



QUEUING THEORY AND TELECOMMUNICATIONS

Networks and Applications

Giovanni Giambene

Contents

DEDICATION	V
AUTHOR BIOGRAPHY	XIII
PREFACE	XV
ACKNOWLEDGMENTS	XIX
PART I: TELECOMMUNICATION NETWORKS	1
1. Introduction to Telecommunication Networks	3
1.1 Historic steps in the telecommunication era	3
1.2 Standardization bodies in telecommunications	7
1.3 Telecommunication networks: general concepts	9
1.3.1 Transmissions in telecommunication networks	11
1.3.2 Switching techniques in telecommunication networks	17
1.3.3 The ISO/OSI reference model	23
1.3.4 Traffic engineering: general concepts	32
1.3.5 Queuing theory in telecommunications	33
1.4 Transmission media	34
1.4.1 Copper medium: the twisted pair	34
1.4.2 Copper medium: the coaxial cable	35
1.4.3 Wireless medium	37

1.4.4 Optic fibers	41
1.5 Multiplexing hierarchy	46
1.5.1 FDM	47
1.5.2 TDM	48
1.5.3 The E1 bearer structure	50
1.6 The telephone network	51
1.6.1 Digital transmissions through POTS	55
1.6.2 Switching elements in PSTN	59
1.7 Bibliographic references	66
2. Digital Networks	69
2.1 Digital networks introduction	69
2.1.1 X.25-based networks	69
2.1.2 ISDN	75
2.1.3 Frame Relay-based networks	85
2.2 B-ISDN and ATM technology	96
2.2.1 ATM protocol stack	100
2.2.2 Cell format	101
2.2.3 ATM protocol stack	105
2.2.4 Traffic classes and ALL layer protocols	106
2.2.5 ATM switches	111
2.2.6 ATM switch architectures	112
2.2.7 Management of traffic	120
2.2.8 ATM physical later	134
2.2.9 Internet access through ATM over ADSL	145
2.3 Bibliographic references	146
3. IP-based Networks	151
3.1 Introduction	151
3.2 The Internet	151
3.2.1 Introduction to the TCP/IP protocol suite	153
3.2.2 TCP/IP protocol architecture	154
3.3 IP Addressing	156
3.3.1 IPv4 datagram format	158
3.3.2 IP subnetting	162
3.3.3 IP version 6	165
3.4 IP Routing	168
3.4.1 Routing algorithms	171
3.4.2 Interior routing and exterior routing	175
3.5 Transport layer	180
3.5.1 TCP and UDP protocols	181

3.5.2 Port numbers and sockets	191
3.6 IP traffic over ATM networks	192
3.6.1 The LIS method	195
3.6.2 The Next Hop Routing Protocol	196
3.6.3 The integrated approach for IP over ATM	197
3.7 MultiProtocol Label Switching technology	200
3.7.1 Comparison between IP routing and label switching	202
3.7.2 Operations on labels	204
3.7.3 MPLS header	205
3.7.4 MPLS nested domains	207
3.7.5 MPLS forwarding tables	208
3.7.6 Protocols for the creation of an LSP	211
3.7.7 IP/MPLS over ATM	214
3.7.8 MPLS traffic management	216
3.8 GMPLS technology	220
3.9 Next-Generation Networks	221
3.9.1 NGN architecture	224
3.9.2 DWDM technology	226
3.9.3 QoS provision in IP-based networks	226
3.9.4 Voice over IP	229
3.10 Bibliographic references	232

PART II: QUEUING THEORY AND APPLICATIONS **235**

4. Survey on Probability Theory	237
4.1 The notion of probability and basic properties	237
4.2 Random variables: basic definitions and properties	241
4.2.1 Sum of independent random variables	247
4.2.2 Minimum and maximum of random variables	248
4.2.3 Comparisons between random variables	250
4.2.4 Moments of the random variables	250
4.2.5 Random variables in the field of telecommunications	254
4.3 Transformations for random variables	273
4.3.1 The probability generating function	274
4.3.2 The characteristic function of a pdf	282
4.3.3 The Laplace transform of a pdf	288
4.4 Methods for the generation of random variables	290
4.4.1 Method of the inverse of the distribution function	291
4.4.2 Method of the transformation	291
4.5 Solved exercises	292

