FAST CONGESTION NOTIFICATION MECHANISM FOR NEXT GENERATION ROUTERS

A Thesis submitted to the College of Arts and Sciences in full fulfillment of the requirements for the degree of Doctor of Philosophy
Universiti Utara Malaysia

by
Mohammed M. Kadhum

© 2010, Kadhum

Kolej Sastera dan Sains
(UUM College of Arts and Sciences)
Universiti Utara Malaysia

PERAKUAN KERJA TESIS / DISERTASI
(Certification of thesis / dissertation)

Kami, yang bertandatangan, memperakukan bahawa
(We, the undersigned, certify that)

MOHAMMED M. KADHUM

calon untuk Ijazah **PhD**
(candidate for the degree of)

telah mengemukakan tesis / disertasi yang bertajuk:
(has presented his/her thesis / dissertation of the following title):

"FAST CONGESTION NOTIFICATION MECHANISM FOR NEXT GENERATION ROUTERS"

seperti yang tercatat di muka surat tajuk dan kulit tesis / disertasi.
(as it appears on the title page and front cover of the thesis / dissertation).

Bahawa tesis/disertasi tersebut boleh diterima dari segi bentuk serta kandungan dan meliputi bidang ilmu dengan memuaskan, sebagaimana yang ditunjukkan oleh calon dalam ujian lisan yang diadakan pada : ***14 Jun 2010.***
That the said thesis/dissertation is acceptable in form and content and displays a satisfactory knowledge of the field of study as demonstrated by the candidate through an oral examination held on:
June 14, 2010.

Pengerusi Viva: *(Chairman for Viva)*	**Assoc. Prof. Dr. Engku Muhammad Nazri Engku Abu Bakar**	Tandatangan *(Signature)*
Pemeriksa Luar: *(External Examiner)*	**Assoc. Prof. Dr. Rahmat Budiarto**	Tandatangan *(Signature)*
Pemeriksa *Dalam*: *(Internal Examiner)*	**Dr. Massudi Mahmuddin**	Tandatangan *(Signature)*
Nama Penyelia/Penyelia-penyelia: *(Name of Supervisor/Supervisors)*	**Assoc. Prof. Dr. Suhaidi Hassan**	Tandatangan *(Signature)*

Tarikh:

(Date) ***June 14, 2010***

PERMISSION TO USE

In presenting this thesis in fulfillment of the requirements for a postgraduate degree from Universiti Utara Malaysia, I agree that the University Library may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purpose may be granted by my supervisor(s) or, in their absence by the Dean of Research and Graduate Studies. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Utara Malaysia for any scholarly use which may be made of any material from my thesis.

Requests for permission to copy or to make other use of materials in this thesis, in whole or in part, should be addressed to

Dean of Research and Graduate Studies
College of Arts and Sciences
Universiti Utara Malaysia
06010 UUM Sintok
Kedah Darul Aman

ABSTRAK (BAHASA MALAYSIA)

Matlamat utama tesis ini adalah untuk mengemukakan mekanisma baru kawalan kesesakan proaktif yang dinamakan "Notifikasi Pantas Kesesakan (FN)" untuk penghala TCP/IP berkemampuan ECN. FN telah dibangunkan dan dilaksanakan menggunakan Network Simulator versi 2 (ns-2). Ia menggunakan panjang baris gilir serta merta (semasa) dan kadar purata ketibaan bingkisan untuk membuat keputusan. FN menggugurkan bingkisan yang sampai (jika bukan ECN) dan menandakan bingkisan (jika ECN) pada permulaan baris gilir sebelum limpahan penimbal berlaku. Ini dilakukan bagi mengawal panjang baris gilir semasa (Q_{cur}) agar berada di bawah keperluan panjang baris gilir optimum (Q_{opt}) bagi mengurangkan lengah dan menghindari limpahan penimbal. Ianya juga digunakan untuk mengekalkan kadar purata ketibaan bingkisan (R) sekitar keupayaan kesesakan dan panjang baris gilir. Pada masa ini, mekanisma pengesanan awal rawak (RED) digunakan dalam Internet. RED menggunakan purata panjang baris gilir untuk membuat keputusan kawalan. Pengunaan purata panjang baris gilir membuatkan RED lambat bertindak balas terhadap kesesakan mengakibatkan kelainan dalam saiz baris gilir yang besar serta pengesanan dan pemberitahuan kesesakan yang tidak kena pada masanya menyebabkan penurunan prestasi akibat daripada lengah baris gilir serta merta (semasa) dan kadar purata ketibaan bingkisan yang tinggi. Kombinasi panjang baris gilir serta merta (semasa) dan kadar purata ketibaan bingkisan yang digunakan oleh FN menunjukkan prestasi yang lebih tinggi berbanding RED dalam pengesanan dan pemberitahuan kesesakan yang pantas. Kekangan FN adalah ianya berkesan hanya dengan perhubungan responsif yang memainkan peranan yang besar dalam menghindari dan mengawal kesesakan. Sumbangan utama tesis ini adalah memperkenalkan mekanisma baru pengurusan baris gilir proaktif yang responsif pada kesesakan dengan lebih pantas, memberikan pemberitahuan tepat pada waktinya, dan mengawal panjang baris gilir secara terus yang secara langsung meminimumkan kelainan panjang baris gilir. Kesemua ini dapat membantu meningkatkan prestasi Internet.

ABSTRACT (ENGLISH)

The aim of this thesis is to present a new proactive congestion control mechanism, namely "Fast Congestion Notification (FN)" for TCP/IP ECN-capable routers. FN has been developed and implemented in Network Simulator 2 (ns-2). It uses the instantaneous (current) queue length and the average packet arrival rate to make its control decisions. The new mechanism drops the arriving packets (if non-ECN) and marks packets (if ECN) at the head of the queue before the buffer overflows, to effectively control the current queue length (Q_{cur}) below the required optimal queue length (Q_{opt}) in order to reduce the queuing delay and avoid the buffer overflows; and to maintain the average packet arrival rate (R) about the outgoing transmission link capacity (μ) in order to enable the congestion and queue length control. Currently, Random Early Detection (RED) mechanism is used in the Internet. RED uses the average queue length for making the control decisions. The use of average queue length makes RED reacts to congestion slowly. This results in large queue length variation and untimely congestion detection and notification which would cause performance degradation due to high queuing delays and high packet loss. The combination of the instantaneous (current) queue length and the average packet arrival rate used by FN showed superior performance to that of RED in term of fast congestion detection and notification. The limitation of the new mechanism is that it works only with responsive connections which play a big role in avoiding and controlling the congestion. Since this thesis considers the necessity for modern queue management mechanisms that can control the Internet traffic efficiently and improve the Internet performance, the major contribution of this thesis is to provide a new pro-active queue management mechanism that responds to congestion more quickly, delivers congestion notification timely, and controls queue length directly to congestion which results in minimizing queue length variation. All these would help improve the Internet performance.

DECLARATION

Some of the work presented in this thesis have been published as listed below.

[1] M. M. Kadhum and S. Hassan, "The Effect of ECN on Short TCP Sessions," in *IEEE International Conference on Telecommunications and Malaysia International Conference on Communications (ICT-MICC)*, Malaysia, pp. 708-712, 2007.

[2] M. M. Kadhum and S. Hassan, "A Study of ECN Effects on Long-lived TCP Connections using RED and Drop tail Gateway Mechanisms," in *International Symposium on Information Technology (ITSim)*, Malaysia, pp. 2283-2294, 2008.

[3] M. M. Kadhum and S. Hassan, "TCP ECN-capable Performance in a Differentiated Services Network," in *International Conference on Information Technology and Multimedia 2008 (ICIMU 2008)*, Malaysia, Track 10:CSN, pp. 345-350, 18-19 Nov. 2008.

[4] M. M. Kadhum and S. Hassan, "Fast Congestion Notification Mechanism for ECN-capable Routers," in *International Symposium on Information Technology (ITSim)*, Malaysia, pp. 2295-2300, 2008.

[5] M. M. Kadhum and S. Hassan, "A New Congestion Management Mechanism for Next Generation Routers," *Journal of Engineering Science and Technology*, vol. 3, pp. 265-271, 2008.

[6] M. M. Kadhum and S. Hassan, "The Design Motivation and Objectives for Fast Congestion Notification (FN)," in the *28th APAN Network Research Workshop*, Malaysia, pp. 25-30, 2009.

[7] M. M. Kadhum and S. Hassan, "A Linear Packet Marking Probability Function for Fast Congestion Notification (FN)," *International Journal of Computer Science and Network Security*, vol. 9, pp. 45-50, 2009.

[8] M. M. Kadhum and S. Hassan, "The Impact of the Average Arrival Rate on the FN Drop/Mark Probability," submitted to *Journal of Advanced Computing and Applications*, 2009.

[9] M. M. Kadhum and S. Hassan, "FN Packet Marking/Dropping Probability as a Function of Required/Allowed Changes in Queue Level," in *First International Conference on Future Information Networks (ICFIN2009)*, Beijing, China, pp. 61-65, 2009.

[10] M. M. Kadhum and S. Hassan, "A Demonstration of the FN Packet Marking Probability " in the *9th International Symposium on Communications and Information Technologies (ISCIT 2009)*, Incheon, Korea, pp. 1540-1543, 2009.

[11] M. M. Kadhum and S. Hassan, "On the Linear FN Performance in a Heterogeneous Network," submitted to the *Journal of Universal Computer Science (J.UCS)*, 2009.

[12] M. M. Kadhum and S. Hassan, "The FN Quadratic Marking-Dropping Probability Function," in *The First International Conference on Networks & Communications (NetCoM-2009)*, Chennai, India, pp. 135-140, 2009.

[13] M. M. Kadhum and S. Hassan, "The Uniformization of the Fast Congestion Notification (FN)," *International Journal of Computer Science and Information Security (IJCSIS)*, vol. 4, Paper 31070968, pp. 166-170, Aug. 2009.

