MULTI-CRITERIA EVALUATION AND BENCHMARKING FOR ACTIVE QUEUE MANAGEMENT METHODS OF NETWORK CONGESTION CONTROL

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SULTAN IDRIS EDUCATION UNIVERSITY

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"In the name of Allah, the Most Gracious and the Most Merciful"

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MULTI-CRITERIA EVALUATION AND BENCHMARKING FOR ACTIVE QUEUE MANAGEMENT METHODS OF NETWORK CONGESTION CONTROL

ABSTRACT

This research aimed to propose a benchmarking decision matrix for the Active Queue Management (AQM) methods of network congestion control based on multi-criteria analysis to aid the developers of AQM methods to make the right decision of selecting the best AQM method. In this study, an experiment was conducted on the basis of several stages. First, decision matrix was proposed for selecting suitable AQM methods based on multi criteria (performance, process overhead and configuration), with each criterion has several sub criteria (Throughput, Mean Queue Length, Drop Rate, Packet Loss, Delay, Time, Space, Estimated Calculation, Sensitivity). In addition, six AQM methods of alternatives were used. Subsequently, the ranking of the AQM methods was utilized by the developed decision matrix using Multi Criteria Decision Making (MCDM) techniques, namely, the Analytic Hierarchy Process (AHP) to weight the evaluation criteria, and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was used to benchmark and rank the AQM methods. TOPSIS has been applied in two decision-making contexts: individual and group decision making (GDM), as well as in GDM, internal and external group aggregation has applied where internal aggregation is receiving the higher ranked value of 62.50% for RED method, which is ranked first in GDM. Data consisting of three main criteria as the required criteria were collected by developing a Sub-Process that is responsible for implementing the AQM methods to generate the data that used in the constructed Decision Matrix. The research findings showed that the integration of Multi-Layer AHP and Group-TOPSIS was effective in solving the problems associated with the selection of AQM methods, as evidenced by the systematic ranking of six AQM methods. In conclusion, the internal and external aggregations of Group TOPSIS used in different contexts were able to generate the results of AQM method ranking that were similar. The implication of the study is that the AQM developers could use such a novel technique to make the right decision of selecting the best AQM method to prevent the router congestion and improve the performance of the computer networks as a whole.

MULTI-CRITERIA EVALUATION AND BENCHMARKING UNTUK PENGURUSAN QUEUE MANAGEMENT KAEDAH KAWALAN CONGESTION RANGKAIAN

ABSTRAK

Penyelidikan ini bertujuan untuk mencadangkan matriks keputusan penanda aras untuk kaedah Pengurusan Beratur Aktif (AQM) kawalan kesesakan rangkaian berdasarkan analisis pelbagai kriteria untuk membantu pemaju kaedah AQM untuk membuat keputusan yang tepat untuk memilih kaedah AQM yang terbaik. Dalam kajian ini, satu eksperimen dijalankan berdasarkan beberapa peringkat. Pertama, matriks keputusan dicadangkan untuk memilih kaedah AQM yang sesuai berdasarkan pelbagai kriteria (prestasi, overhed proses dan konfigurasi), dengan setiap kriteria mempunyai beberapa sub kriteria (Throughput, Mean Queue Length, Drop Rate, Kerugian Packet, Delay, Time, Anggaran Pengiraan, Kepekaan). Di samping itu, enam kaedah alternatif AQM digunakan. Selanjutnya, kedudukan kaedah AQM digunakan oleh matriks keputusan yang dibangunkan menggunakan teknik Multi Decision Making Decision (MCDM), iaitu, Proses Hierarki Analitik (AHP) untuk menimbang kriteria penilaian, dan Teknik Pesanan Keutamaan oleh Kesamaan Penyelesaian Ideal (TOPSIS) digunakan untuk penanda aras dan pangkat kaedah AQM. TOPSIS telah digunakan dalam dua konteks membuat keputusan: pengambilan keputusan individu dan kumpulan (GDM), serta GDM, pengumpulan kumpulan dalaman dan luaran telah memohon di mana pengagregatan dalaman menerima nilai lebih tinggi 62.50% untuk kaedah RED, yang mana adalah menduduki tempat pertama dalam GDM. Data terdiri daripada tiga kriteria utama kerana kriteria yang dikehendaki dikumpulkan dengan membangun Sub-Proses yang bertanggungjawab untuk melaksanakan kaedah AQM untuk menghasilkan data yang digunakan dalam Matrik Keputusan yang dibina. Hasil penyelidikan menunjukkan bahawa integrasi Multi-Layer AHP dan Kumpulan-TOPSIS berkesan dalam menyelesaikan masalah yang berkaitan dengan pemilihan kaedah AQM, seperti yang dibuktikan oleh kaedah sistematik enam kaedah AQM. Sebagai kesimpulan, agregasi dalaman dan eksternal Kumpulan TOPSIS yang digunakan dalam konteks yang berbeza dapat menghasilkan keputusan peringkat kaedah AQM yang serupa. Implikasi kajian ini adalah bahawa pemaju AQM boleh menggunakan teknik seperti itu untuk membuat keputusan yang tepat untuk memilih kaedah AQM yang terbaik untuk mencegah kesesakan penghala dan meningkatkan prestasi rangkaian komputer secara keseluruhan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
AQM	Active Queue Management
CBR	case-based reasoning
CR	Consistency Ratio
DEA	data envelopment analysis
DM	Decision Matrix
DMs	Decision makers
DT	Drop Tail
ERED	Effective Random Early Detection
FCRED	Fuzzy Could-based Random Early Detection
GDM	Group Decision Making
GRED	Gentle Random Early Detection
HAW	hierarchical adaptive weighting
MAUT	multi-attribute utility theory
MCDM	Multi- Criteria Decision Making
MEW	Multiplicative Exponential Weighting
RED	Random Early Detection
SAW	Simple Additive Weighting
SMART	simple multi-attribute rating technique
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
WPM	weighted product model
WSM	Weighted Sum Mode

