

ENHANCING ACTIVE QUEUE MANAGEMENT TECHNIQUES  
FOR IMPROVING NETWORK PERFORMANCE IN  
CONGESTION PROBLEM

Adeeb Mansour Falah Al-Saaidah

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IN THE NAME OF ALLAH THE ALL-COMPASSIONATE, ALL-MERCIFUL

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ISLAMIC SCIENCE UNIVERSITY OF MALAYSIA

## ABSTRAK

Dengan pesatnya perkembangan teknologi Internet pada masa kini dan kepelbagaian aplikasi yang menyokongnya, sangat diperlukan alatan (i.e router buffer) yang berkapasiti tinggi bagi membolehkan penghantaran data dilakukan dengan cepat kepada penerima yang dikenalpasti. Bila terlampau banyak data yang hendak dihantar, maka satu masalah yang jelas akan berlaku ialah kesesakan pada laluan. Secara asasnya, masalah kesesakan ini sering dikaitkan dengan prestasi and imej aplikasi Internet tersebut. Masalah ini berlaku bila mana kehendak dan keperluan sumber rangkaian melebihi sumber yang ada dan kesan langsung dari masalah ini ialah prestasi laluan Internet yang merosot. Bagi mengatasi permasalahan ini, beberapa teknik yang dikenalpasti yang dinamakan "Active Queue Management" (AQM) dicadangkan. Dalam tesis ini, kajian literature secara menyeluruh telah dijalankan terhadap AQM. Hasilnya, satu kaedah yang lebih baik dicadangkan, yang dinamakan sebagai Gentle BLUE (GB). GB berfungsi dengan mengawal dan mengenalpasti kesesakan sebelum berlakunya limpahan atau lebihan pada alatan. Kaedah ini juga cuba mengurangkan 'parameter' yang digunakan dan pada masa yang sama menjadikan ia lebih dinamik. GB diuji dengan kaedah simulasi (menggunakan JAVA) dan dapatan dari simulasi ini dibandingkan dengan kaedah AQM sediaada. Untuk mengesahkan agar simulasi yang dijalankan betul dan tepat, GB juga diuji bersama model analitik yang berasaskan "discrete-time", dikenali GB-MPP2. Seterusnya, pengujian terakhir dilaksanakan terhadap GB dengan menggabungkannya bersama keadah "Fuzzy Logic", dinamakan GBFL. Tujuannya lebih kepada untuk melihat kesan kebergantungan GB kepada parameter (i.e dropping probabilities, delay, mean queue length, etc) secara minimum. Keseluruhannya, dapat disimpulkan bahawa kaedah GB menawarkan prestasi yang lebih baik berbanding kaedah yang sedia ada dalam pengurusan kesesakan, validasi yang dijalankan adalah tepat dan betul kerana kedua-dua dapatan simulasi daripada GB dan GB-MMP-2 adalah sama dan akhirnya GBFL boleh diambilkira dalam mengurangkan kebergantungan kepada parameter dan boleh diautomasikan untuk prestasi yang lebih baik.

## ABSTRACT

As a result of the considerable development of Internet technology in numerous applications, Internet applications currently require high-speed router buffers to quickly transmit data to their potential recipients. Congestion is a crucial problem associated with the performance of Internet applications. Congestion occurs at a particular router buffer when the demand for network resources exceeds the available resources. Consequently, network performance declines. To achieve good network performance, router buffers should be managed with a congestion control method, such as active queue management (AQM). Several AQM methods have been proposed to overcome the congestion problem. However, they failed to show improvement in the network performance. In this thesis, a comprehensive review of the literature on congestion control is conducted. A new method, called the gentle BLUE (GB) method, is also proposed. The GB method, which is based on the BLUE method, detects congestion before the router buffer overflowed, thereby avoiding congestion. The proposed method also reduces the parameter settings by providing a dynamic mechanism for calculating the dropping probability (DP) based on the status of the queue length (ql). The proposed GB method is simulated, and the obtained results are compared with those of existing AQM methods. The properties of packet arrival traffic, such as burstiness and correlation, should also be considered inputs in evaluating AQM methods. Therefore, discrete-time performance analysis is conducted for the GB method using the two-state Markov modulate Bernoulli process (MMBP-2) to model the queuing process and deal with traffic properties. The resulting method is called GB-MMBP-2. A discrete-time analytical model is adopted to validate the performance of the proposed GB simulation. This validation is achieved when similar performance measure results are obtained for GB simulation and the GB analytical model. Finally, a congestion control technique based on the GB method is proposed using fuzzy logic (FL) to control congestion at router buffers at an early stage and reduce the dependency of the GB method on its parameters. The GB method using FL (GBFL) adopts ql and delay rate as input linguistic variables for an FL system to produce a single output (DP). Compared with existing methods, the proposed GB method provides improved mean queue length, delay, and packet loss in case of heavy congestion. Moreover, the GB-MMBP-2 method provides the best performance result in terms of mean queue length, delay, packet loss, and DP under bursty and correlation traffic, particularly when heavy congestion occurs. The results of the analytical model are compared with those of the simulator to validate and prove that the obtained simulator results are correct and that the simulator is working properly. The GBFL method offers better mean queue length, delay, and packet loss under light and heavy congestion compared with REDD1 and GREDFL.

