

Broadband Satellite Communications for Internet Access



Foreword by
Raymond L. Pickholtz

Sastri L. Kota
Kaveh Pahlavan
Pentti Leppanen

Contents

List of Figures	xvii
List of Tables	xxiii
Foreword	xxv
Preface	xxvii
1. Overview of Broadband Satellite Networks	1
1.1. Introduction	1
1.2. Broadband Satellite Internet	4
1.2.1. Internet Evolution	4
1.2.2. Next Generation Internet	9
1.2.2.1. Interplanetary Internet	10
1.2.3. What is Broadband?	10
1.2.3.1. Broadband Applications	11
1.2.4. Broadband Satellite	13
1.3. Global Network Infrastructure	15
1.3.1. Requirements	17
1.4. Satellite Networks Evolution	18
1.4.1. Circuit Oriented	20
1.4.2. Packet Oriented	20
1.4.3. Multimedia	23
1.5. Backbone Technologies	24
1.5.1. Frame Relay	24
1.5.2. ATM	27
1.5.3. IP	31
1.5.4. DWDM	38
1.5.5. MPLS	41
1.5.6. GMPLS	42
1.5.7. GFP	43
1.6. Access Technologies	44
1.6.1. DSL	46
1.6.2. Cable	48
1.6.3. Hybrid Fiber Coax	50
1.6.4. Wireless	53
1.6.4.1. Broadband Wireless	54
1.6.5. Satellite	56
1.7. Structure of the Book	58
1.7.1. Part One: Principles of Satellite Networks	58

1.7.2.	Part Two: Satellite Networks Technical Challenges	60
1.7.3.	Part Three: Satellite IP Networks Performance	61
1.7.4.	Part Four: Satellite ATM Networks Performance	61
Part I: Principles of Satellite Networks		63
2.	Basics of Networks	65
2.1.	Introduction	65
2.2.	Basic Characteristics	65
2.3.	Orbits and Coverage	66
2.3.1.	Geostationary Earth Orbit (GEO)	68
2.3.2.	Medium Earth Orbit (MEO)	69
2.3.3.	Low Earth Orbit (LEO)	70
2.3.4.	Comparison	71
2.4.	Frequency Bands	72
2.4.1.	Filing Status	73
2.4.2.	Ka-band and Beyond	73
2.5.	Network Topologies	73
2.5.1.	Point-to-Point Networks	74
2.5.2.	Point-to-Multipoint Networks	74
2.5.3.	Multipoint-to-Point Networks	74
2.5.4.	Multipoint-to-Multipoint Networks	74
2.6.	Satellite Services	75
2.6.1.	Fixed Satellite Service	75
2.6.2.	Mobile Satellite Service	75
2.6.3.	Broadcast Satellite Service	76
3.	Satellite System Engineering Methodology	77
3.1.	Introduction	77
3.2.	Approach	77
3.2.1.	Business Model	80
3.2.2.	Service Requirements	80
3.2.3.	Satellite Internet Applications	81
3.2.3.1.	Internet Application Protocols	82
3.2.4.	Application Profiles	83
3.2.5.	Requirements	83
3.2.5.1.	System Level Requirements	84
3.2.5.2.	Network Level Requirements	84
3.2.6.	System Architecture – Candidate(s)	84
3.2.6.1.	Space Segment – GSO vs. NGSO	85
3.2.6.2.	Ground Segment	90
3.2.6.3.	Control Segment	91
3.2.6.4.	Interfaces	92
3.2.6.5.	Tradeoff Studies	92
3.2.6.6.	Baseline System Architecture	93
3.2.6.7.	Business and Operations Support Systems (BSS/OSS)	93
3.2.7.	Performance Evaluation	93
3.2.8.	Integration Testbed	94
3.2.9.	Outputs	94