[14] M. M. Kadhum and S. Hassan, "A Quantitative Analysis and Performance Study of Fast Congestion Notification (FN) Mechanism," in *The 15th Asia-Pacific Conference on Communications (APCC2009)*, Shanghai, China, pp. 816-820, 2009.

[15] M. M. Kadhum and S. Hassan, "The Mark-Drop Activation Function of the Fast Congestion Notification (FN) Mechanism," *International Journal of Communication Networks and Information Security (IJCNIS)*, vol. 1, pp. 46-51, Dec. 2009.

[16] M. M. Kadhum and S. Hassan, "A Quadratic Version of Fast Congestion Notification (FN) Algorithm," submitted to the *International Journal of Computer Networks & Communications* (IJCNC), 2009.

[17] M. M. Kadhum and S. Hassan, "Performance Study of Quadratic FN Algorithm on Heterogeneous Internet Sources," submitted to *Journal of Computer Science and Engineering*, 2010.

[18] M. M. Kadhum and S. Hassan, " The Effect of the Packet Sliding Window Size on FN Drop/Mark Probability," submitted to *The Global Journal of Computer Science and Technology (GJCST)*, 2010.

[19] M. M. Kadhum and S. Hassan, "On the Optimal Settings for Fast Congestion Notification Mechanism (FN)," submitted to *World Applied Sciences Journal (WASJ)*, 2010.

ACKNOWLEDGEMENT

In the name of ALLAH, Most Gracious, Most Merciful.

I would like to express my deep and sincere gratitude to my supervisor, Associate Professor Dr. Suhaidi Hassan, Assistant Vice Chancellor and Head of the UUM College of Arts and Sciences. His wide knowledge and his logical way of thinking have been of great value for me. His understanding, encouragement and personal guidance have provided a good basis for this thesis.

I would also like to express my warm and sincere thanks to Dr. Mahmood Ahmad, Senior Lecturer at School of Computer Sciences, University of Montreal who introduced me to the field of Internet Congestion Control and Dr. Athear Abaas, Senior Lecturer at Faculty of Computer Engineering , University of Auckland, whose letters gave me useful guidance during my first steps in researching Congestion Control.

I owe my most sincere gratitude to UUM InterNetWorks Research Group, USM Network Research Group, who gave me the opportunity to work for them which helped me to overcome the difficulties.

I would also like to thank Mr. Ghayth Al-Shaibani, for editing this manuscript. Dr. Akram M. Zeki, Dr. Normaziah, Mr. Sayid M. Abdulle, Dr. Mohuddin Ahmad, Ms. Noor Mohammed, Mr. Salah Darwesh, Dr. Wan Tat Chee, Mr Mustafa Safa'a are all thanked for their excellent and moral support and during my research.

I owe my loving thanks to my wife, Intidhar, my daughter, Al-Huraa, my sons, Thu-Alfikar and Mohammed Al-Mujtaba, who has lost a lot due to my research abroad. Without their encouragement and understanding it would have been impossible for me to finish this work.

TABLE OF CONTENTS

PERMISSION TO USE i

ABSTRAK (BAHASA MALAYSIA) ii

ABSTRACT (ENGLISH) iii

DECLARATION iv

ACKNOWLEDGEMENT vii

TABLE OF CONTENTS viii

LIST OF TABLES xv

LIST OF FIGURES xvi

ABBREVIATIONS xx

CHAPTER ONE: INTRODUCTION

1.1 Congestion Issues in Computer Networks 1
1.2 Queue Management and Congestion Control 2
1.2.1 Passive Queue Management Mechanisms (PQM) 4
1.2.2 Active Queue Management (AQM) 5
1.3 Congestion Information 6
1.4 Research Problem 7
1.5 Research Motivation 7
1.6 Scope of Research 9
1.7 Research Objectives 10
1.8 Key Research Steps 11
1.9 Key Contributions 11

1.9.1 Design of Fast Congestion Notification (FN) Algorithm . . . 11
1.9.2 Implementation of Fast Congestion Notification (FN) Mechanism . . . 12
1.9.3 Comparison of FN to Random Early Detection (RED) Mechanism . . . 12
1.9.4 Performance Study of Linear FN . . . 12
1.9.5 Study of Linear FN Drop/Mark Probability Dynamics . . . 13
1.9.6 Performance Study of Quadratic FN to Random Early Detection (RED) Mechanism . . . 13
1.10 Organization of the Thesis . . . 13

CHAPTER TWO: LITERATURE REVIEW

2.1 Congestion in TCP-Based Networks . . . 16
2.2 Router Buffer . . . 17
2.3 The Function of Queue Management Mechanisms . . . 18
2.4 Algorithmic Structure of Queue Management Mechanism . . . 19
2.4.1 Connection Aggregation . . . 19
2.4.2 Drop/Mark Position . . . 21
2.4.3 Drop/Mark Activation . . . 22
2.4.4 Drop/Mark Probability . . . 23
2.5 Classification of Queue Management Mechanisms . . . 23
2.5.1 Re-active vs. Pro-active . . . 23
2.5.2 Global-State vs. Flow-State . . . 24
2.5.2.1 Global-State (Global Aggregation) Mechanisms . . 24
2.5.2.2 Perflow-State (Perflow-Aggregation) Mechanisms . 25
2.5.2.3 Limited-State (Limited-Aggregation) Mechanisms . 25
2.5.3 Deterministic vs Probabilistic . . . 25
2.6 Re-active (Passive) Queue Management Mechanisms . . . 26
2.6.1 Tail-Drop (TD) . . . 27
2.6.1.1 Congestion Detection . . . 28
2.6.1.2 Congestion Notification . . . 28
2.6.1.3 Buffer Overflow Events . . . 29
2.6.1.4 Dropping Multiple Packets . . . 29
2.6.1.5 TCP Recovery . . . 29
2.6.1.6 Throughput Proportional Drop Fairness . . . 30
2.6.1.7 High Packet Loss . . . 30

2.6.1.8 Global Synchronization Phenomenon 30
2.6.1.9 Low Link Utilization 30
2.6.1.10 Large Queuing Delay 30
2.6.1.11 Large End-to-End Delay 31
2.6.2 Random-Drop (RD) 31
2.6.3 Front-Drop (FD) 33
2.7 Pro-active (Active) Queue Management Mechanisms 36
2.7.1 Congestion Detection 38
2.7.2 Congestion Notification 38
2.7.3 Queue Length Control 38
2.7.4 Data Stream Modification 39
2.7.5 Tradeoffs 39
2.7.6 Popular Pro-active Queue Management Mechanisms 40
2.7.6.1 Early Random-Drop (ERD) 41
2.7.6.2 BLUE 42
2.7.6.3 Stochastic Fair Blue (SFB) 43
2.7.6.4 CHOKe 45
2.7.6.5 Random Early Marking (REM) 46
2.7.6.6 Random Early Detection (RED) 47
2.8 Improving Random Early Detection 58
2.8.1 Stabilized RED (SRED) 59
2.8.2 Adaptive RED 60
2.8.3 Double-Slope RED (DSRED) 61
2.8.4 Multilevel RED (MRED) 63
2.8.5 Hyperbola RED (HRED) 63
2.8.6 ARED 64
2.9 Network Feedback 64
2.9.1 Explicit Congestion Notification (ECN) 65
2.10 Summary 68

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Evaluating Network System Techniques 71
3.1.1 Analytical Modeling 72
3.1.2 Measurement 73
3.1.3 Simulation 74
3.2 Computer Network Simulator 77

3.2.1 REAL 78
3.2.2 GloMoSim 79
3.2.3 J-Sim 79
3.2.4 ns-2 79
3.3 Experiments Setup 81
3.3.1 Client-server models 82
3.3.2 Router model 82
3.3.3 Simulation Topology 83
3.3.4 Traffic Generation 85
3.3.5 Common FN/RED Router Setting 86
3.3.6 RED Experiments 87
3.3.7 FN Experiments 88
3.4 Performance Metrics 88
3.4.1 Outgoing transmission Link Utilization 88
3.4.2 Packet loss 89
3.4.3 Queue Length 89
3.4.4 Throughput 89
3.4.5 Average Packet Arrival Rate 90
3.5 Validation and Verification 91
3.5.1 Validation of Network Simulators 92
3.5.2 Validation of FN implementation on ns-2 92
3.5.3 Simulation Runs and Confidence Interval 92
3.6 Summary 97

CHAPTER FOUR: DESIGN OF FAST CONGESTION NOTIFICATION (FN) MECHANISM

4.1 Design Motivation of Fast Congestion Notification (FN) 100
4.1.1 Instantaneous & Average Queue Length 101
4.1.2 Average Queue Speed 102
4.2 Design Objectives of Fast Congestion Notification (FN) 105
4.3 Fast Congestion Notification Algorithm (FN) Algorithm 106
4.3.1 General Description 106
4.3.2 Behavior of a FN Router 108
4.3.3 Connection Aggregation 109
4.3.4 Drop/Mark Position 110
4.3.5 Decision Criterion 110

4.3.6 Control Decisions 111
4.3.7 Control Update Frequency 113
4.3.8 Drop/Mark Probability Function 113
4.4 FN Linear Packet Dropping/Marking Probability Function 116
4.4.1 Queue Variables 116
4.4.2 The Derivation of FN Linear Probability Function 118
4.4.3 Instance of the Use of FN Linear Probability Function 120
4.4.4 FN Packet Probability as a Function of Average Arrival Rate . 123
4.4.5 FN Packet Probability as a Function of Required/Allowed Changes in Queue Length 125
4.4.6 Uniformization of Packet Drops/Marks 126
4.5 FN Quadratic Packet Dropping/Marking Probability Function 131
4.5.1 Queue Variables 131
4.5.2 The Derivation of FN Quadratic Packet Dropping/Marking Probability Function 133
4.6 FN Drop/Mark Activation Function 135
4.7 Summary 143

