Analysis and Design of Active Queue Management for TCP-RED Congestion Control Strategies

By

Nabhan Hamadneh

A thesis submitted for the degree of Doctor of Philosophy

Murdoch University

School of Information Technology,
Murdoch University.

November 2012
Declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

Signed: ___________________________________________
Abstract

This thesis investigates the problems of the Active Queue Management (AQM) techniques for congestion control in TCP networks. Random Early Detection (RED) and the RED-based strategies, which adopt the AQM approach, are evaluated through simulation. Two main problems of RED, and its variants, are considered. The first problem is the mismatch between the average and actual queue sizes. The second problem is the parameter configuration. This thesis proposes three new RED-based strategies and simulates them using the NS-2 simulator. These novel strategies are evaluated and compared with current RED based strategies. The proposed strategies are: Queue Sectors RED (QSRED), Risk Threshold RED (RTRED) and Weighted RED (WTRED). The performance of these strategies is evaluated using performance indicators such as: throughput, link utilization, packet loss and delay.

QSRED divides the router buffer into equal subsectors and monitors the queue dynamics. The actual drop probability $p_a$ and maximum drop probability $max_p$ are adjusted depending on the position of the actual and average queue sizes; $q$ and $avg$ respectively.

Currently, RED maintains a maximum threshold $max_th$ and minimum threshold $min_th$. The second RED modification, RTRED, adds a third dropping level. This new dropping level is the risk threshold $risk_th$ which works with the actual and average queue sizes to detect the immediate congestion in gateways. Congestion reaction by RTRED is on time. The reaction to congestion is neither too early, to avoid unfair packet losses, nor too late to avoid packet dropping from time-outs.

The third proposed RED modification, WTRED, adjusts the weight parameter $w_q$ dynamically, to reduce the mismatch between the average and ac-
tual queue size. WTRED also adjusts the maximum and minimum thresholds, to increase network throughput and link utilization.

The simulation results demonstrate the shortcomings of RED and RED-based strategies. The results also show that QSRED, RTRED and WTRED achieve greater network performance over other strategies.
Contents

Abstract i
List of Figures v
List of Tables vii
Dedication viii
Acknowledgement ix
Publications x

Chapter 1. Introduction 1
1.1. Overview of the congestion problem 1
1.2. Queue management and congestion control 3
1.3. Organization of the thesis 6

Chapter 2. Literature Review 7
2.1. What is congestion? 8
2.2. TCP performance parameters 12
2.3. Acknowledgments 13
2.4. Flow control and sliding window 14
2.5. Traditional source congestion control 14
2.6. TCP variants 16
2.7. Queue management and congestion control 21
2.8. Intermediate router congestion control 22
2.9. Random Early Detection (RED) 23
2.10. RED-based strategies 31
2.11. Problems with AQM 34
2.12. Congestion control approaches other than AQM 35
2.13. Summary 37

Chapter 3. Queue Sectors RED (QSRED) Strategy 38
3.1. Background 38
3.2. The queue sizes mismatch and buffers overflow 40
3.3. Effective RED (ERED) Strategy 43
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4. Gaps in ERED’s evaluation</td>
<td>54</td>
</tr>
<tr>
<td>3.5. QSRED Algorithm</td>
<td>62</td>
</tr>
<tr>
<td>3.6. Network Topology</td>
<td>66</td>
</tr>
<tr>
<td>3.7. Simulation Results</td>
<td>67</td>
</tr>
<tr>
<td>3.8. Summary</td>
<td>71</td>
</tr>
<tr>
<td>Chapter 4. A Third Drop Level For RED</td>
<td>73</td>
</tr>
<tr>
<td>4.1. Background</td>
<td>74</td>
</tr>
<tr>
<td>4.2. Lock Out and Full Queue problems</td>
<td>75</td>
</tr>
<tr>
<td>4.3. Adaptive RED</td>
<td>78</td>
</tr>
<tr>
<td>4.4. RTRED strategy</td>
<td>80</td>
</tr>
<tr>
<td>4.5. Network topology</td>
<td>83</td>
</tr>
<tr>
<td>4.6. Simulation and analysis</td>
<td>84</td>
</tr>
<tr>
<td>4.7. Summary</td>
<td>94</td>
</tr>
<tr>
<td>Chapter 5. RED Performance Enhancement Using The Weight Parameter</td>
<td>95</td>
</tr>
<tr>
<td>5.1. Background</td>
<td>96</td>
</tr>
<tr>
<td>5.2. RED performance over TD</td>
<td>98</td>
</tr>
<tr>
<td>5.3. Flow RED</td>
<td>102</td>
</tr>
<tr>
<td>5.4. Refined design of RED (FRED)</td>
<td>103</td>
</tr>
<tr>
<td>5.5. WTRED design guidelines</td>
<td>108</td>
</tr>
<tr>
<td>5.6. Simulation and Discussion</td>
<td>113</td>
</tr>
<tr>
<td>5.7. Summary</td>
<td>117</td>
</tr>
<tr>
<td>Chapter 6. Conclusions</td>
<td>119</td>
</tr>
<tr>
<td>6.1. Proposed solutions</td>
<td>120</td>
</tr>
<tr>
<td>6.2. Simulation results</td>
<td>121</td>
</tr>
<tr>
<td>6.3. Future work</td>
<td>122</td>
</tr>
<tr>
<td>References</td>
<td>124</td>
</tr>
</tbody>
</table>
List of Figures