4. Network Systems and Examples	95
4.1. Introduction	95
4.1.1. Connectivity Network	96
4.1.2. Access Network	96
4.2. Next Generation Ka-Band	97
4.3. Broadband Satellite Network	99
4.3.1. Requirements	100
4.3.2. Protocol Stack	101
4.3.3. Onboard Processing	101
4.3.4. Onboard Switching	102
4.3.5. Intersatellite Links	104
4.3.6. Spot Beam Technology	105
4.4. Global Broadband Satellite Systems	105
4.4.1. EuroSkyWay Example	106
4.5. Broadband Satellite Access Network	109
4.5.1. Gateway	110
4.5.2. Terminal	111
4.5.3. Regional Satellite Access Systems	111
4.5.4. StarBand Example	112
4.6. Mobile Satellite Network	113
4.6.1. Inmarsat	113
4.6.2. Mobile Satellite Systems	114
4.6.3. ACeS System Example	116
4.7. VSAT Networks	118
4.7.1. VSAT Applications	118
4.7.2. VSAT Network Types	118
4.7.3. Multiple Access	120
4.7.4. VSAT Example – LINKWAY	121
5. Quality of Service in Layered Architecture	123
5.1. Introduction	123
5.2. End-to-End Quality of Service	123
5.2.1. Why QoS?	123
5.2.2. What is QoS?	124
5.2.3. End-to-End QoS Layer Model	126
5.2.4. QoS Parameters	128
5.2.5. QoS Building Blocks	129
5.2.6. Protocol Architecture - ETSI	132
5.2.7. QoS Functional Allocation	133
5.2.8. Mobile QoS	135
5.2.9. QoS Challenges	135
5.2.10. System Availability	136
Part II: Satellite Network Technical Challenges	139
6. Physical and Link Layers	141
6.1. Introduction	141
6.2. Physical Layer	141

6.2.1.	Higher Order Modulation	142
6.2.2.	Encoding Techniques – Turbo and Concatenated	142
6.2.3.	Propagation Effects	143
6.2.4.	Adaptive Coding Techniques	143
6.2.5.	Adaptive Power Control	147
6.3.	Link Layer: Media Access Control	148
6.3.1.	Fixed Assignment Multiple Access	149
6.3.1.1.	Frequency Division Multiple Access (FDMA)	150
6.3.1.2.	Time Division Multiple Access (TDMA)	150
6.3.1.3.	Code Division Multiple Access (CDMA)	150
6.3.2.	Random Access	151
6.3.2.1.	Pure ALOHA	151
6.3.2.2.	Slotted ALOHA	152
6.3.2.3.	Selective-Reject ALOHA	152
6.3.2.4.	Capture ALOHA	152
6.3.2.5.	Contention Resolution Algorithm	153
6.3.3.	Demand Assignment Multiple Access	153
6.3.3.1.	Reservation ALOHA	154
6.3.3.2.	Round-Robin Reservation	155
6.3.3.3.	Priority Oriented Demand Assignment (PODA)	156
6.3.3.4.	Fixed Priority Oriented Demand Assignment (FPODA)	157
6.3.4.	MAC Protocols Comparison	157
6.3.5.	ATM and Satellite MAC Protocols	158
6.3.6.	Interactive Multimedia over Satellite	160
6.3.6.1.	Combined Free Demand Assignment Multiple Access (CF-DAMA)	161
7.	Satellite TCP/IP: Technical Challenges	165
7.1.	Introduction	165
7.2.	Satellite IP	166
7.2.1.	Satellite IP Traffic Management	166
7.2.1.1.	Functions	167
7.2.2.	QoS Mechanisms	169
7.2.2.1.	Best Effort	170
7.2.2.2.	IntServ	171
7.2.2.3.	DiffServ	175
7.2.2.4.	MPLS	178
7.2.3.	Voice over IP	180
7.2.4.	Satellite IP Security	183
7.2.5.	Satellite IP Multicast	188
7.2.5.1.	Multicast Routing Protocol	189
7.2.5.2.	Satellite IP Multicast	190
7.2.6.	Interactive Satellite IP	191
7.2.6.1.	Satellite IP Multimedia Protocol Stacks	192
7.2.6.2.	Mapping between PHB and Bandwidth Allocation Schemes	193
7.2.6.3.	Security	194
7.3.	Satellite TCP	195
7.3.1.	Satellite Link Characteristics Affecting TCP	195