CHAPTER FIVE: FN IMPLEMENTATION

5.1 Average Packet Arrival Estimation 147
5.2 Computation of Average Packet Arrival Rate Acceleration 147
5.3 FN Algorithm 148
5.4 The Computational Complexity of FN 151
5.5 FN State Storage Space 151
5.6 FN Process Model 152
5.7 FN Parameter Settings 153
5.8 Verification and Validation of the FN Implementation 154
5.8.1 Verification of FN Mechanism 155
5.8.2 Validation of FN Mechanism 156
5.9 Summary 157

CHAPTER SIX: RESULTS AND DISCUSSIONS

6.1 Linear FN - RED Comparison 160
6.1.1 Average Queue Length - Packet Loss - Link Utilization 160
6.1.2 Queue length Control 163
6.1.3 Packet Arrival Rate Control 168
6.1.4 Throughput Proportional Drop Fairness 175

6.2 Performance Study of Linear FN Algorithm 177
6.2.1 Average Queue Length 178
6.2.1.1 Effect of Time (T) Settings 178
6.2.1.2 Effect of Window Size (W_s) Settings 179
6.2.2 Average Packet Arrival Rate 179
6.2.2.1 Effect of Time (T) Settings 180
6.2.2.2 Effect of Window Size (W_s) Settings 181
6.2.3 Average Link Utilization 181
6.2.3.1 Effect of Time (T) Settings 182
6.2.3.2 Effect of Window Size (W_s) Settings 185
6.3 Study of FN Drop/Mark Probability Dynamics 187
6.3.1 The Effect of the Uniformization Process 188
6.3.2 The Effect of the Time Constant (T) 194
6.3.2.1 Dynamics of FN Dropping/Marking Probability . . 194
6.3.2.2 System Dynamics 198
6.3.3 The Effect of the Packet Sliding Window Size (W_s) 205
6.3.3.1 Dynamics of FN Drop/Mark Probability 206
6.3.3.2 The Effect of the Packet Sliding Window on Average Packet Arrival Rate 206
6.3.3.3 The Effect of Packet Arrival Rate on Packet Drop/Mark Probability 207
6.3.3.4 The Effect of Packet Sliding Window on Packet Drop/Mark Probability 209
6.3.3.5 System Dynamics 212
6.4 Optimal (T, W_s) settings for Linear FN Algorithm 218
6.5 Linear FN - RED Complexity Comparison 220
6.5.1 Comparison of Computational complexity 220
6.5.2 Comparison of State Storage Space 221
6.6 Quadratic FN - RED Comparison 222
6.7 Summary 225

CHAPTER SEVEN: CONCLUSION AND FUTURE RESEARCH WORK

7.1 Conclusion 228
7.2 Contributions of the Thesis 234
7.2.1 Design of Fast Congestion Notification (FN) Mechanism . . 235

7.2.2 Implementation of Fast Congestion Notification (FN) Mechanism 235
7.2.3 Comparison of FN to RED Mechanism 235
7.2.4 Performance Study of Linear FN 236
7.2.5 Study of Linear FN Drop/Mark Probability Dynamics 237
7.2.6 Performance Study of Quadratic FN to RED 237
7.3 Suggestions for Future Work 238

REFERENCES **240**

LIST OF TABLES

3.1 Criteria for Selecting an Evolution Technique (Adapted from [134]) . 76
3.2 Common FN/RED Router Setting 86

4.1 Expected & Allowed/Required Queue Length Changes 136

6.1 Linear FN - RED Comparison - Packet Loss, Queue Length, Utilization 162
6.2 Linear FN – RED Average Packet Arrival Rate Comparison 174
6.3 Linear FN – Effect of T on Link Utilization - $W_s = 256$ 183
6.4 Linear FN – Effect of W_s on Link Utilization - $T = 0.343$ seconds . . 187
6.5 Effect of Dropping/Marking Probability Uniformization on Utilization 193
6.6 The Effect of W_s Settings on the Average Packet Arrival Rate – T = 0.125 seconds 216
6.7 Effect of W_s on Queue Length – $T = 0.125$ seconds 217
6.8 Quadratic FN – RED Comparison: Utilization, Packet Loss, Queue Length 223

LIST OF FIGURES

1.1 The Effects of Congestion Collapse (Adapted from [2]) 2
1.2 End-Host Congestion Control - Queue Management Interaction 3
1.3 Scope of the Research - Shaded Area 10

2.1 Tail-Drop Mechanism (Adapted from [12]) 28
2.2 Random-Drop Mechanism (Adapted from [12]) 32
2.3 Front-Drop Mechanism (Adapted from [12]) 34
2.4 The BLUE Algorithm (Adopted from [44]) 42
2.5 The SFB Algorithm (Adopted from [79]) 43
2.6 Example of SFB Algorithm (Adopted from [79]) 44
2.7 CHOKe Algorithm (Adopted from [80]) 45
2.8 Packet Dropping/Marking Probability Function of REM (Adapted from [85]) 47
2.9 RED Router Buffer (Adopted from [12]) 49
2.10 RED Algorithm (Adapted from [17]) 54
2.11 RED Packet Drop/Mark Function (Adapted from [12]) 54
2.12 Gentle RED Algorithm (Adapted from [95]) 56
2.13 Gentle RED Packet Drop/Mark Probability Function (Adapted from [86]) 57
2.14 SRED Drop Function (Adapted from [87]) 60
2.15 DSRED Router Model (Adapted from [6]) 61
2.16 DSRED Dropping/Marking Function (Adapted from [12]) 62
2.17 Definitions of Some Fields in the IP and TCP Headers (Adopted from [122]) 66
2.18 ECN in Action (Adapted from [100]) 67

3.1 Performance Evaluation Techniques (Adapted from [136]) 71
3.2 FN Router Node Model 83

3.3 The Network Topology 84
3.4 Implementation of Confidence Interval with Terminating Simulation (Adapted from [12]) 95
3.5 *awk* Script for Computing the Sample Variance and Confidence Interval 96
3.6 Flowchart of FN Methodology 97

4.1 Pseudo Code of General FN Algorithm 108
4.2 Pseudo Code of the Behavior of FN Router 109
4.3 FN Queuing Model 116
4.4 Queue Directing Control Dynamics 119
4.5 Family of FN Packet Dropping/Marking Probability Functions - C = 105,000 bytes, T = 0.064 seconds, μ = 10 Mbps 121
4.6 Packet Dropping/Marking Probability Function - Q_{opt}= 13,125 bytes, C = 105,000 bytes, T = 0.064 seconds, μ = 10 Mbps 122
4.7 FN Dropping/Marking Probability as a Function of Rate – C = 105,000 bytes, T = 0.064 seconds, μ = 10 Mbps 124
4.8 FN Dropping/Marking Probability as a Function of Required/Allowed Changes in Queue Length – C =105,000 bytes, T = 0.064 seconds, μ=10 Mbps 125
4.9 FN Uniformization Function -$P_{fin} = \frac{P_{ini}}{2-count.P_{ini}}$ 128
4.10 Expected Packet Dropping/Marking Intervals – Uniform Distribution: $(1/P_{ini}) + (1/2)$, Geometric Distribution: $1/P_{ini}$ 130
4.11 $(\triangle Q_\mu, \triangle Q_d)$ Plane Partitioning by FN Dropping/Marking Probability Function 139
4.12 FN Dropping/Marking Activation Function in $(\triangle Q_\mu, Q_d)$ Plane . . . 141
4.13 FN Dropping/Marking Activation Function in (R_i, Q_{cur}) Plane 142

5.1 Pseudo Code of Linear FN Algorithm 149
5.2 Pseudo Code of Quadratic FN Algorithm 149
5.3 FN's Finite State Machine Model 152

6.1 Linear FN – RED Instantaneous Queue Length - RED: (Max_{th}, Min_{th}) = (5, 15), FN: (W_s, T)=(32, 0.512), (64, 0.216), (128, 0.215), (256, 0.064), (512, 0.064) 164
6.2 Linear FN – RED Instantaneous Queue Length - FN: (W_s, T) = (1024, 0.027), (2048, 0.027), (4096, 0.027) 165

6.3 Linear FN – RED Instantaneous Queue Length Cumulative Density Functions - FN: $W_s = (32, 64, 128, 256, 512, 1024)$, RED: $Min_{th}, Max_{th} = (5, 15)$, $Q_{opt} = 105$ Kbits 166
6.4 Linear FN – RED Instantaneous Queue Length Cumulative Density Functions - FN: $W_s = (2048, 4096)$, RED: $Min_{th}, Max_{th} = (5, 15)$, $Q_{opt} = 105$ Kbits 167
6.5 Linear FN – RED Average Packet Arrival Rates - $W_s = (32, 64, 128, 256)$ 170
6.6 Linear FN – RED Average Packet Arrival Rates - W_s = (512, 1024, 2048, 4096) 171
6.7 Linear FN – RED Average Packet Arrival Rate Cumulative Density Functions 173
6.8 Linear FN – RED Throughput Proportional Drop Fairness - FN: (W_s, T) = (32, 0.512), (64, 0.216), (128, 0.125), (256, 0.064), (512, 0.064), RED: $(Min, Max) = (5, 15)$ 176
6.9 Linear FN – RED Throughput Proportional Drop Fairness, FN: $(W_s, T) = (1024, 0.027), (2048, 0.027), (4096, 0.027)$, RED: $(Min, Max) = (5, 15)$ 177
6.10 Linear FN – Average Queue Length $(\bar{Q})$ 178
6.11 Linear FN – Average Packet Arrival Rate $(\bar{R})$ 180
6.12 Linear FN – Outgoing Transmission Link Utilization $(\overline{U})$ 182
6.13 Linear FN – Queue Length Cumulative Density Functions - $W_s = 256$ 183
6.14 Linear FN – Queue Length Cumulative Density Functions - $T = 0.343$ seconds 186
6.15 Effect of FN Uniformization - $W_s = 256$, $T = 0.064$ seconds – Uniformized Case (Initial, Final FN Dropping/Marking Probability, and Rate of Dropping/Marking Packets) 189
6.16 Effect of FN Uniformization - $W_s = 256$, $T = 0.064$ seconds – Uniformized Case (Current Queue Length and Average Packet Arrival Rate) 190
6.17 Effect of FN Uniformization - $W_s = 256$, $T = 0.064$ seconds – Non-Uniformized Case (Initial, Final FN Dropping/Marking Probability, and Rate of Dropping/Marking Packets) 191
6.18 Effect of FN Uniformization - $W_s = 256$, $T = 0.064$ seconds – Non-Uniformized Case (Current Queue Length and Average Packet Arrival Rate) 192
6.19 Effect of Small T Settings on FN Packet Dropping/Marking Probability Function - $W_s = 256$, $T = 0.001$ seconds 196
6.20 Effect of Large T Settings on FN Packet Dropping/Marking Probability Function - $W_s = 512$, $T = 10.000$ seconds 197

