Multifractal Based Network Traffic Modeling

Murali Krishna. P
Vikram M. Gadre
Uday B. Desai

Kluwer Academic Publishers

Contents

List of Symbols xi
List of Acronyms xiii
List of Figures xv
List of Tables xix
Acknowledgments xxi
Preface xxiii

1. **INTRODUCTION** 1
   1 Complexity of Broadband Network Traffic 1
      1.1 Geographical Complexity 2
      1.2 Behavior Generated Complexity 3
      1.3 Temporal Complexity 3
   2 Teletraffic Modeling: Historical Perspective 4
   3 Motivation for the Problem 7
   4 Contributions of the Monograph 9
   5 Organization of the Monograph 12

2. **MATHEMATICAL PRELIMINARIES** 15
   1 Random Processes 16
      1.1 Stationary and Non Stationary Random Process 16
   2 Bernoulli (Counting) Process 18
   3 Poisson Process 20
      3.1 Applications to Queuing Theory 22
   4 Markov Process 24
   5 Independent Increment Processes 25
   6 Self Similar Processes 28

	6.1	Structure of Variance	28
	6.2	Structure of Covariance	29
	6.3	Long Range Dependence Property	30
7	Fractional Brownian Motion		31
	7.1	fBm from Linear System Theory	32
	7.2	Correlation of fBm	35
	7.3	Multifractal Brownian Motion	37
	7.4	Fractional ARIMA	37
	7.5	Wavelet Based Models for Self Similar Process	39
8	Heavy Tailed Processes		41
9	Analysis and Estimation Techniques for Self Similar Processes		42
	9.1	R/S Statistic	43
	9.2	Variance Aggregation plot	43
	9.3	Spectral Estimator	44
10	Wavelet Based Analysis of Self Similar Process		45
	10.1	Statistical Properties of Wavelet Coefficients of Self Similar Processes	47
	10.2	Abry - Veitch Estimator	47
11	The Need for Multifractal Processes		48
	11.1	Characterizing the Distribution of α	50
	11.2	Local Singularity Analysis Using Wavelets	51
	11.3	Holder Exponents from Taylor Series	51
	11.4	Wavelet Vanishing Moments and Local Regularity	52
12	Salient points from the chapter		53
3.	**BROADBAND NETWORK TRAFFIC MODELING**		55
1	Broadband Network Traffic Characteristics		55
2	Network Traffic Modeling Methodology		57
3	State-of-the-Art in Teletraffic Modeling		58
	3.1	ON - OFF Model	58
	3.2	CIPP Process	60
	3.3	Multiple Scaling in Network Data	61
	3.4	From Self similarity to Multifractals	62
	3.5	Multifractal Wavelet Model	63
4	Video Traffic Modeling		67
	4.1	MPEG Video Source Encoding	67
	4.2	Models for VBR Video Traffic	69
5	Summary of Broadband Traffic Models		70

4. **MULTIPLICATIVE CASCADES** 71
1 Binomial Multiplicative Cascade 72
2 Characterizing Multifractals through Multifractal Spectrum 75
3 Methods to Estimate Multifractal Spectrum 81
3.1 Histogram Method 81
3.2 Method Of Moments 82
4 Interpreting the Multifractal Spectrum 84
4.1 Multifractal Spectrum as Fractal Dimension 84
4.2 Multifractal Spectrum from Large Deviation theory 84
5 Generalized Dimensions 87
6 Summary of the Chapter 90

5. **V.V.G.M MULTIFRACTAL MODEL** 93
1 Development of V.V.G.M Multifractal Model 94
1.1 Estimation of Multiplier Distributions 96
1.2 Synthesis Algorithm 97
2 Statistical Comparison Tests 98
2.1 Autocorrelation Function 98
2.2 Higher Order Moments of Aggregated Data 99
2.3 Multifractal Spectrum Curve 101
3 Test for Robustness of the Parametric Model 104
4 Performance and Queuing Tests 107
4.1 Queue length Distribution 107
4.2 Comparison of Packet Loss 108
4.3 Comparison of Delay 110
5 Inter Departure Process 111
6 V.V.G.M and MWM : A Comparison 112
7 Salient Points of the V.V.G.M Model 114

6. **ANALYSIS OF THE MULTIPLEXING OF TRAFFIC** 115
1 Analysis of Multiplexing using V.V.G.M Model 116
2 Analysis of Multiplexing using Multifractal Spectrum 118
3 Analysis of the Multiplexing using Entropy 120
3.1 Proof of Entropy Scaling 123
3.2 Relation with Generalized Dimensions 124
4 How Complex is Inter Arrival Data ? 125
5 Salient points from the chapter 127

7. **MODELING OF VBR VIDEO TRACES** 129
1 VBR Video Modeling Using Multifractals 130
2 Statistical Tests for Model Evaluation 132
2.1 Higher Order Moments of Aggregated Data 132
2.2 Index Of Dispersion of Counts 134
2.3 Multifractal Spectrum 135
3 Results of Queuing Simulations 137
3.1 Behavior of Queue Lengths 137
3.2 Variance of Cell Delay 137
3.3 Comparison of Cell Loss 139
4 Complexity of VBR Video Traces 140
5 Salient points from the Chapter 142

8. **QOS ISSUES AND CONTROL OF BROADBAND TRAFFIC** 143
1 Statistics of Multiplicative Cascade Processes 144
1.1 Global Scaling Parameter 146
1.2 Heavy Tailed Distribution of V.V.G.M 149
2 Queuing Theory for Cascade Processes 150
3 Effective Bandwidth Estimation for QoS 152
3.1 Effective Bandwidth for V.V.G.M Process 153
4 Estimation and Prediction of Burstiness 156
4.1 Results of Estimation of Traffic Burstiness 157
4.2 Burstiness Prediction Using Kalman Filter 159
5 Salient points from the chapter 161

9. **CONCLUSIONS** 165
1 V.V.G.M Cascade Process for Broadband Network Traffic 165
2 Future Work 166
2.1 System theoretic Modeling of Computer Networks 166
2.2 Development of Network Processors 167
2.3 Signal Processing and Networking 167
2.4 Study of Complex Systems 167

Appendices 169
A. Wavelet Transform 169
B. Legendre Transform 171
C. Large Deviation Theory 175

D. Norros's Queuing Model 179
D.1 Parameterizing QoS Requirements 180
D.1.1 Parameterizing Buffer Length 182
D.1.2 Parameterizing Service Rate 182
D.1.3 Parameterizing Queue Length Distribution 182
E. Effective Bandwidth 185
E.1 Properties 185
E.2 Application in Queuing Systems 186
F. Kalman Filter 189
G. Some Websites of Interest 195

References 197

Index 209