7.3.2.	TCP Protocol	197
7.3.2.1.	Bandwidth-Delay Product	197
7.3.2.2.	Slow Start and Congestion Avoidance	199
7.3.2.3.	Fast Retransmit and Fast Recovery	200
7.3.3.	TCP Enhancements for Satellite Networks	202
7.3.3.1.	Large Initial Window	202
7.3.3.2.	Delayed ACKs after Slow Start	203
7.3.3.3.	Byte Counting	203
7.3.3.4.	TCP Vegas	203
7.3.3.5.	TCP NewReno	204
7.3.3.6.	TCP Selective Acknowledgment (SACK)	205
7.3.3.7.	Forward Error Correction (FEC)	206
7.3.3.8.	Explicit Congestion Notification (ECN)	207
7.3.3.9.	TCP/IP Header Compression	207
7.3.3.10.	Window Scaling	208
7.3.3.11.	TCP for Transactions	208
7.3.3.12.	Pacing TCP Segments	209
7.3.3.13.	Path MTU	209
7.3.3.14.	TCP Enhancements Comparison	210
7.3.4.	Performance Enhancing Proxies (PEP)	211
7.3.4.1.	TCP Spoofing	212
7.3.4.2.	TCP Splitting	212
7.3.4.3.	PEP Mechanisms	215
7.3.4.4.	Implications of Using PEP	216
7.3.4.5.	Performance Examples	216
7.3.4.6.	Security over PEP	220
7.3.5.	Wireless IP Suite Enhancer (WISE)	221
7.3.6.	Network Path Asymmetry	222
7.3.7.	Other Transport Protocols	222
7.3.7.1.	Satellite Transport Protocol (STP)	223
7.3.7.2.	Space Communications Protocol Specifications – Transport Protocol (SCPS-TP)	225
7.3.7.3.	Stream Controlled Transmission protocol (SCTP)	225
7.3.8.	Recent TCP Enhancements	225
7.3.8.1.	Quick Start TCP	225
7.3.8.2.	TCP Peach	226
7.3.8.3.	Explicit Transport Error Notification (ETEN)	226
7.3.8.4.	TCP Westwood	227
7.3.9.	TCP Friendly Congestion Control	227
8.	Satellite ATM: Technical Challenges	229
8.1.	Introduction	229
8.2.	Satellite ATM Architectures	229
8.2.1.	Satellite ATM: Bent Pipe	230
8.2.2.	Satellite ATM: On-Board Processing and Switching	231
8.2.3.	Satellite ATM Protocols	232
8.3.	Satellite ATM Technical Challenges	234
8.4.	Traffic Management and Congestion Control	235
8.4.1.	Functional Allocation	236

8.4.2. Traffic Parameters and QoS	237
8.5. Explicit Rate Congestion Control for ABR	238
8.6. Virtual Source/Virtual Destination (VS/VD) Algorithm for ABR	239
8.7. Satellite ATM Security	241
8.8. Technical Challenges Summary	242
9. Standards and Regulations	245
9.1. Introduction	245
9.2. Why Satellite System Standards?	245
9.2.1. Technology Impact on Satellite Standards	246
9.2.2. Important Standardization Areas	246
9.3. Standard Activities	247
9.3.1. ITU-R	247
9.3.2. ITU-T	248
9.3.3. ETSI	248
9.3.4. IETF Satellite IP Standardization	249
9.3.5. TIA Satellite IP Standardization	249
9.3.6. ESA	250
9.3.7. DVB	250
9.3.8. The ATM Forum	250
9.4. Regulatory Issues	251
Part III: Satellite IP Networks Performance	253
10. Quality of Service in IP Networks	255
10.1. Introduction	255
10.2. IP QoS Classes	256
10.3. IP QoS Performance Objectives	257
10.3.1. Satellite IP QoS Objectives	257
10.4. IP QoS Mechanisms Revisited	258
10.4.1. Integrated Services (IntServ)	259
10.4.2. Differentiated Services (DiffServ)	260
10.4.2.1. Queue Management	261
10.4.3. Multi-Protocol Label Switching (MPLS)	264
10.5. Architectural Alternatives	265
10.6. Satellite IP QoS Architecture 1 – IntServ	266
10.7. Satellite IP QoS Architecture 2: DiffServ	267
10.8. Satellite IP QoS Architecture: IntServ/DiffServ	268
10.8.1. Access Network Example	270
10.9. Architectures Comparison	270
11. Performance of DiffServ Based Satellite IP	273
11.1. Introduction	273
11.2. DiffServ QoS	274
11.3. Buffer Management Classifications	276
11.4. Simulation Configuration and Parameters	277
11.4.1. GEO Simulation Configuration	277
11.4.2. Performance Metrics	280
11.5. GEO Satellite Network Simulation Results	281