6.21 Initial FN Packet Dropping/Marking Probability - $W_s = 256$, $T = \{0.001, 0.008, 0.027, 0.064, 0.125, 0.216, 0.343, 0.512\}$ seconds 199
6.22 Initial FN Packet Dropping/Marking Probability - $W_s = 256$, $T = \{0.279, 1.000, 1.331, 1.728\}$ seconds 200
6.23 Average Packet Arrival Rate - $W_s = 256$, $T = \{0.001, 0.008, 0.027, 0.064, 0.125, 0.216, 0.343, 0.512\}$ seconds 201
6.24 Average Packet Arrival Rate - $W_s = 256$, $T = \{0.729, 1.000, 1.331, 1.728\}$ seconds 202
6.25 Current Queue Length - $W_s = 256$, $T = \{0.001, 0.008, 0.027, 0.064, 0.125, 0.216, 0.343, 0.512\}$ seconds 203
6.26 Current Queue Length - $W_s = 256$, $T = \{0.729, 1.000, 1.331, 1.728\}$ seconds 204
6.27 FN Packet Dropping/Marking Probability as a Function of Average Packet Arrival Rate (R) and Current Queue Length (Q_{cur}) - $T = 0.125$ seconds, $\mu = 10$ Mbps, $Q_{opt} = 13{,}125$ bytes 208
6.28 Effect of Small W_s Settings on Packet Dropping/Marking Probability Function - $W_s = 128$, $T = 0.125$ seconds 210
6.29 Effect of Large W_s settings on Packet Dropping/Marking Probability Function - $W_s = 4096$, $T = 1.728$ seconds 211
6.30 Initial Packet Dropping/Marking Probability - $T = 0.125$ seconds . . . 213
6.31 Average Packet Arrival Rate – $T = 0.125$ seconds 214
6.32 Current Queue Length – $T = 0.125$ seconds 215
6.33 Optimal (T, W_s) Settings 218
6.34 FN Adjusting Procedure 220

ABBREVIATIONS

ACKs	Acknowledgements
AQM	Active Queue Management
avg	Average Queue Length
AVQ	Adaptive Virtual Queue
B_c	Physical Buffer Capacity
BDP	Bandwidth Delay Product
CBR	Continuous Bit Rate
cwnd	Congestion Window Size
DRED	Dynamic Random Early Detection
$E(X)$	Expected Average of n Numbers
ECN	Explicit Congestion Notification
ERD	Early Random Drop
EWMA	Exponentially Weighted Moving Average
FD	Front-Drop
FN	Fast Congestion Notification
FRED	Flow Random Early Detection
FTP	File Transfer Protocol
IETF	Internet Engineering Task Force
IP	Internet Protocol
ISP	Internet Service Provider
J-Sim	Java-Based Simulation
L	Packet Loss
LPF	Low Pass Filter
LPF/ODA	Low Pass Filter/Over Drop Avoidance

LSE	Least Square Error
Max_{drop}	Maximum Packet Drop Probability
Max_{th}	Maximum Threshold
Min_{th}	Minimum Threshold
MSS	Maximum Segment Size
ns-2	Network Simulator 2
P_f	Final Dropping/Marking Probability
PQM	Passive Queue Management
P_{ini}	Initial Packet Drop/Mark Probability
Q_{cur}	Current Queue Length
Q_{opt}	Optimal Queue Length
QoS	Quality Of Service
$\bar{Q}$	Expected Average Queue Length
R	Average Packet Arrival Rate
RARED	Refined Adaptive RED
RD	Random Drop
REAL	REalistic And Large Network Simulator
RED	Random Early Detection
$\bar{R}$	Mean of Average Packet Arrival Rate
SFB	Stochastic Fair Blue
SMTP	Simple Mail Transfer Protocol
SRED	Stabilize Random Early Detection
T	Time Constant
TCP/IP	Transmission Control Protocol / Internet Protocol
TD	Tail-Drop
thr	Throughput
U	Transmission Link Utilization
$\overline{U}$	Average Transmission Link Utilization
UDP	User Datagram Protocol
VBR	Variable Bit Rate
W	Weight Parameter
W_s	Packet Sliding Window Size
WWW	World Wide Web

CHAPTER ONE

INTRODUCTION

This thesis is about creating a new congestion management mechanism for TCP/IP networks' routers to help control and avoid congestion. The aim of this chapter is to place the thesis in its context. In this chapter, an introduction to computer network congestion issues, the importance of congestion management, and signalling the congestion information are provided in Sections 1.1, 1.2, and 1.3, respectively. Sections 1.4, 1.5, and 1.6 of this chapter, respectively, include the motivation, scope, and objectives of the research presented in this thesis. The contributions of the work done in this thesis are stated in Section 1.7 while the thesis organization is presented in Section 1.8 of this chapter.

1.1 Congestion Issues in Computer Networks

A computer network is a collection of resources which has a finite capacity that causes users to compete for the network resources such as buffers, transmission bandwidth and processing time. As stated by Agnew [1], the limitation of capacity can result in a degradation of performance of the system to the point that the throughput of the system goes to zero. If the network is overloaded, the throughput degradation becomes unavoidable. Networks cannot afford to accept all the traffic that is offered, unless there

The contents of the thesis is for internal user only

REFERENCES

[1] C. E. Agnew, "National Networks Including Satellite Service," in *International Congress on Transportation Electronics*, pp. 237-243, 1988.

[2] M. Gerla, L. Kleinrock, "Flow Control: A Comparative Survey," *IEEE Transactions on Communications*, vol. 28, pp. 553-574, 1980.

[3] Majithia, J. C., M. Irland, J. L. Grange, N. Cohen, C. O'Donnell, "Experiments in Congestion Control Techniques," *in Proceedings of International Symposium Flow Control Computer Networks Symposium*, Versailles. France, pp. 211-234, Feb. 1979.

[4] F. Sally and F. Kevin, "Promoting the Use of End-to-End Congestion Control in the Internet," *IEEE/ACM Transactions on Networking*, vol. 7, pp. 458-472, Aug. 1999.

[5] S. Ha, I. Rhee, and L. Xu, "Cubic: A New TCP-friendly High-speed TCP Variant," in *SIGOPS Operating System Review*, vol. 42, pp. 64-74, 2008.

[6] S. Ryu, C. Rump, and C. Qiao, "Advances in Active Queue Management (AQM) Based TCP Congestion Control," *Telecommunication Systems*, vol. 25, pp. 317-351, 2004.

[7] W. Michael, *Network Congestion Control: Managing Internet Traffic*, John Wiley & Sons, 2005.

[8] M. M. Kadhum and S. Hassan, "A New Congestion Management Mechanism for Next Generation Routers," *Journal of Engineering Science and Technology*, vol. 3, pp. 265-271, 2008.

[9] Widmer, C. Boutremans, J.-Y. Le Boudec, "End-to-end Congestion Control for TCP-friendly Flows with Variable Packet Size," *SIGCOMM Computer Communication Review*, vol. 34, pp. 137-151, Apr. 2004.

[10] D. Harrison, S. Kalyanaraman, S. Ramakrishnan, "Congestion Control as a Building Block for QoS," *SIGCOMM Computer Communication Review*, Student Poster, vol. 32, Aug. 2001.

[11] Ramesh Johari, David Kim Hong Tan, "End-to-End Congestion Control for the Internet: Delays and Stability," *IEEE/ACM Transactions on Networking*, vol. 9, pp. 818-832, Dec. 2001.

[12] H. Mahbub and J. Raj, *High Performance TCP/IP Networking: Concepts, Issues, and Solutions*, U.S ed., Prentice-Hall, 2003.

[13] M. M. Kadhum and S. Hassan, "A Study of ECN Effects on Long-lived TCP Connections using RED and Drop Tail Gateway Mechanisms," in *International Symposium on Information Technology (ITSim)*, Malaysia, pp. 1-12, 2008.

[14] B. Braden, D. Clark, J. Crowcroft, B. Davie, S. Deering, D. Estrin, S. Floyd, V. Jacobson, G. Minshall, C. Partridge, L. Peterson, K. Ramakrishnan, S. Shenker, J. Wroclawski, and L. Zhang, *Recommendations on Queue Management and Congestion Avoidance in the Internet*, RFC Editor, 1998.

[15] M. Welzl, M. Muhlhauser, "Scalability and Quality of Service: A Trade-off?," *IEEECommunications Magazine*, vol. 41, pp. 32-36, 2003.

[16] S. Leonardo, P. Adriano, and M. Wagner, Jr., "Reactivity-based Scheduling Approaches For Internet Services," in *Proceedings of the Fourth Latin American Web Congress*, IEEE Computer Society, 2006.

[17] S. Floyd and V. Jacobson, "Random Early Detection Gateways for Congestion Avoidance," *IEEE/ACM Transactions on Networking*, vol.1, pp. 397-413, 1993.

[18] M. Ratul, M. B. Steven, F. Sally, I. John, P. Vern, and S. Scott, "Controlling High Bandwidth Aggregates in the Network," *ACM SIGCOMM Computer Communication Review*, vol. 32, pp. 62-73, 2002.