2.1 Throughput as a function of the offered load. 10
2.2 Example of a sliding window in TCP networks. 14
2.3 Slow start and congestion avoidance. 16
2.4 TCP Vegas algorithm. 20

3.1 The mismatch between macroscopic and microscopic of queue length dynamics. 44
3.2 Simulation network topology to evaluate ERED’s performance [1]. 49
3.3 Packet loss rate versus number of flows for 50s simulation time [1]. 51
3.4 Packet loss rate versus number of flows for 100s simulation time [1]. 51
3.5 Queue length dynamics for ERED [1]. 53
3.6 Queue length dynamics for RED [1]. 53
3.7 Queue length dynamics for SRED [1]. 53
3.8 Queue length dynamics for REM [1]. 53
3.9 Queue length dynamics for LCD [1]. 54
3.10 Queue length dynamics for FRED [1]. 54
3.11 Compression between ERED’s delay and other AQM algorithms [1]. 55
3.12 Compression between ERED’s jitter and other AQM algorithms [1]. 55
3.13 RED gateway sectors 59
3.14 ERED sectors 63
3.15 The simulator network topology. 66
3.16 Network throughput. 67
3.17 Network link utilization. 68
3.18 Average network delay. 68
3.19 Packet loss rate. 68
3.20 Network jitter. 69

4.1 Time out and unfair drop scenarios. 81
4.2 RTRED algorithm. 83
LIST OF FIGURES

4.3 Network topology. 84
4.4 Total percentage of packets dropped for three scenarios. 85
4.5 Percentage values for packets dropped in each drop area. 87
4.6 Drop probability and $max_p$ parameters for scenario I. 88
4.7 Average and actual queue sizes for scenario I. 89
4.8 Drop probability and $max_p$ parameters for scenario II. 90
4.9 Average and actual queue sizes for scenario II. 91
4.10 Drop probability and $max_p$ parameters for scenario III. 92
4.11 Average and actual queue sizes for scenario III. 93

5.1 Full queue problem of TD strategy. 96
5.2 Lock out problem of TD strategy. 96
5.3 TD global synchronization. 99
5.4 TD global synchronization (x 50 zoom in). 99
5.5 Average and actual queue sizes on a RED gateway. 101
5.6 Congestion window size on a RED gateway. 101
5.7 Congestion window size on a RED gateway without global synchronization. 102
5.8 Dynamic adjustment of FRED's maximum drop probability. 105
5.9 Throughput for a range of weight parameters from 0.001 - 0.1. 112
5.10 Loss rate for a range of weight parameters from 0.001 - 0.1. 112
5.11 Delays for a range of weight parameters from 0.001 - 0.1. 113
5.12 Link utilization for a range of weight parameters from 0.001-0.1. 113
5.13 WTRED algorithm. 114
5.14 Simulation network topology. 115
5.15 Network throughput for RED, FRED and WTRED. 115
5.16 Packet loss rate for RED, FRED and WTRED. 116
5.17 Average delay for RED, FRED and WTRED. 116
5.18 Link utilization for RED, FRED and WTRED. 117
List of Tables

2.1 Detailed Algorithm of RED. 26
2.2 Blue-RED algorithm. 33

3.1 Detailed algorithm of ERED. 49
3.2 Parameter configuration for ERED evaluation 50
3.3 Performance evaluation for ERED and other RED variants 50
3.4 Sample of ERED’s sectors 63
3.5 QSRED algorithm 65
3.6 Parameter configuration for ERED and QSRED 66

4.1 Adaptive RED algorithm. 80
4.2 Simulation and analysis (drop levels in packets) 84
4.3 Network performance for the three scenarios. 86

5.1 The maximum drop probability for FRED’s sub-phases. 100
5.2 The weight parameter for FRED’s sub-phases. 103
5.3 Dynamic adjustment of FRED’s weight parameter. 106
5.4 Buffer sizes for FRED’s sub-phases. 114
Dedication

“...My Lord, enable me to be grateful for Your favor which you have bestowed upon me and upon my parents and to do righteousness of which You approve. And admit me by Your mercy into (the ranks of) Your righteous servants.”[An’nam1, 19].

I lovingly dedicate this thesis to my brothers, sisters and my fiancée Sheraz for their love and support. Deepest appreciation to my eldest brother Safwan for his financial support.
Acknowledgement

I owe an immense debt of gratitude to my principle supervisor Dr. David Murray for his encouragement and advice in preparing my publications and writing this thesis. I would like to thank my second supervisor Prof. Michael Dixon who agreed to cooperate; in which supervision of this thesis was greatly needed. I would like also to thank my third supervisor Assoc/Prof. Peter Cole for his support from the earliest stage of my Ph.D course.
Publications


This paper presents a new configuration for the weight parameter in RED. The dynamic weight parameter enhances the performance of RED. This paper is edited in Chapter 5.


This paper presents WTRED strategy for congestion handling. The strategy uses adjustable weight parameter to avoid the mismatch between the microscopic and macroscopic behaviours of AQM strategies. This paper is edited in Chapter 5. The paper also won the prize of the best paper in the ICIEIS 2011 conference, Kuala Lumpur, Malaysia.


This paper presents RTRED congestion control strategy. The strategy adds a third threshold to enhance the performance of RED. This paper is edited as Chapter 4.

This paper presents QSRED congestion control strategy. The strategy adjusts the algorithm of ERED to enhance the network performance. This paper is edited as Chapter 3.