<i>Basics of RTP</i>	328
7.7.2	<i>RTP Control Protocol (RTCP)</i>	331
7.7.3	<i>Sender Report (SR) Packets</i>	332
7.7.4	<i>Receiver Report (RR) Packets</i>	333
7.7.5	<i>Source Description (SDS) RTCP Packet</i>	333
7.7.6	<i>SAP and SIP Protocols for Session Initiations</i>	334
7.7.7	<i>Session Directory Service (SDS)</i>	336
7.8	Voice over IP	336
7.8.1	<i>Gateway Decomposition</i>	336
7.8.2	<i>Protocols</i>	336
7.8.3	<i>Gatekeepers</i>	337
7.8.4	<i>Multimedia Conferencing (MMC)</i>	337
7.8.5	<i>Conference Control</i>	337
	Further Readings	337
	Exercises	338
8	Next Generation Internet (NGI) over Satellite	341
8.1	Introduction	342
8.2	New Services and Applications	342
8.2.1	<i>Internet Integrated Services</i>	343
8.2.2	<i>Elastic and Inelastic Traffic</i>	343
8.2.3	<i>QoS Provision and Network Performance</i>	344
8.3	Traffic Modelling and Characterisation	344
8.3.1	<i>Traffic Engineering Techniques</i>	345
8.3.2	<i>Traffic Modelling</i>	345
8.3.3	<i>Statistical Methods for Traffic Modelling</i>	346
8.3.4	<i>Renewal Models</i>	346
8.3.5	<i>Markov Models</i>	346
8.3.6	<i>Fluid Models</i>	347
8.3.7	<i>Auto-regressive and Moving Average Models</i>	347
8.3.8	<i>Self-similar Models</i>	348
8.4	The Nature of Internet Traffic	348
8.4.1	<i>World Wide Web (WWW)</i>	348
8.4.2	<i>Pareto Distribution Model for Self-similar Traffic</i>	350
8.4.3	<i>Fractional Brownian Motion (FBM) Process</i>	350
8.4.4	<i>Consideration of User Behaviour in Traffic Modelling</i>	351
8.4.5	<i>Voice Traffic Modelling</i>	352
8.4.6	<i>On-off Model for Voice Traffic</i>	354
8.4.7	<i>Video Traffic Modelling</i>	355
8.4.8	<i>Multi-layer Modelling for WWW Traffic</i>	356
8.5	Traffic Engineering	357
8.5.1	<i>Traffic Engineering Principles</i>	358
8.5.2	<i>Internet Traffic Engineering</i>	360
8.6	Multi-protocol Label Switching (MPLS)	361
8.6.1	<i>MPLS Forwarding Paradigm</i>	362
8.6.2	<i>MPLS Basic Operation</i>	363
8.6.3	<i>MPLS and Diffserv Interworking</i>	366
8.6.4	<i>MPLS and ATM Interworking</i>	367
8.6.5	<i>MPLS with Traffic Engineering (MPLS-TE)</i>	368

8.7	Internet Protocol Version 6 (IPv6)	369
8.7.1	<i>Basics of Internet Protocol Version 6 (IPv6)</i>	369
8.7.2	<i>IPv6 Addressing</i>	371
8.7.3	<i>IPv6 Networks over Satellites</i>	374
8.7.4	<i>IPv6 Transitions</i>	375
8.7.5	<i>IPv6 Tunnelling Through Satellite Networks</i>	375
8.7.6	<i>The 6to4 Translation via Satellite Networks</i>	376
8.7.7	<i>Issues with 6to4</i>	377
8.7.8	<i>Future Development of Satellite Networking</i>	378
	Further Readings	380
	Exercises	381
	Index	383