[19] F. Sally, "TCP and Explicit Congestion Notification," *SIGCOMM Computer Communication Review*, vol. 24, pp. 8-23, 1994.

[20] M. M. Kadhum and S. Hassan, "The Effect of ECN on Short TCP Sessions," in *IEEE International Conference on Telecommunications and Malaysia International Conference on Communications (ICT-MICC)*, Malaysia, pp. 708-712, 2007.

[21] A. Durresi, M. Sridharan, R. Jain, Liu, and Goyal, "Traffic Management using Multilevel Explicit Congestion Notification," in *5th World MultiConference on Systemics, Cybernetics and Informatics (SCI2001)*, pp. 12-17, July 2001.

[22] M. P. Barcellos and A. Detsch, "Congestion Control with ECN Support in Poll-based Multicast Protocols," in *Proceedings of the 10th IEEE Symposium on Computers and Communications (ISCC)*, pp. 724-729, 2005.

[23] R. Jain, "Congestion Control in Computer Networks: Issues and Trends," *IEEE Network*, vol. 4, pp. 24-30, 1990.

[24] L. Rizzo, "PGMCC: A TCP-friendly Single-Rate Multicast Congestion Control Scheme," in *Proceedings of the Conference on Applications, Technologies, Architectures, and Protocols for Computer Communication*, New York, USA, vol. 30, pp. 17-28, Oct. 2000.

[25] Matrawy, A., Lambadaris I., "A Survey of Congestion Control Schemes for Multicast Video Applications," *IEEE Communications Surveys & Tutorials*, pp. 22-31, 2004.

[26] P. Molinero-Fernandez and N. McKeown, "TCP switching: Exposing Circuits to IP," in *Hot Interconnects 9*, pp. 43-48, 2001.

[27] G. Liang and I. Matta, "The War between Mice and Elephants," in *Ninth International Conference on Network Protocols*, pp. 180-188, 2001.

[28] S. Floyd and K. Fall, "Promoting the Use of End-to-End Congestion Control in the Internet," *IEEE/ACM Transactions on Networking*, vol. 7, pp. 458-472, 1999.

[29] M. Tarmizi, A. Albagul, O. O. Khalifa, and Wahyudi, "QoS Evaluation of Different TCPs Congestion Control Algorithm using NS2," in *2nd Information and Communication Technologies (ICTTA '06)*, pp. 3222-3227, 2006.

[30] R. Ramani and A. Karandikar, "Explicit Congestion Notification (ECN) in TCP over Wireless Network," in *International Conference on Personal Wireless Communications*, IEEE, pp. 495-499, 2000.

[31] L. Massoulie, "Stability of Distributed Congestion Control with Heterogeneous Feedback Delays," Microsoft Research, Cambridge, UK, Technical Report, pp. 895-902, 2000.

[32] Jitendra Pahdye, Sally Floyd, "On Inferring TCP Behavior," in *Proceedings of the Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications*, San Diego, California, United States, vol. 31, pp. 287-298, Aug. 2001.

[33] S. Floyd and K. Fall, "Promoting the Use of End-to-End Congestion Control in the Internet," *IEEE/ACM Transactions on Networking*, vol. 7, pp. 458-472, 1999.

[34] V. Srihari, "Economics of Buffer Space Provisioning in Data-Communication Systems," in *Proceedings of the 26th Annual IEEE Conference on Local Computer Networks,* IEEE Computer Society, 2001.

[35] G. Xiaojie, J. Kamal, and J. S. Leonard, "Fair and Efficient Router Congestion Control," in *Proceedings of the Fifteenth Annual ACM-SIAM Symposium on Discrete Algorithms*, Society for Industrial and Applied Mathematics, New Orleans, Louisiana, 2004.

[36] S. Keshav, *An Engineering Approach to Computer Networking: ATM networks, the Internet, and the Telephone Network,* Addison-Wesley Longman Publishing Co.,1997.

[37] S. Shriram, R. Rudolf, and B. Richard, "Connection-level Analysis and Modeling of Network Traffic," in *Proceedings of the 1st ACM SIGCOMM Workshop on Internet Measurement,* San Francisco, California, USA, 2001.

[38] L. Rodr, L. Guez De, A. E. Garc, and K. Hackbarth, "Influence of the Traffic Engineering Scheme and QoS in the Dimensioning of Broadband Access Networks," in *Proceedings of the 8th WSEAS International Conference on Distance learning and Web Engineering* Santander, World Scientific and Engineering Academy and Society (WSEAS), Cantabria, Spain, 2008.

[39] B. Herbert, "Open Extensible Network Control," *Journal of Network and Systems Management*, vol. 8, pp. 73-97, 2000.

[40] Y. Jui-Pin, "Self-Configured Fair Queueing," *Simulation*, vol. 83, pp. 189-198, 2007.

[41] G. Kinshuk, T. Dan, H. Yongqiang, and R. Mendel, "Cellular Disco: Resource Management using Virtual Clusters on Shared-Memory Multiprocessors," *ACM Transactions on Computer Systems*, vol. 18, pp. 229-262, 2000.

[42] K. Mark, S. J. Golestani, and L. David, "Prevention of Deadlocks and Livelocks in Lossless Backpressured Packet Networks," *IEEE/ACM Transactions on Networking*, vol. 11, pp. 923-934, 2003.

[43] J. Y. Boudec, "*Rate Adaptation, Congestion Control and Fairness: A Tutorial*," [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.16.3326. [Accessed: Aug. 17, 2008].

[44] F. Wu-chang, G. S. Kang, D. K. Dilip, and S. Debanjan, "The BLUE Active Queue Management Algorithms," *IEEE/ACM Transactions on Networking*, vol. 10, pp. 513-528, 2002.

[45] H. Yi-Hung, L. Kuan-Cheng, K. Chao-Yu, C. Chin-Hsing, and C. Yen-Ping, "Enhancement of Fairness in a DiffServ Network using a Novel Queuing Algorithm," *Computer Standards & Interfaces,* vol. 30, pp. 52-61, 2008.

[46] S. Jagannathan, "End to End Congestion Control in High-speed Networks," in *Proceedings of the 27th Annual IEEE Conference on Local Computer Networks*, IEEE Computer Society, 2002.

[47] T. Henderson, J. Crowcroft, and S. Bhatti, "Congestion Pricing, Paying Your Way in Communication Networks," in *IEEE Proceedings of Internet Computing*, vol. 5, pp. 85-89, 2001.

[48] P. Erich and Z. Thomas, "A RED Function Design Targeting Link Utilization and Stable Queue Size Behavior," *Computer Networks: The International Journal of Computer and Telecommunications Networking,* vol. 44, pp. 383-410, 2004.

[49] Z. Mingyu and G. Guanqun, "Achieving Fair Bandwidth Allocation without Per-Flow State," in *Proceedings of the 2001 International Conference on Computer Networks and Mobile Computing (ICCNMC'01)*, IEEE Computer Society, 2001.

[50] D. Katabi, "Decoupling Congestion Control and Bandwidth Allocation Policy with Application to High Bandwidth-delay Product Networks," Ph.D. Dissertation, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, 2003.

[51] Zheng Wang, *Internet QoS: Architectures and Mechanisms for Quality of Service (1st ed.)*, Morgan Kaufmann Publishers Inc., 2001.

[52] K. Aditya and K. Anurag, "Performance of TCP Congestion Control with Explicit Rate Feedback," *IEEE/ACM Transactions on Networking*, vol. 13, pp. 108-120, 2005.

[53] T. V. Lakshman, M. Upamanyu, and S. Bernhard, "TCP/IP Performance with Random Loss and Bidirectional Congestion," *IEEE/ACM Transactions on Networking*, vol. 8, pp. 541-555, 2000.

[54] E. C. Douglas, *Internetworking with TCP/IP (5th ed.)*, vol. 1, Prentice-Hall, 2005.

[55] K. Jong-hwan and Y. Ikjun, "Reducing Queue Oscillation at a Congested Link," *IEEE Transactions on Parallel and Distributed Systems*, vol. 19, pp. 394-407, 2008.

[56] A. Mankin, "Random Drop Congestion Control," in *Proceedings of the ACM Symposium on Communications Architectures and Protocols*, Philadelphia, Pennsylvania, United States, ACM, 1990.

[57] Srinivasan Keshav, "Congestion Control in Computer Networks," Ph.D Thesis, University of California at Berkeley, Berkeley, USA, 1992

[58] M. Archan, "Dynamics of TCP Congestion Avoidance with Random Drop and Random Marking Queues," Ph.D. Thesis, University of Maryland at College Park, pp. 194, 2000.

[59] S. Low, F. Paganini, J. Wang, S. Adlakha, J. C. Doyle, "Dynamics of TCP/RED and a Scalable Control," in *Proceedings of IEEE Infocom*, New York, USA, pp. 239-248, 2002.

[60] D. Parijat, A.-H. Omar, and A. Eitan, "On Loss Probabilities in Presence of Redundant Packets with Random Drop," in *Proceedings of the Second International IFIP-TC6 Networking Conference on Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks and Mobile and Wireless Communications*, vol. 53, pp. 147-167, 2003.

[61] H. Yaqing, G. Roch, and Rin, "A Simple FIFO-based Scheme for Differentiated Loss Guarantees," *Computer Networks: The International Journal of Computer and Telecommunications Networking*, vol. 51, pp. 1133-1150, 2007.

[62] T. V. Lakshman, A. Neidhardt, and T. J. Ott, "The Drop from Front Strategy in TCP and in TCP over ATM," in *IEEE Proceedings on Fifteenth Annual Joint Conference of the IEEE Computer Societies*, vol. 3, pp. 1242-1250, 1996.

[63] Courcoubetis C, Weber R, *Pricing Communication Networks: Economics, Technology, and Modelling*, John Wiley & Sons Ltd, 2003.

[64] E. S. Hashem, "Analysis of Random Drop for Gateway Congestion Control," Massachusetts Institute of Technology, Dept. of Electrical Engineering and Computer Science, Technical Report, Nov. 1989.