APPENDICES LIST

CHAPTER 1

INTRODUCTION

1.1 Introduction

In order to introduce the goal of this research, this chapter gives a brief background on the research field of the Active Queue Management (AQM). Besides, this chapter presents the problem that needs to be addressed in this research, scope, goals and objectives and the outlines of the thesis.

The content of this chapter are as follows: First, the background of this research is presented in Section 1.2. Section 1.3 gives the problem statement. Section 1.4 presents research questions. The goal and objectives are presented in Section 1.5. Relationship

between Research Objectives, Research Questions and Research problem is elaborated in Section 1.6. The scope is presented in Section 1.7. Section 1.8 gives the Significance of the study. Finally, Organization of research is discussed in Section 1.9.

1.2 Research Background

Active queue management (AQM), which was proposed in the early 1990s by (Abdel-Jaber et al., 2014; Baklizi, M., & Ababneh, J. 2016; Floyd, 1993; Hamdi et al., 2018; Sharma, A. K., & Behra, A. K. 2016), is defined as a software mechanism installed in the router to manage the packets queued in its buffer and prevent congestion. Each router is supplied with storage space in the form of first-in-first-out queueing, which is called buffering, to accommodate incoming packets (Chitra & Padamavathi, 2010; Hamdi et al., 2018; Seifaddini, Abdullah, & Vosough, 2013; Woodward, 1994). Similar to other network resources, the buffer possesses limited capabilities (i.e. limited space) when the queue length of the accommodated packets increases, which implies a prolonged packet delay, thereby decreasing the performance of the entire network. Moreover, arrival packets are lost if the buffer is saturated and overflowing, which negatively affects network performance. Overflowing and over utilization the available resources is the phenomena known as congestion. Congestion occurs in the buffer when the number of queued packets increases over time. These packets are queued in the buffer, and all subsequent packets face considerable delay. The delay in the router buffer naturally expands to other network resources, which decreases network performance. All arrival packets will be lost when the number of the queued packets exceeds the maximum buffer capacity. Packet loss (PL) is a serious performance problem in network management (Abualhaj, Abu-Shareha, & Al-Tahrawi, 2018; Patel & Bhatnagar, 2016; Baklizi, M., &

Ababneh, J. 2016). In general, AQM depends on marking and dropping arrival packets to avoid buffer overflow and PL (Chitra & Padamavathi, 2010).

Developers of AQM encounter two problems, namely, knowing how to benchmark new AQM methods vis-à-vis existing methods and determining conflicts amongst AQM evaluation criteria. The problems arise because of the absence of well-accepted approaches for benchmarking AQM methods other than determining criteria conflicts. In this scenario, optimising all the results by using all criteria sets is impossible. These problems are confirmed by the comparative studies of Koo, Ahn, and Chung (2004) and Baklizi, Abdel-jaber, Ramadass, Abdullah, and Anbar (2012). In their comparative study, Ahammed and Banu (2010) also concluded that 'an important finding of study is the inability to conclude which of these methods is better than the others because these methods provide improved performance in a specific metric(s)'. Therefore, an integrated platform that covers all criteria aspects in the benchmarking of AQM methods should be developed. This integrated methodology will serve the AQM developer for benchmarking available alternative methods to determine the best one.

