Abstract

Since the field of computer networks has rapidly grown in the last two decades, congestion control of traffic loads within networks has become a high priority. Congestion occurs in network routers when the number of incoming packets exceeds the available network resources, such as buffer space and bandwidth allocation. This may result in a poor network performance with reference to average packet queueing delay, packet loss rate and throughput. To enhance the performance when the network becomes congested, several different active queue management (AQM) methods have been proposed and some of these are discussed in this thesis. Specifically, these AQM methods are surveyed in detail and their strengths and limitations are highlighted. A comparison is conducted between five known AQM methods, Random Early Detection (RED), Gentle Random Early Detection (GRED), Adaptive Random Early Detection (ARED), Dynamic Random Early Drop (DRED) and BLUE, based on several performance measures, including mean queue length, throughput, average queueing delay, overflow packet loss probability, packet dropping probability and the total of overflow loss and dropping probabilities for packets, with the aim of identifying which AQM method gives the most satisfactory results of the performance measures.

This thesis presents a new AQM approach based on the RED algorithm that determines and controls the congested router buffers in an early stage. This approach is called Dynamic RED (REDD), which stabilises the average queue length between minimum and maximum threshold positions at a certain level called the target level to prevent building up the queues in the router buffers. A comparison is made between the proposed REDD, RED and ARED approaches regarding the above performance measures. Moreover, three methods based on RED and fuzzy logic are proposed to control the congested router buffers incipiently. These methods are named REDD1, REDD2, and REDD3 and their performances are also compared with RED using the above performance measures to identify which method achieves the most satisfactory results. Furthermore, a set of discrete-time queue analytical models are developed based on the following approaches: RED, GRED, DRED and BLUE, to detect the congestion at router buffers in an early stage. The proposed analytical models use the instantaneous queue length as a congestion measure to capture short term changes in the input and prevent packet loss due to overflow. The proposed analytical models are experimentally compared with their corresponding AQM simulations with reference to the above performance measures to identify which approach gives the most satisfactory results.

The simulations for RED, GRED, ARED, DRED, BLUE, REDD, REDD1, REDD2 and REDD3 are run ten times, each time with a change of seed and the results of each run are used to obtain mean values, variance, standard deviation and 95% confidence intervals. The performance measures are calculated based on data collected only after the system has reached a steady state. After extensive experimentation, the results show that the proposed REDD, REDD1, REDD2 and REDD3 algorithms and some of the proposed analytical models such as DRED-Alpha, RED and GRED models offer somewhat better results of mean queue length and average queueing delay than these achieved by RED and its variants when the values of packet arrival probability are greater than the value of packet departure probability, i.e. in a congestion situation. This suggests that when traffic is largely of a non bursty nature, instantaneous queue length might be a better congestion measure to use rather than the average queue length as in the more traditional models.

Keywords: Active Queue Management, Analytical Model, Congestion Control, Discrete-time Queues, Fuzzy Logic, Performance Measures, Quality of Service, Random Early Detection, Simulation, Statistical analysis.

Dedication

I would like to thank Allah to give me the health, patience and the ability to do this research work. I dedicate this thesis to every part in my family, especially my lovely parents and my oldest brother Dr. Fadi who helped and supported me to accomplish my thesis. In addition, this thesis is dedicated to only those who believe in the richness of learning. The following is some blessing surats and verses of Quran.

(In the name of Allah, the Beneficent, the Merciful) بسم الله الرحمن الرحيم

سوره البقره-آية الكرسى (255)

(اللّهُ لاَ إِلَـهَ إِلاَّ هُوَ الْحَيُّ الْقَيُّومُ لاَ تَأْخُذُهُ سِنَةٌ وَلاَ نَوْمٌ لَّهُ مَا فِي السَّمَاوَاتِ وَمَا فِي الأَرْضِ مَن ذَا الَّذِي يَشْفَعُ عِنْدَهُ إِلاَّ بِإِذْنِهِ يَعْلَمُ مَا بَيْنَ أَيْدِيهِمْ وَمَا خَلْفَهُمْ وَلاَ يُحِيطُونَ بِشَيْءٍ مِّنْ عِلْمِهِ إِلاَّ بِمَا شَاء وَسِعَ كُرْسِيُّهُ السَّمَاوَاتِ وَالأَرْضَ وَلاَ يَؤُودُهُ حِفْظُهُمَا وَهُوَ الْعَلِيُّ الْعَظِيمُ).