[65] Jae Chung Claypool, "Analysis of Active Queue Management," in *Proceedings of the 2nd IEEE International Symposium on Network Computing and Applications*, USA, pp. 359-366, Apr. 2003.

[66] Z. Heying, L. Baohong, D. Wenhua, "Design of a Robust Active Queue Management Algorithm Based on Feedback Compensation," in *Proceedings of the Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications*, New York, USA, pp. 277-285, 2003.

[67] Gorry Fairhurst, Aaron Falk, Dan Grossman, Reiner Ludwig, Jamshid Mahdavi, Saverio Mascolo, Marie-jose Montpetit, Lloyd Wood, *Advice for Internet Subnetwork Designers*, RFC 3819, 2004.

[68] M. Hassan and R. Jain, *High Performance TCP/IP Networking: Concepts, Issues, and Solutions*, Pearson Prentice Hall, 2004.

[69] M. Welzl, "Scalable Router Aided Congestion Avoidance for Bulk Data Transfer in High Speed Networks," in *Proceedings of the Third International Workshop on Protocols for Fast Long-Distance Networks*, pp. 1-6, Feb. 2005.

[70] L. Xue and H. Wenbo, "Active Queue Management Design using Discrete-Event Control," in *46th IEEE Conference on Decision and Control*, pp. 3806-3811, 2007.

[71] K. Francine, "Self-aware Management of IP Networks with QoS Guarantees," *International Journal of Network Management*, vol. 14, pp. 351-364, 2004.

[72] K. Aleksandar, "The Power of Explicit Congestion Notification," in *Proceedings of the 2005 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications*, Philadelphia, Pennsylvania, USA, pp. 61-72, 2005.

[73] Guido Appenzeller, Isaac Keslassy, Nick McKeown, "Sizing Router Buffers," in *Proceedings of the* Conference *on Applications, Technologies, Architectures, and Protocols for Computer Communications,* Portland, Oregon, USA, pp. 281-292, Aug. 2004.

[74] A. Mankin and K. Ramakrishnan, *Gateway Congestion Control Survey*, RFC Editor, 1991.

[75] V. Jacobson, "Congestion Avoidance and Control," in *Symposium Proceedings on Communications Architectures and Protocols,* Stanford, California, United States, 1988.

[76] L. Long, A. Jay, J. Kevin, and F. D. Smith, "The Effects of Active Queue Management on Web Performance," in *Proceedings of the 2003 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications,* Karlsruhe, Germany, 2003.

[77] G.Thiruchelvi, J.Raja, "A Survey on Active Queue Management Mechanisms," *International Journal of Computer Science and Network Security*, vol. 8, no. 12, pp. 130-145, Dec. 2008.

[78] S. Ling, Z. Rong, and J. C. Hou, "An Active Queue Management Scheme for Internet Congestion Control and its Application to Differentiated Services," in *Proceedings of the Ninth International Conference on Computer Communications and Networks*, pp. 62-68, 2000.

[79] F. Wu-Chang, D. D. Kandlur, D. Saha, and K. G. Shin, "Stochastic Fair Blue: A Queue Management Algorithm for Enforcing Fairness," in *IEEE Proceedings Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies*, vol. 3, pp. 1520-1529, 2001.

[80] P. Rong, B. Prabhakar, and K. Psounis, "CHOKe - A Stateless Active Queue Management Scheme for Approximating Fair Bandwidth Allocation," in *Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM)*, vol. 2, pp. 942-95, 2000.

[81] G. Chatranon, M. A. Labrador, and S. Banerjee, "A Survey of TCP-Friendly Router-based AQM Schemes," *Computer Communications*, vol. 27, no. 15, pp. 1424–1440, 2004.

[82] A. Tang, J. Wang, and S. H. Low, "Understanding CHOKe: Throughput and Spatial Characteristics," *IEEE/ACM Transactions on Networking*, vol. 12, no. 4, pp. 694-707, 2004.

[83] H. Yan and Z. Guangzhao, "A Stateless Active Queue Management Scheme for Approximating Fair Bandwidth Allocation and Stabilized Buffer Occupation," in *Proceedings of the Second IEEE Pacific Rim Conference on Multimedia: Advances in Multimedia Information Processing*, Springer-Verlag, 2001.

[84] G. Chatranon, M. A. Labrador, and S. Banerjee, "A Credit-Based Active Queue Management (AQM) Mechanism to Achieve Fairness in the Internet," in *4th International IFIP-TC6 Networking Conference,* Waterloo, Canada, pp. 930-942, May 2-6, 2005.

[85] S. Athuraliya, S. H. Low, V. H. Li, and Y. Qinghe, "REM: Active Queue Management," *IEEE Network*, vol. 15, pp. 48-53, 2001.

[86] M. Welzl, *Network Congestion Control: Managing Internet Traffic*, John Wiley & Sons, 2005.

[87] J. H. C. Nga, H. H. C. Iu, S. H. Ling, and H. K. Lam, "Comparative Study of Stability in Different TCP/RED Models," *Chaos, Solitons & Fractals,* vol. 37, pp. 977-987, 2008.

[88] V. Firoiu and M. Borden, "A Study of Active Queue Management for Congestion Control," in *IEEE Proceedings on Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies*, vol.3, pp. 1435-1444, 2000.

[89] M. May, C. Diot, B. Lyles, and J. Bolot, "Influence of Active Queue Management Parameters on Aggregate Traffic Performance," Institut National De Recherche En Informatique Et En Automatique, INRIA.RR3995, 2000.

[90] F. Wu-Chang and D. K. Dilip, "Adaptive Packet Marking for Maintaining End-to-End Throughput in a Differentiated-Services Internet," *IEEE/ACM Transactions on Networking*, vol. 7, pp. 685-697, 1999.

[91] S. Floyd, "RED: Discussion of Setting Parameters," [Online]. Available: http://www.icir.org/floyd/REDparameters.txt. [Accessed: Nov. 14, 2007].

[92] Z. Bing and A. Mohammed, "A Framework to Determine Bounds of Maximum Loss Rate Parameter of RED Queue for Next Generation Routers," *Journal of Network and Computer Applications*, vol. 31, pp. 429-445, 2008.

[93] M. Parris, K. Jeffay, and F. D. Smith, "Lightweight Active Router-Queue Management for Multimedia Networking," in *Multimedia Computing and Networking (MMCN)*, San Jose, CA, pp. 162-174, Jan. 1999.

[94] W. C. Feng, D. D. Kandlur, D. Saha, and K. G. Shin, "A Self-configuring RED Gateway," in *IEEE Proceedings of the Eighteenth Annual Joint Conference of the IEEE Computer and Communications Societies*, vol. 3, pp. 1320-1328, 21-25 Mar. 1999.

[95] S. Floyd, "Recommendation on Using the "Gentle" Variant of RED," [Online]. Available: http://www.icir.org/floyd/red/gentle.html. [Accessed: Nov. 22, 2007].

[96] S. Kunniyur, R. Srikant, "Analysis and Design of an Adaptive Virtual Queue (AVQ) Algorithm for Active Queue Management," in *Proceedings of SIGCOMM*, San Diego, USA, pp. 123-134, Aug. 2001.

[97] C. Wang, B. Li, Y. Hou, K. Sohraby, Y. Lin, "LRED: A Robust Active Queue Management Scheme Based on Packet Loss Rate," in *Proceedings of the IEEE International Conference on Computer Communications,* Hong Kong, pp. 1-12, 2004.

[98] T. J. Ott, T. V. Lakshman, and L. H. Wong, "SRED: Stabilized RED," in *IEEE Proceedings of the Eighteenth Annual Joint Conference of the IEEE Computer and Communications Societies*, vol. 3, pp. 1346-1355, 1999.

[99] L. Dong and M. Robert, "Dynamics of Random Early Detection," in *Proceedings of the Conference on Applications, Technologies, Architectures, and Protocols for Computer Communication,* Cannes, France, 1997.

[100] S. Floyd, R. Gummadi, and S. Shenker, "Adaptive RED: An Algorithm for Increasing the Robustness of RED's Active Queue Management," Berkely, USA, [Online]. Available: http://www.icir.org/floyd/red.html. [Accessed: Oct. 24, 2007].

[101] B. Zheng and M. Atiquzzaman, "DSRED: Improving Performance of Active Queue Management over Heterogeneous Networks," in *International Conference on Communications*, IEEE, vol. 8, pp. 2375-2379, 2008.

[102] Z. Bing and A. Mohammed, "Study of Active Queue Management Using OPNET," [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=?doi=10.1.1.130.2330. [Accessed: Oct. 27, 2007].

[103] S. N. K. and S. T. R., "Triple Queue Management Based Fuzzy Distributed Admission Control for High Performance Internet Routers," *International Journal of Information Technology*, vol. 11, pp. 38-51, 2005.

[104] K. Jahon, S. Byunghun, C. Kwangsue, L. Hyukjoon, and K. Hyunkook, "MRED: A New Approach to Random Early Detection," in *Proceedings of the 15th International Conference on Information Networking,* pp. 347-352, 2001.

[105] L. Hu. and K. D., "HRED: A Simple and Efficient Active Queue Management Algorithm," in *13th International Conference on Computer Communications and Networks (ICCCN)*, Chicago, IL, pp. 387-393, 11-13 Oct. 2004.

[106] X. Yue-Dong, W. Zhen-Yu, and W. Hua, "ARED: A Novel Adaptive Congestion Controller," in *Proceedings of the International Conference on Machine Learning and Cybernetics*, vol. 2, pp. 708-714, 2005.

[107] T.-H. Kim and K.-H. Lee, "Refined Adaptive RED in TCP/IP Networks," in *International Joint Conference SICE-ICASE*, Busan, pp. 3722-3725, 18-21 Oct. 2006.

[108] K. K. Ramakrishnan , R. Jain, "A Binary Feedback Scheme for Congestion Avoidance in Computer Networks with a Connectionless Network Layer," *Symposium Proceedings on Communications Architectures and Protocols*, Stanford, California, United States, pp 303-313, 1988.