## الملخص

نتيجة للتطور الكبير لتكنولوجيا الإنترنت في العديد من التطبيقات ، حيث ان تطبيقات الإنترنت حالياً تتطلب مخازن أجهزة التوجيه عالية السرعة لنقل البيانات بسرعة إلى المستلمين المحتملين. يعد الازدحام مشكلة حاسمة مرتبطة بأداء تطبيقات الإنترنت. يحدث الازدحام عند مخازن جهاز التوجيه محدد عندما يكون الطلب على المصادر من قبل الشبكة أعلى من المصادر المتاحة. بناءً على ذلك، يصبح أداء الشبكة ضعيفاً. لتحقيق أداء جيد للشبكة ، يجب إدارة مخازن جهاز التوجيه باستخدام طريقة للتحكم بالازدحام، مثل إدارة الطابور النشط (AQM). تم طرح أكثر من طريقة لإدارة الطابور النشط (AQM) للتغلب على مشكلة الازدحام. لكن أثبتت فشلاً في تحسين أداء الشبكة. في هذه الأطروحة، سيتم تقديم دراسة شاملة عن إدارة الازدحام في الشبكات كما وردت في دراسات سابقة. كما سيتم طرح طريقة جديدة تدعى Gentle BLUE (GB) حيث تقوم هذه الطريقة على نفس مبدأ طريقة BLUE مع فارق أن لها القدرة على كشف الازدحام قبل أن يمتلئ مخازن أجهزة التوجيه، وبالتالي يمنع حدوث الازدحام. تعمل الطريقة المقترحة أيضاً على تقليل المتغيرات من خلال توفير آلية ديناميكية لحساب احتمال الإسقاط (DP) استناداً إلى حالة طول الطابور (ql). تم عمل محاكاة للطريقة المقترحة ومقارنة النتائج مع نتائج طرق أخرى موحدة (AQM). خصائص تدفق وصول الحزم مثل التقطع والارتباط يجب أن يتم أخذهم بعين الاعتبار عند تقييم AQM. لذلك تم تطبيق تحليل الأداء لطريقة GB باستخدام (MMBP-2) لنموذج عملية الطابور والتعامل مع خصائص التدفق والطريقة الناتجة تدعى (GB-MMBP-2). تم تبني نموذج تحليلي منفصل للتحقق من أداء الطريقة المقترحة باستخدام المحاكاة فإذا كانت نتائج محاكاة GB تساوي نتائج النموذج التحليلي GB تكون نتائج الطريقة صحيحة. أخيراً، تم اقتراح تقنية للتحكم بالازدحام بناءً على GB باستخدام المنطق المضبض تدعى (GBFL) للتحكم بالازدحام في مرحلة ما قبل حدوث إمتلاء في مخازن أجهزة التوجيه وتقليل اعتماد GB على متغيراتها. في (GBFL) تم أخذ معدل التأخير وطول الطابور كمدخلات لنظام المنطق المضبض ليتم إنتاج مخرج واحد فقط وهو احتمال الإسقاط. بالمقارنة مع الطرق الأخرى، أظهرت نتائج طريقة GB تحسناً في معدل طول الطابور، التأخير وضياع الحزم عند الازدحام الشديد. كما أظهرت طريقة GB-MMBP-2 أفضل النتائج في معدل طول الطابور، التأخير وضياع الحزم واحتمال الإسقاط تحت التدفق المرتبط والمتقطع خصوصاً عند حدوث الازدحام الشديد. جميع النتائج المحصلة من النموذج التحليلي تم مقارنتها مع نتائج المحاكاة للتحقق منها وضمان أن نتائج المحاكاة دقيقة وصحيحة. نتائج طريقة GBFL أظهرت تحسناً في معدل طول الطابور، التأخير وضياع الحزم عند الازدحام الشديد والخفيف في آن معاً مقارنة بنتائج REDD1 و GREDFL.