11.5.1. Fairness	281
11.5.2. Reserved Rate Utilization	283
11.6. Analysis Of Variation (ANOVA) Technique	286
11.6.1. ANOVA Analysis for Reserved Rate Utilization	287
11.6.2. ANOVA Analysis for Fairness	288
11.7. MEO Satellite IP Network Simulation Results	289
11.7.1. Simulation Configuration	289
11.7.2. Fairness	290
11.7.3. Reserved Rate Utilization	292
11.7.4. MEO Simulation Results Discussion	295
11.8. UDP-Based Audio-Video Example	295
12. Performance of MPLS	299
12.1. Introduction	299
12.2. MPLS Overview	299
12.3. Network Topology	303
12.4. Simulation Results	304
12.4.1. LEO Performance Results	304
12.4.1.1. Throughput Analysis	304
12.4.1.2. Jitter and Packet Loss Analysis	305
12.4.2. MEO Performance Results	306
12.4.3. GEO Performance Results	308
12.5. Discussion	309
13. Interactive Multimedia over Satellite	311
13.1. Introduction	311
13.2. MF-TDMA Return Channel Protocol Analysis	312
13.2.1. Digital Video Broadcasting – Return Channel via Satellite (DVB-RCS) Protocol	313
13.2.1.1. MultiFrequency Time Division Multiple Access (MF-TDMA)	314
13.2.2. Data over Cable Service Interface Specification (DOCSIS)	315
13.2.3. Comparison	316
13.3. CDMA Access Protocol	317
13.3.1. Spread ALOHA Multiple Access for Satellite Network	317
13.3.1.1. Multiple Access Architectures for Return Channel	318
13.3.1.2. Connection-Oriented Architecture	319
13.3.1.3. Contention-Oriented Architecture	320
13.3.1.4. CDMA based Contention Multiple Access Schemes	322
13.3.1.5. Performance of SAOC and SAOLC	323
13.3.1.6. Simulation Results	326
13.4. Discussion	329
Part IV: Satellite ATM Networks Performance	331
14. Quality of Service in ATM Networks	333
14.1. Introduction	331
14.2. ATM Quality of Service Model	334
14.3. Satellite ATM QoS Requirements	338

14.3.1. ATM QoS Objectives	338
14.3.2. Performance Objectives for Satellites (Class 1 Service)	339
14.3.3. CTD and CDV Contributions	340
14.3.3.1. Transmit Terminal Queuing Delay	340
14.3.3.2. Transmission Delay	340
14.3.3.3. Propagation Delay	340
14.3.3.4. MAC Layer Delays	341
14.3.3.5. Onboard Processing Delays	341
14.3.3.6. Receive Terminal Smoothing Buffer	341
14.3.3.7. Timing Synchronization	341
14.4. Buffer Requirements Simulation Model	342
14.4.1. Buffering Requirements	342
14.5. TCP Transport over Satellite ATM – UBR	344
14.5.1. Simulation Model	350
14.5.2. Performance Metrics	351
14.5.3. Simulation Parameters	352
14.5.4. Simulation Results	353
15. Performance Analysis of TCP over Satellite ATM	355
15.1. Introduction	355
15.2. UBR+ Drop Policies	355
15.3. WWW Traffic Model	356
15.3.1. Implications of the HTTP/1.1 standard	356
15.3.2. WWW Server Model	356
15.3.3. WWW Client Model	357
15.4. Simulation Configuration And Experiments	358
15.4.1. Configuration Parameters	358
15.4.2. TCP Parameters	359
15.4.3. Switch Parameters	359
15.5. Performance Metrics	360
15.6. Simulation Analysis	362
15.6.1. Analysis Technique	362
15.7. Simulation Results for LEO links	365
15.7.1. Analysis of Efficiency Values: Results and Observations	367
15.7.2. Analysis of Fairness values: Results and Observations	368
15.8. Simulation Results for MEO links	368
15.8.1. Analysis of Efficiency Values: Results and Observations	370
15.8.2. Analysis of Fairness values: Results and Observations	371
15.9. Simulation Results for GEO links	371
15.9.1. Analysis of Efficiency Values: Results and Observations	373
15.9.2. Analysis of Fairness values: Results and Observations	373
15.10. Discussion	373
16. Bandwidth Allocation – An Example	375
16.1. Introduction	375
16.2. TDMA/DAMA Analytical Model	376
16.2.1. Frame Structure	377
16.2.2. Non-Contiguous Slot Analytical Model	377
16.2.3. Solution to the Analytical Model	380

Contents	xv
16.2.4. The One-Dimensional Recursion	381
16.3. Contiguous Slot Simulation	383
16.4. Performance Results	383
16.5. Discussion	386
References	387
Acronyms	405
Index	413
About the Authors	419