[109] Y. Yaw, H. Modaressi, W. D. Ju, and P. A. Ng, "Credit Management and Source Quenching for the Subscriber Network Interface of Switched Multi-megabits Data Services," in *Proceedings of the First International Conference on Systems Integration*, pp. 150-157, 1990.

[110] Majithia, J. C., M. Irland, J. L. Grange, N. Cohen and C. O'Donnell, "Experiments in Congestion Control Techniques," in *Proceedings of the International Symposium on Flow Control in Computer Networks*, Versailles, France, pp. 211-234, Feb. 1979.

[111] B. T. Doshi, P. K. Johri, A. N. Netravali, and K. K. Sabnani, "Error and Flow Control Performance of a High Speed Protocol," *Transactions on Communications*, IEEE, vol. 41, pp. 707-720, 1993.

[112] K. Keng-Tai, P. M. Partho, and K. T. Satish, "Predictive Congestion Control in High-speed Wide-Area Networks," University of Maryland at College Park, Computer Science Technical Report Series, 1990.

[113] L. W. Carey and R. C. David, "Loss-load Curves: Support for Rate-based Congestion Control in High-speed Datagram Networks," *in Proceedings of the Conference on Communications Architecture and Protocols,* Zurich, Switzerland, vol. 21, pp. 17-28, 3-6 Sept. 1991.

[114] F. Kamoun, "A Drop and Throttle Flow Control Policy for Computer Networks," *Transactions on Communications*, IEEE , vol. 29, pp. 444-452, 1981.

[115] F. A. Ian, Zg, Akan O. B., and M. Giacomo, "A Rate Control Scheme for Adaptive Real-time Applications in IP Networks with Lossy Links and Long Round Trip Times," *IEEE/ACM Transactions on Networking*, vol. 13, pp. 554-567, 2005.

[116] L. Zhang, "Why TCP Timers Don't Work Well," in *Proceedings of the ACM SIGCOMM Conference on Communications Architectures and Protocols*, Stowe, Vermont, United States, pp. 397-405, 1986.

[117] H. V. Nitin, ""De-randomizing" Congestion Losses to Improve TCP Performance over Wired-wireless Networks," *IEEE/ACM Transactions on Networking*, vol. 13, pp. 596-608, 2005.

[118] R. Jain, "A Delay-based Approach for Congestion Avoidance in Interconnected Heterogeneous Computer Networks," *ACM SIGCOMM Computer Communication Review*, vol. 19, pp. 56-71, 1989.

[119] K. Ramakrishnan and S. Floyd, A Proposal to add Explicit Congestion Notification (ECN) to IP: RFC 2481 (Experimental). Obsoleted by RFC 3168, 1999.

[120] K. Ramakrishnan, S. Floyd, and D. Black, *The Addition of Explicit Congestion Notification (ECN) to IP*, RFC 3168, 2001.

[121] J. H. Salim and U. Ahmed, Performance Evaluation of Explicit Congestion Notification (ECN) in IP Networks, RFC Editor, 2000.

[122] M. Malowidzki, "Simulation-based Study of ECN Performance in RED Networks," SIMULATION SERIES, vol. 35, pp. 447-451, 2003.

[123] L. Chunlei and J. Raj, "Improving Explicit Congestion Notification with the Mark-front Strategy," *Computer Networks: The International Journal of Computer and Telecommunications Networking*, vol. 35, pp. 185-201, 2001.

[124] Kunniyur, S. Srikant, R., "A Time Scale Decomposition Approach to Adaptive ECN Marking," *IEEE Transactions on Automatic Control*, vol. 47, pp. 882-894, 2002.

[125] T. Kelly, "An ECN Probe-Based Connection Acceptance Control," *ACM Computer Communication Review*, pp. 14-25, 2001.

[126] M. Kwon and S. Fahmy, "TCP Increase/Decrease Behavior for Explicit Congestion Notification (ECN)," in *Proceedings of the IEEE International Conference on Communications*, vol. 4, pp. 2335-2340, Apr. 2002.

[127] Peerapol Tinnakornsrisuphap, Armand M. Makowski, "Limit Behavior of ECN/RED Gateways Under a Large Number of TCP Flows," in *Proceedings of IEEE INFOCOM*, San Francisco, USA, pp. 873-883, 2003.

[128] M. M. Kadhum and S. Hassan, "TCP ECN-Capable Performance in a Differentiated Services Network," in *International Conference on Information Technology and Multimedia 2008 (ICIMU 2008)*, Malaysia, Track 10:CSN, pp. 345-350, 18-19 Nov. 2008.

[129] M. M. Kadhum and S. Hassan, "A Study of ECN Effects on Long-lived TCP Connections using RED and Drop Tail Gateway Mechanisms," in *International Symposium on Information Technology (ITSim)*, Malaysia, vol.4, pp. 1-12, 2008.

[130] K. Minseok and F. Sonia, "On TCP Reaction to Explicit Congestion Notification," *Journal of High Speed Networks*, vol. 13, pp. 123-138, 2004.

[131] C. Liu and R. Jain. "Delivering Faster Congestion Feedback with the Mark-FrontStrategy," in *Proceedings of the International Conference on Communication Technology*, Beijing, vol.1, pp.665-672, 2000.

[132] F. Akujobi, I. Lambadaris, R. Makkar, N. Seddigh, B. Nandy, "BECN for Congestion Control in TCP/IP Networks: Study and Comparative Evaluation," *IEEE Global Telecommunications Conference*, Taipei, Taiwan, vol. 3, pp.2588-2593, Nov. 2002.

[133] K. Byung-Chul and C. You-Ze, "Mark-relay Strategy for Explicit Congestion Notification in the Internet," *Electronics Letters,* vol. 38, pp. 612-614, 2002.

[134] R. K. Jain, *The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation, and Modeling,* Wiley 1991.

[135] O. Ghazali, "Scaleable and Smooth TCP-friendly Receiver-based Layered Multicast Protocol," Ph.D. Thesis, Universiti Utara Malaysia, Malaysia, 2008.

[136] S. Hassan, "Simulation-based Performance Evaluation of TCP-friendly Protocols for Supporting Multimedia Applications in the Internet," Ph.D. Thesis, University of Leeds, 2002.

[137] A. Law and W. D. Kelton, *Simulation Modeling and Analysis (3rd ed.)*, McGraw-Hill Science, 2000.

[138] K. Srinivasan, "Congestion Control in Computer Networks," Ph.D. Thesis, University of California at Berkeley, USA, 1991.

[139] E. Eide, L. Stoller, T. Stack, J. Freire, and J. Lepreau, "Integrated Scientific Workflow Management for the Emulab Network Testbed," in *2006 USENIX Annual Technical Conference*, Boston, MA, pp. 363–368, 2006.

[140] L. Rizzo, "Dummynet," [Online]. Available: http://info.iet.unipi.it/~luigi/dummynet/. [Accessed: Apr. 14, 2008].

[141] P. Communications, "The PacketStorm IP Network Emulators," [Online]. Available: http://www.packetstorm.com/psc/psc.nsf/site/index. [Accessed: Jan. 14, 2008].

[142] B. Lee, E. Deborah, F. Kevin, F. Sally, H. John, H. Ahmed, H. Polly, M. Steven, V. Kannan, X. Ya, and Y. Haobo, "Advances in Network Simulation," *Computer*, vol. 33, pp. 59-67, 2000.

[143] W. D. Kelton, R. P. Sadowski, and D. T. Sturrock, *Simulation with Arena*, McGraw-Hill Science, 2003.

[144] B. Jerry, *Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice*, John Wiley & Sons, 1998.

[145] K. Pawlikowski, H. D. J. Jeong, and J. S. R. Lee, "On Credibility of Simulation Studies of Telecommunication Networks," *IEEE Communications Magazine*, vol. 40, pp. 132-139, 2002.

[146] C. F. Michael, "Simulation Optimization," in *Proceedings of the 33rd Conference on Winter Simulation* Arlington, Virginia, IEEE Computer Society, pp. 53-61, 2001.

[147] F. Sally and P. Vern, "Difficulties in Simulating the Internet," *IEEE/ACM Transactions on Networking*, vol. 9, pp. 392-403, 2001.

[148] S. B. John, "Simulation of Large Networks: Modeling and Simulation of Telecommunication Networks for Control and Management," in *Proceedings of the 35th Conference on Winter Simulation: Driving Innovation*, New Orleans, Louisiana, pp. 431-440, 2003.

[149] S. Keshav, "REAL Simulator," [Online]. Available: http://www.cs.cornell.edu/skeshav/real/overview.html. [Accessed: Jan. 22, 2008].

[150] X. Zeng, R. Bagrodia, and M. Gerla, "GloMoSim: A Library for Parallel Simulation of Large-scale Wireless Networks," in *Proceedings of the Twelfth Workshop on Parallel and Distributed Simulation*, pp. 154-161, 1998.

[151] B. Rajive, M. Richard, T. Mineo, C. Yu-an, Z. Xiang, M. Jay, and S. Ha Yoon, "Parsec: A Parallel Simulation Environment for Complex Systems," *Computer*, vol. 31, pp. 77-85, 1998.

[152] E. Butterworth, "JSim," [Online]. Available: http://nsr.bioeng.washington.edu/jsim/. [Accessed: May. 29, 2008].

[153] S. Ahmed, C. Wei-Peng, C. H. Jennifer, K. Lu-Chuan, L. Ning, L. Hyuk, T. Hung-Ying, and Z. Honghai, "J-Sim: A Simulation Environment for Wireless Sensor Networks," in *Proceedings of the 38th Annual Symposium on Simulation*, IEEE Computer Society, pp. 175-187, 2005.

[154] T. Issariyakul and E. Hossain, *Introduction to Network Simulator NS2*, Springer US, 2009.

[155] P. Meeneghan and D. Delaney, "An Introduction to NS, Nam and OTcl Scripting," [Online]. Available: http://www.cs.nuim.ie/research/reports/2004/nuim-cs-tr-2004-05.pdf. [Accessed: Jan. 9, 2008].