Lapsley and Low (1999); Athuraliya, Low, Li, and Yin (2001); Hollot, Misra, Towsley, and Gong (2001); Feng, D., D., and G. (2001); Feng, G., D., and D. (2002); Baklizi et al. (2013); Alshimaa, Ayman, Zeiad, and Z (2014); and Fakharian and Abbasi (2015) used throughput, dropping rate, mean queue length (MQL), loss rate and delay despite the contradictory nature of these performance criteria. They attempted to select the best

AQM technique based on performance. However, the concept of 'performance' was established using different definitions and criteria, and thus was not standardised. Nonetheless, the number of parameters and the ease of parameter initialisation are adopted as evaluation criteria in the benchmarking of AQM methods (Baklizi, Abdel-Jaber, Abu-Shareha, Abualhaj, & Ramadass, 2014; Mohammadi, Pour, Jafari, & Javadi, 2010). A reduced number of parameters implies more flexibility for a certain AQM method compared with others that use several parameters. Similarly, configuration complexity, which refers to the sensitivity towards parameter initialisation, is used for measuring and comparing different AQM methods (Ahammed & Banu, 2010). In this aspect, AQM methods with fuzzy-based configurations are considered more preferable than other methods because the former is less sensitive. Processing overhead is another criterion used for evaluating AQM methods (S. Kunniyur & Srikant, 2003). Overall, different benchmarking processes result in various comparison criteria on performance (i.e. throughput, delay, loss and dropping rate), configuration sensitivity and processing overhead.

Therefore, other investigations need to be conducted to standardize the basic requirements for AQM techniques. Besides, a clear Decision Matrix for benchmarking needs to be developed.

1.3 Research problem

The developers of AQM methods have been faced difficulty to take right decision of selecting the best AQM method in order to estimate the status of the buffer and take a

suitable action of accommodating or dropping the arrival packets and prevent the router congestion.

The word “benchmarking”, in the area of information and computer technologies, benchmarking is comparing a calculated set of criteria to measure quality of a system or a method (Damien et al. 2013). For example, there are benchmarking that always conducted between mobiles industry, computer hardware industry and software industry. Similarly, AQM techniques need to be benchmarked correctly.

Overall, a large number of AQM approaches are proposed to achieve specific goals. These approaches focus mainly on enhancing the performance of the queue management results, such as delay and PL. The benchmarking of these approaches are conducted by using measures that matched the desired goal, such as measuring delay with AQM methods aimed at reducing delay. However, the abovementioned benchmarking approaches have two drawbacks. Firstly, irregularity is observed in the verification mechanisms and measurements used in the experiments. For example, some of the proposed approaches compare processing overhead whilst many other approaches ignore this measure. Second, most of the empirical studies focus on the comparison with RED, which is the first and most well-known approach in AQM (Baklizi et al., 2014). The reason behind these limitations is the lack of a well-established and acceptable mechanism for AQM benchmarking. Important factors, which are mostly related to the literature, must be explored to facilitate their discussion. Figure 1.1 illustrates the problem statement structure and the main issues of benchmarking.