سُورَةُ الإِخْلَاصِ

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

قُلْ هُوَ ٱللَّهُ أَحَدٌ ﴿١﴾ ٱللَّهُ ٱلصَّمَدُ ﴿٢﴾ لَمْ يَلِدْ
وَلَمْ يُولَدْ ﴿٣﴾ وَلَمْ يَكُن لَّهُۥ كُفُوًا أَحَدٌۢ ﴿٤﴾

سُورَةُ الفَلَقِ

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

قُلْ أَعُوذُ بِرَبِّ ٱلْفَلَقِ ﴿١﴾ مِن شَرِّ مَا خَلَقَ ﴿٢﴾ وَمِن
شَرِّ غَاسِقٍ إِذَا وَقَبَ ﴿٣﴾ وَمِن شَرِّ ٱلنَّفَّٰثَٰتِ فِى
ٱلْعُقَدِ ﴿٤﴾ وَمِن شَرِّ حَاسِدٍ إِذَا حَسَدَ ﴿٥﴾

سُورَةُ النَّاسِ

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

قُلْ أَعُوذُ بِرَبِّ ٱلنَّاسِ ﴿١﴾ مَلِكِ ٱلنَّاسِ ﴿٢﴾ إِلَٰهِ
ٱلنَّاسِ ﴿٣﴾ مِن شَرِّ ٱلْوَسْوَاسِ ٱلْخَنَّاسِ ﴿٤﴾ ٱلَّذِى
يُوَسْوِسُ فِى صُدُورِ ٱلنَّاسِ ﴿٥﴾
مِنَ ٱلْجِنَّةِ وَٱلنَّاسِ ﴿٦﴾

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List of Publications

Publications – International Journals Papers

1. Abdeljaber H., Thabtah F., Woodward M., Kofahi N.” Congestion Control Discrete-time Queueing Network Analytical Models”. Submitted to The Journal of Network and Computer Applications, 2008 Elsevier.
2. Abdeljaber H., Woodward M., Thabtah F., ”Performance evaluation for DRED discrete-time queueing network analytical model,” Proceedings of the Journal of Network and Computer Applications, Volume 31, Issue 4, pp. 750-770, Elsevier, November 2008.

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Abbreviations

- AFG: The Assured Forwarding Per Hop Group
- AIMD: Additive Increase Multiplicative Decrease
- AQM: Active Queue Management
- ARED: Adaptive Random Early Detection
- BO: Buffer Occupancy
- CA: Congestion Avoidance
- CBL: Current Buffer Length or Classical Binary Logic
- COG: Centre of Gravity
- CRB: Changing Rate in the Buffer
- CST: Classical Set Theory
- cwnd: Congestion Window or Transmission Rate
- D: Deterministic
- DRED: Dynamic Random Early Drop
- DT: Drop-Tail
- DUPSACK: Duplicate Selective Acknowledgement
- ECN: Explicit Congestion Notification
- EFG: The Expedited Forwarding Per Hop Group
- EPA: Equilibrium Point Analysis
- EWMA: Exponential Weighted Moving Average
- FB: Fuzzy BLUE

- FBC: Fuzzy BLUE Controller
- FCFS: First Come First Served
- FEM: Fuzzy Exponential Marking
- FI: Fuzzy Inference
- FIP: Fuzzy Inference Process
- FL: Fuzzy Logic
- FLC: Fuzzy Logic Controller
- FR: Fast Retransmission
- FRec: Fast Recovery
- FST: Fuzzy Set Theory
- G: Generally
- Geo: Geometrically
- GRED: Gentle Random Early Detection
- GREEN: Generalised Random Early Evasion Network
- IETF: Internet Engineering Task Force
- i.i.d: Identical, Independently Distributed
- IP: Internet Protocol
- IQs: Input Queues
- LCFS: Last Come First Served
- M: Markovian
- MIMD : Multiplicative Increase Multiplicative Decrease
- MMBP: Markov-modulated Bernoulli Process