[156] S. Bajaj, L. Breslau, D. Estrin, K. Fall, S. Floyd, P. Haldar, M. Handley, A. Helmy, J. Heidemann, P. Huang, S. Kumar, S. Mccanne, R. Rejaie, P. Sharma, K. Varadhan, H. Y. Ya Xu, and D. Zappala, "Improving Simulation for Network Research," [Online]. Available: http://www.citeulike.org/user/p2p-sec/article/1637936. [Accessed: Jan. 9, 2008].

[157] J. Heidemann, K. Mills, and S. Kumar, "Expanding Confidence in Network Simulations," *IEEE Network*, vol. 15, pp. 58-63, 2001.

[158] S. Floyd, *The New Reno Modification to TCP's Fast Recovery Algorithm*, RFC 2582, 1999.

[159] F. Hirose, M. Fukuhara, T. Hatano, H. Shigeno, and K. Okada, "A Two-level ECN Marking for Fair Bandwidth Allocation between HSTCP and TCP Reno," in *25th IEEE International Conference on Distributed Computing Systems Workshops*, pp. 763-769, 2005.

[160] P. Fei, C. Shiduan, and M. Jian, "An Effective Way to Improve TCP Performance in Wireless/Mobile Networks," in *Information Systems for Enhanced Public Safety and Security (IEEE/AFCEA)*, pp. 250-255, 2000.

[161] T. Hamann and J. Walrand, "A New Fair Window Algorithm for ECN Capable TCP (new-ECN)," in *Proceedings of the Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies*, vol.3, pp. 1528-1536, 2000.

[162] E. C. Mark and B. Azer, "Self-similarity in World Wide Web Traffic: Evidence and Possible Causes," *IEEE/ACM Transactions on Networking*, vol. 5, pp. 835-846, 1997.

[163] S. Biplab, S. Kalyanaraman, and S. V. Kenneth, "An Integrated Model for the Latency and Steady-state Throughput of TCP Connections," *Performance Evaluation*, vol. 46, pp. 139-154, 2001.

[164] G. Schay, *Introduction to Probability with Statistical Applications*, Birkhäuser, Boston, 2007.

[165] J. Li and S. Kalyanaraman, "MCA: An End-to-End Multicast Congestion Avoidance Scheme with Feedback Suppression," *Computer Communications,* vol. 27, pp. 1264-1277, 2004.

[166] W. Richard Stevens, *TCP/IP Illustrated, Volume 1: The Protocols,* Addison-Wesley Professional Computing Series, 1994.

[167] D. Imadud and S. Nazar Abbas, "Passive Packet Loss Detection and its Effect on Web Traffic Characteristics," in *Proceedings of the 2008 International Conference on Computer and Electrical Engineering*, IEEE Computer Society, pp. 729-733, 2008.

[168] M. Charles and L. Swee, "The Expanding Role of Simulation in Future Manufacturing," in *Proceedings of the 33rd Conference on Winter Simulation* Arlington, Virginia, IEEE Computer Society, pp. 1478-1486, 2001.

[169] C. F. Michael, W. G. Fred, and A. Jay, "Simulation Optimization: A Review, New Developments, and Applications," in *Proceedings of the 37th Conference on Winter Simulation* Orlando, Florida, Winter Simulation Conference, pp. 83-95, 2005.

[170] J. Kiefer, "Conditional Confidence Statements and Confidence Estimators," *Journal of the American Statistical Association*, vol. 72, pp. 789–827, 1977.

[171] Wikipedia, "Confidence Interval," [Online]. Available: http://en.wikipedia.org/wiki/Confidence_interval. [Accessed: June. 14, 2008].

[172] S. M. Ross, *Simulation, Third Edition*, Academic Press, 2001.

[173] M. M. Kadhum and S. Hassan, "The Design Motivation and Objectives for Fast Congestion Notification (FN)," in *28th APAN Network Research Workshop*, Malaysia, pp. 25-30, 2009.

[174] T. Bonald, M. May, and J. C. Bolot, "Analytic Evaluation of RED Performance," in *IEEE Proceedings of the Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies*, vol.3, pp. 1415-1424, 2000.

[175] M. M. Kadhum and S. Hassan, "Fast Congestion Notification Mechanism for ECN-capable Routers," in *International Symposium on Information Technology (ITSim)*, Malaysia, vol.4, pp. 2295-2300, 2008.

[176] M. M. Kadhum and S. Hassan, "The Uniformization of the Fast Congestion Notification (FN)," *International Journal of Computer Science and Information Security (IJCSIS)*, vol. 4, Paper 31070968, pp. 166-170, Aug. 2009.

[177] S. Srinivas and R. Srikant, "Network Optimization and Control," *Foundations and Trends in Networking*, vol. 2, pp. 271-379, 2007.

[178] M. M. Kadhum and S. Hassan, "A Linear Packet Marking Probability Function for Fast Congestion Notification (FN)," *International Journal of Computer Science and Network Security*, vol. 9, pp. 45-50, 2009.

[179] S. T. D. TAN, *Applied Mathematics, (3rd ed.)*, Thomson Brooks/Cole, 2004.

[180] M. M. Kadhum and S. Hassan, "A Demonstration of the FN Packet Marking Probability," in *9th International Symposium on Communications and Information Technologies (ISCIT 2009),* Incheon, Korea, pp. 1540 - 1543, 2009.

[181] M. M. Kadhum and S. Hassan, "The Impact of the Average Arrival Rate on the FN Drop/Mark Probability," submitted to *Journal of Advanced Computing and Applications*, 2009.

[182] M. M. Kadhum and S. Hassan, "FN Packet Marking/Dropping Probability as a Function of Required/Allowed Changes in Queue Level," in *First International Conference on Future Information Networks (ICFIN2009)*, Beijing, China, pp. 61-65, 2009.

[183] S. De Cnodder, O. Elloumi, and K. Pauwels, "RED Behavior with Different Packet Sizes," in *Proceedings of the Fifth IEEE Symposium on Computers and Communications (ISCC)*, pp. 793-799, 2000.

[184] M. M. Kadhum and S. Hassan, "The FN Quadratic Marking-Dropping Probability Function," in *The First International Conference on Networks & Communications (NetCoM-2009)*, Chennai, India, pp. 135-140, 2009.

[185] M. M. Kadhum and S. Hassan, "The Mark-Drop Activation Function of the Fast Congestion Notification (FN) Mechanism," *International Journal of Communication Networks and Information Security (IJCNIS)*, vol. 1, pp. 46-51, Dec. 2009.

[186] I. J. Khor, J. Thomas, and I. Jonyer, "Sliding Window Protocol for Secure Group Communication in Ad-Hoc Networks," *Journal for Universal Computer Science (J-JUCS)*, vol. 11, pp. 37-55, 2005.

[187] A. P. Bovo, E. C. Rizzi, L. A. Martello, R. P. d. G. Tittoto, M. N. P. Bertocco, C. M. Narduzzi, and A. M. Biasutto, "Non-invasive Estimation of Round Trip Time a Packet-oriented Acknowledge-based Transmission System," vol. 7289454, FreePatentsOnline, 2007.

[188] M. M. Kadhum and S. Hassan, "A Quadratic Version of Fast Congestion Notification (FN) Algorithm" submitted to *International Journal of Computer Networks & Communications (IJCNC)*, 2009.

[189] S. Floyd, "Setting Parameters," [Online]. Available: http://www.icir.org/floyd/red.html#parameters. [Accessed: July, 15, 2008].

[190] A. Haider, H. Sirisena, V. Sreeram, and R. Harris, "Stability Conditions For Scalable TCP-RED Based AQM," in *International Conference on Mechatronics and Automation (ICMA)*, pp. 576-581, 2007.

[191] Q. Dashun, C. Zhixiang, and C. Bi, "An Improvement Algorithm Based on RED and its Performance Analysis," in *9th International Conference on Signal Processing (ICSP9)*, pp. 2005-2008, 2008.

[192] C. V. Hollot, V. Misra, D. Towsley, and G. Wei-Bo, "A Control Theoretic Analysis of RED," in *Proceedings of the Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM)*, vol.3, pp. 1510-1519, 2001.

[193] C. Xi, W. Siu-Chung, C. K. Tse, and L. Trajkovic, "Stability Analysis of RED Gateway with Multiple TCP Reno Connections," in *IEEE International Symposium on Circuits and Systems (ISCAS)*, pp. 1429-1432, 2007.

[194] S. Miskovic, G. Petrovic, and L. Trajkovic, "Implementation and Performance Analysis of Active Queue Management Mechanisms," in *7th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services*, vol.2, pp. 317-326, 2005.

[195] B. Osman and G. S. Robert, "Some Examples of Simulation Model Validation using Hypothesis Testing," in *Proceedings of the 14th Conference on Winter Simulation,* San Diego, California, vol. 2, pp. 621-629 1982.

[196] M. M. Kadhum and S. Hassan, "A Quantitative Analysis and Performance Study of Fast Congestion Notification (FN) Mechanism," in *15th Asia-Pacific Conference on Communications (APCC2009)*, Shanghai, China, pp. 816-820, 2009.

[197] M. M. Kadhum and S. Hassan, "On the Linear FN Performance in a Heterogeneous Network," submitted to *Journal of Universal Computer Science (J.UCS)*, 2009.

[198] M. M. Kadhum and S. Hassan, "Performance Study of Quadratic FN Algorithm on Heterogeneous Internet Sources," submitted to *Journal of Computer Science and Engineering*, 2010.

[199] M. M. Kadhum and S. Hassan, "The Effect of the Packet Sliding Window Size on FN Drop/Mark Probability," submitted to *Global Journal of Computer Science and Technology (GJCST)*, 2010.

[200] M. M. Kadhum and S. Hassan, "On the Optimal Settings for Fast Congestion Notification Mechanism (FN)," submitted to *World Applied Sciences Journal (WASJ)*, 2010.