4.6 Bibliographic references	304
5. Markov Chains and Queuing Theory	305
5.1 Queues and stochastic processes	305
5.2 Poisson arrival process	309
5.2.1 Sum of independent Poisson processes	311
5.2.2 Random splitting of a Poisson process	312
5.2.3 Compound Poisson processes	313
5.3 Birth-death Markov chains	314
5.4 Notations for queuing systems	317
5.5 The Little theorem	318
5.6 M/M/1 queue analysis	322
5.7 M/M/1/K queue analysis	324
5.7.1 M/M/S queue analysis	326
5.8 M/M/S/S queue analysis	328
5.9 The M/M/ ∞ queue analysis	332
5.10 Distribution of the queuing delays in the FIFO case	333
5.10.1 M/M/1 case	333
5.10.2 M/M/S case	336
5.11 Erlang-B generalization for non-Poissonian arrivals	338
5.11.1 The traffic types in the M/M/S/S queue	338
5.11.2 Blocking probability for non-Poissonian arrivals	340
5.12 Solved exercises	345
5.13 Bibliographic references	382
6. M/G/1 Queuing Theory and Applications	385
6.1 The M/G/1 queue	385
6.1.1 The M/D/1 case	392
6.2 M/G/1 system delay distribution in the FIFO case	393
6.3 Laplace transform numerical inversion method	394
6.4 Generalizations of the M/G/1 theory	398
6.5 Applications of the M/G/1 analysis to ATM	401
6.6 Different imbedding instants in the M/G/1 theory	405
6.6.1 Chain imbedded to the slot end instants of the output line	407
6.6.2 Chain imbedded to the cell transmission completion	408
6.6.3 Chain imbedded to the message transmission completion	411
6.7 M/G/1 with geometrically distributed messages	412
6.7.1 Chain imbedded to packet transmission completion	413
6.7.2 Chain imbedded to message transmission completion	416
6.8 M/G/1 and differentiated service times	418
6.9 Solved exercises	420
6.10 Bibliographic references	448

7. Local Area Networks Analysis	449
7.1 Introduction	449
7.1.1 Standards for local area networks	454
7.2 Contention-based protocols	456
7.2.1 Aloha protocol	456
7.2.2 Slotted-Aloha protocol	463
7.2.3 The Aloha protocol with ideal capture effect	467
7.2.4 CSMA schemes	470
7.3 Demand-assignment protocols	506
7.3.1 Polling protocol	506
7.3.2 Token passing protocols	507
7.3.3 Analysis of token and polling schemes	510
7.3.4 Reservation Aloha (R-Aloha) protocol	514
7.3.5 Packet Reservation Multiple Access (PRMA) protocol	519
7.3.6 Comparison between CSMA/CD and token protocols	520
7.4 Fixed assignment protocols	526
7.4.1 Frequency Division Multiple Access (FDMA)	526
7.4.2 Time Division Multiple Access (TDMA)	526
7.4.3 Resource reuse in cellular systems	527
7.4.4 Code Division Multiple Access (CDMA)	528
7.5 Solved exercises	530
7.6 Bibliographic references	553
8. Networks of Queues	557
8.1 Introduction	557
8.1.1 Traffic rate equations	560
8.1.2 The Little theorem for the whole network	560
8.2 The Burke theorem	561
8.3 The Jackson theorem	562
8.3.1 Analysis of a queue with feedback	564
8.4 Traffic matrices	566
8.5 Network planning aspects	567
8.6 Solved exercises	567
8.7 Bibliographic references	579