- OQs: Output Queues
- PL: Packet Loss
- PS: Processor Sharing
- QoS: Quality of Service
- RED: Random Early Detection
- REDD: Dynamic RED
- REM: Random Exponential Marking
- RIO: RED Input Output
- RTT: Round Trip Time
- SFB: Stochastic Fair BLUE
- SLA: Service Level Agreement
- SRED: Stabilised Random Early Drop
- SS: Slow Start
- ssthreshold: Slow Start Threshold
- TCP: Transport Control Protocol
- ToS: Type of Service

Symbols

- $(\alpha 1, \alpha 2, \alpha 3, \alpha 4)$: The Probabilities of Packet Arrival in A Slot Dependent On the Instantaneous ql At the Router Buffer
- β: The Probability of Packet Departure
- $(p_0 ... p_K)$: The Equilibrium Probabilities
- aql: Average Queue Length
- D: Average Queueing Delay
- D_p: Packet Dropping Probability
- K: Buffer Capacity
- P_L: Overflow Packet Loss Probability
- P_{Loss}: The Total of Loss and Dropping Probabilities For Packets
- T: Throughput
- th: Indication Congestion Threshold
- α: Probability of Packet Arrival
- $\#of\_flows$: Number of Flows
- δ: Fixed Parameter
- ε: System Control Parameter
- ω: Weighting Parameter
- ϕ: Fixed Parameter Larger Than Zero

- ∂ : Fixed Parameter Larger Than Zero
- ∂_B : Fixed Parameter At the Router Buffer B Larger Than Zero
- σ : Standard Deviation
- σ^2 : Variance
- 95% CI: 95% Confidence Interval
- $\sum_{i=0}^{K} p_i = 1$: Normalising Equation
- $\{d_{n+1}, n = 0,1,2,...\}$: The Number of Departures in A Slot n
- a_n : The Number of Arrivals in A Slot n
- B : Number of Bins, Router Buffer or Fuzzy Set
- $Band$: Bandwidth
- B_{size} : Bin Occupancy Threshold
- $BufferCapacity$: Buffer Capacity
- C : Counter
- c and o: Linguistic Variables
- C and O: Linguistic Values
- Ct: Fix Unit of Time
- $current\_time$: Current Time
- D: The Probability That Two Packets are not Matched
- $D = \frac{aql}{T}$: Little's Law
- D_B : The Packet Dropping Probability At the Router Buffer B

- D_{init} : Initial Packet Dropping Probability
- $D_{\max}$: The Maximum Probability Value
- $D_{\min}$: The Minimum of D_p
- $double \max threshold$: Twice Maximum Threshold
- $D_{sred}(ql)$: SRED Function uses to calculate the $D_{\max}$
- $d1$: The Amount Removed From the $D_{\max}$
- $d2$: The Amount Added To the $D_{\max}$
- $Err(i)$: The Error Signal
- f : Fix Parameter
- $F_B(s)$: The Membership Function
- $Fil(i)$: The Filtered Error Signal
- $freeze\_time$: Determine the Lowest Time Period Between Two D_p Successive Adjustments
- $Hit(m)$: The Hit Function
- $idle\_time$: Idle Time
- L : Link Capacity
- $L_B(t)$: The Amount of Bandwidth Allocated At the B Router Buffer At t Time Interval
- m : Packet m
- $\max threshold$: Maximum Threshold

- $\min threshold$: Minimum Threshold
- mql : Mean Queue Length
- N: Size of the Zombie List
- n : The number of packets sent to the RED router buffer during an idle interval time
- $P(m)$: Frequency of Hits
- $P(m)^{-1}$: The Number of Estimated Active Flows
- $P(z)$: Generating Function
- P_{dec} : D_p Amount of Decreasing
- P_{inc} : D_p Amount of Increasing
- $\Pr ice_B(t)$: The Price Value at the B Router Buffer At t Time Interval
- $q(time)$: The Linear Function For the Time
- q_instantaneous : Instantaneous Queue Length
- ql : Queue Length
- $ql_B(t)$: The Queue Length At the B Router Buffer At t Time Interval
- qw : Queue Weight
- $R_B(t)$: The Input Transmission Rate At the B Router Buffer At t Time Interval
- $Seg_{\max}$: The Maximum Segment Size
- T_{aql} or T_{ql} : Certain or Target Level
- T_{qlB} : The Target Queue Length For the B Router Buffer
- v : Number of Levels

- W_{Total} : Weighted Total
- X : The Number of Active TCP Flows