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## LIST OF MATHEMATICAL SYMBOLS

Symbol	Meaning / definition
=	Equality
>	greater than
<	less than
$\geq$	greater than or equal to
$\leq$	less than or equal to
()	calculate expression inside first
+	Addition
-	Subtraction
*	Multiplication
/	Division
$a^b$	Exponent
[]	matrix of numbers
—	division / fraction
$\Sigma$	summation - sum of all values in range of series

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## LIST OF ACRONYMS

A	The arrival process
ACK	Acknowledgment
AGRED	Adaptive Gentle Random Early Detection
AIMD	Additive Increase Multiplicative Decrease
aql	Average Queue Length
AQM	Active Queue Management
ARED	Adaptive Random Early Detection
B	The service process
BL	Binary Logic
BLUE-BP	BLUE method their arrival process modelled based on Bernoulli process
BLUE-MMBP-2	BLUE method their arrival process modelled based on Markov-modulated Bernoulli process
BO	Buffer Occupancy
BP	Bernoulli process
C	The Counter
CBL	Current Buffer Length
CI	Confidence Intervals
CRB	Changing rate in the buffer
Cs	Number of servers
cwnd	Congestion window
D	Delay
DGRED	Dynamic Gentle Random Early Detection
DGREDFL	Dynamic Gentle Random Early Fuzzy Logic
D <sub>init</sub>	Initial packet dropping probability
D <sub>max</sub>	Maximum value of D <sub>init</sub>
DP	Dropping probability
DT	Drop Tail
ECN	Explicit congestion notifications
ERED	Effective Random Early Detection
f_time	Freeze Time

FB	Fuzzy BLUE
FBC	Fuzzy BLUE Controller
FCFS	First Come First Served
FEM	Fuzzy explicit marking
FI	Fuzzy inference
FIFO	First-In-First-Out
FIP	Fuzzy inference process
FL	Fuzzy Logic
GBFL	Gentle BLUE Fuzzy Logic
FQ	Fair queue
FRec	The fast recovery
GB	Gentle BLUE
GB-BP	Gentle BLUE arrival modelling based on Bernoulli process
GB-MMBP-2	Gentle BLUE arrival modelling based on two state Markov-modulated Bernoulli process
GRED	Gentle Random Early Detection
GREDFL	Gentle Random Early Detection Fuzzy Logic
IDE	Integrated Development Environment
IETF	Internet Engineering Task Force
iid	Identical And Independently Distributed
initiDP	The initial value of the DP
JDK	Java Development Kit
K	System capacity
L	link capacity
LCFS	Last Come First Served
M	Markovian
MMBP	Markov-Modulated Bernoulli Process
MMBP-2	Two-state Markov-modulated Bernoulli arrival process
mql	Mean Queue Length
P	The customer population
Pde	DP Amount of decreasing
Pin	DP Amount of increasing

PL	Packet Loss
PQ	Priority queue
ql	Queue Length
QoS	quality of service
qw	The Queue Weight.
R	Transmission Rate
RED	Random Early Detection
REM	Random Exponential Marking
RR	Round Robin
RTTs	Round Trip Times
rwnd	Receiver's advertised window
SFB	Stochastic Fair Blue
SRED	Stabilized Random Early Drop
ssthreshold	Slow start threshold
T	Throughput
Taq	Target Average Queue Length
TCP	Transmission Control Protocol
Th	Threshold
Tql	Target Queue Length
VoIP	Voice over Internet Protocol
WFQ	Weighted fair queuing
$\alpha_0$	The packet arrival probability for state 1
$\alpha_1$	The packet arrival probability for state 2
$\beta$	Probability of packet departure
$\sigma$	Standard Deviation
$\sigma^2$	Variance