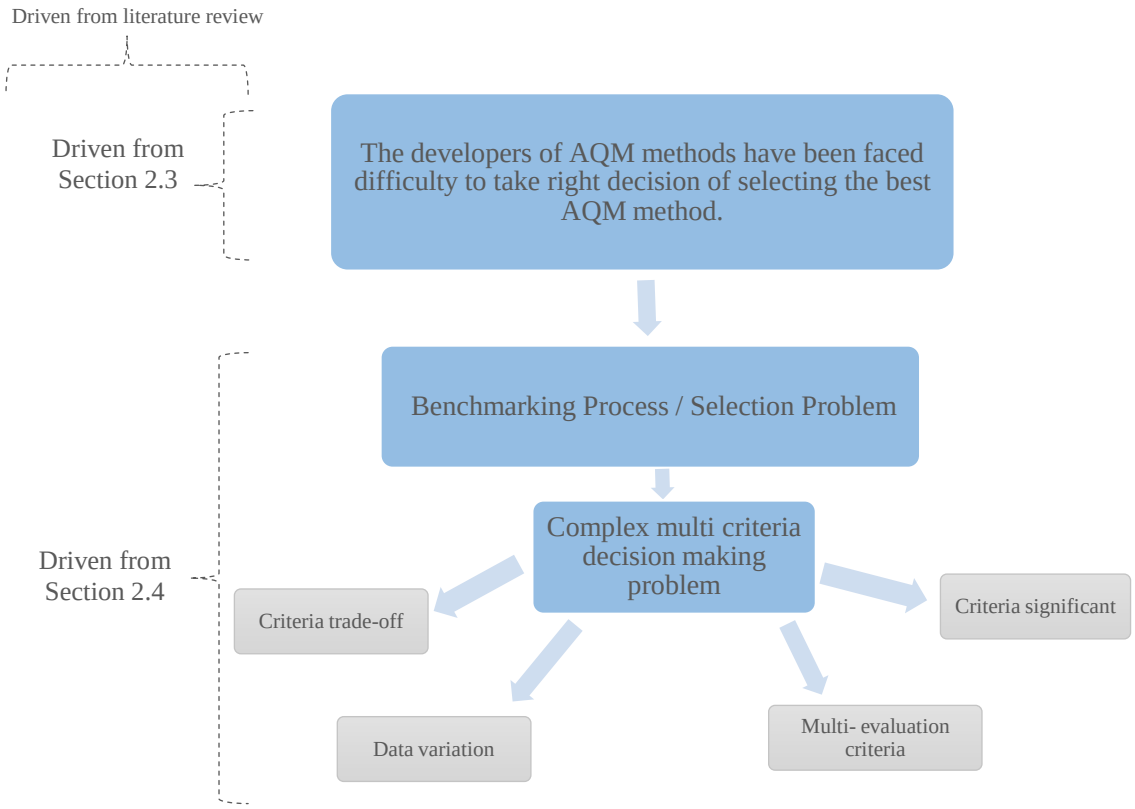

Figure 1. 1. Problem Statement Configuration

The performance criteria in specific and the other AQM evaluation criteria in general, have been used to show the efficiency of the developed AQM methods. However, other criteria such as configuration, has been used as motivators to develop new AQM methods, but has not been used in the benchmarking process. However, while these criteria can be measured and used as evaluation metrics, the researchers continue to ignore them in the literature. That Problem with Multi-Evaluation Criteria is considered the first issue faced the benchmarking of AQM methods.

The second issue that affected on benchmarking is Criteria trade-off that is obviously presented in the benchmarking of AQM methods. According to (Liu et al.,2008). To benchmark AQM methods, the following three main requirements should be measured first: processing overhead, configuration, and performance. In particular, the developers

of any new AQM method focus on either increasing the performance based on some measures with high processing overhead and hard configuration process or simplicity the configuration only which usually favor a method over other but leads to decrease the performance and the processing overhead. Accordingly, this trade-off is reflected in the benchmarking process as illustrated in Figure 1.2.

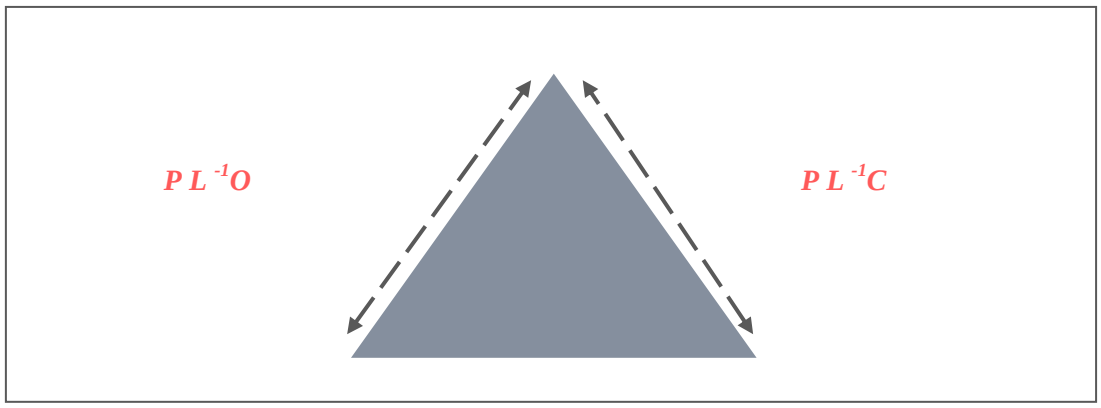

Figure 1.2. Magic Triangle of AQM Requirement

Where, the magic triangle included three basic criteria represented in Performance (P), the processing Overhead (O) and Configuration (C) respectively. Thus, the relationship between these criteria according to formula ($P\ L^{-1}\ C$) as performance and configuration and the relationship ($P\ L^{-1}\ O$) as performance and the processing overhead, so it should be both two relationships are inverses.

Data variation considered the third issue in comparing AQM methods on the basis of multiple criteria (Abdel-Jaber et al., 2014; Baklizi, M., & Ababneh, J. 2016; Hamdi et al., 2018; Sharma, A. K., & Behra, A. K. 2016). Data variation demonstrates that different values exist in criterion with regard to each AQM methods. As criteria values vary from one method to another, identifying the best method is difficult (Ahammed & Banu, 2010).

On other hand, there are limitations of the Criteria Significance, which is considered fourth issue in the benchmarking of AQM methods, that affects comparison because of its tendency to vary and ranking processes becomes a difficult and challenging task. Thus, the researcher should determine the importance of each criterion on the basis of other criteria. For instance, Some criteria are more important than others in terms of the performance, such as decreasing delay, minimizing PL or easing the configuration, which can lead to the use of these related criteria during benchmarking whilst ignoring the rest (Abbasov & Korukoglu, 2009; Floyd & Jacobson, 1993; J. Chen, Hu, & Ji, 2010).

Notably, all researchers in the area of AQM benchmarking have used one criterion or a set of criteria defined in the literature but with different priorities. As a result, the problem of benchmarking process in AQM techniques is defined as a multi-criteria decision making problem.

1.4 Research Questions

In order to formulate the questions for this research, the following research question have been presented in below:

a) Are there any available criteria for benchmarking the existing AQM methods?
b) Are conducted experiments covering all the criteria for AQM benchmarking?
c) Is there a need to make a benchmark process for AQM methods?
d) What are the criteria that have been used to benchmark the existing AQM methods?

e) What are the integrated platforms that have been used to benchmark the existing AQM methods?

f) Is there any integrated platform included “evaluation criteria” and “Active Queue Management methods ” for comparing and benchmarking the existing AQM methods based on multi criteria decision making technique utilized?

g) Is the result of benchmarking the existing AQM methods valid?

1.5 Goal and Objectives

Selecting the best active queue management (AQM) algorithm is important to improve the performance of the computer networks as a whole. Because this problem involves multiple criteria, it can be modeled as Multi-Criteria Decision Making. MCDM required a set of criteria that each can describe an alternative using a single value (single-valued-based) in-order to compare a set of alternatives. The goal of this thesis is to set an acceptable benchmark for the AQM methods based on a set of established criteria.

The objectives of this thesis are as follows:

1. To investigate the evaluation criteria for the existing AQM methods of network congestion control and highlight the weaknesses.
2. To propose a decision matrix based on intersection between ‘evaluation criteria’ and ‘AQM methods of network congestion control’.
3. To benchmark the AQM methods of network congestion control based on the proposed decision matrix using multi-criteria decision-making techniques.
4. To validate the proposed benchmarking solution.

1.6 Relationship between Research Objectives, Research Questions and Research problem

Research questions are formulated to give the direction of the research and the research objectives give answers to the research questions. Table 1.1 illustrates the research questions and their replied by research objectives as well as it figures out what part of research problem will be solved when each research objective achieved.

Table 1.1

Link among research questions, research objectives and research problem

		Research problem mapping	
Research Questions	Research Objectives	Specific Problem	General problem
a) Are there any available criteria for benchmarking the existing AQM methods? b) Are conducted experiments covering all the criteria for AQM benchmarking? c) Is there a need to make a benchmark process for AQM methods?	To investigate the evaluation criteria for the existing AQM methods of network congestion control and highlight the weaknesses.		*Selection problem in Benchmarking the Active Queue Management Methods*
d) What are the criteria that have been used to benchmark the existing AQM methods? e) What are the benchmarking processes that have been used to compare the existing AQM methods?	2. To propose a decision matrix based on intersection between 'evaluation criteria' and 'AQM methods of network congestion control'.	Multi Evaluation criteria problems.	
f) Is there any integrated platform included "evaluation criteria" and "Active Queue Management methods " for comparing and benchmarking the existing AQM methods based on multi criteria decision making technique utilized?	3. To benchmark the AQM methods of network congestion control based on the proposed decision matrix using multi-criteria decision-making techniques.	-Criteria Trade-off. -Multi evaluation criteria. -Criteria significant. -Data Variation	
g) Is the result of benchmarking the existing AQM methods valid?	4. To validate the proposed benchmarking solution.		

1.7 Research Scope

This study is conducted using the underling AQM methods, and aims to set an acceptable benchmark for the AQM methods based on a set of established criteria. Multi criteria decision making have been utilized for AQM benchmarking. According to the case study that has been created, the decision matrix that were constructed in this study, besides the decision making mechanism that were utilized can be used to benchmark AQM methods precisely.

The scope of this research is defined as illustrated in Figure 1.3. The general view for our research and view representing the research method, research type, and research domain.

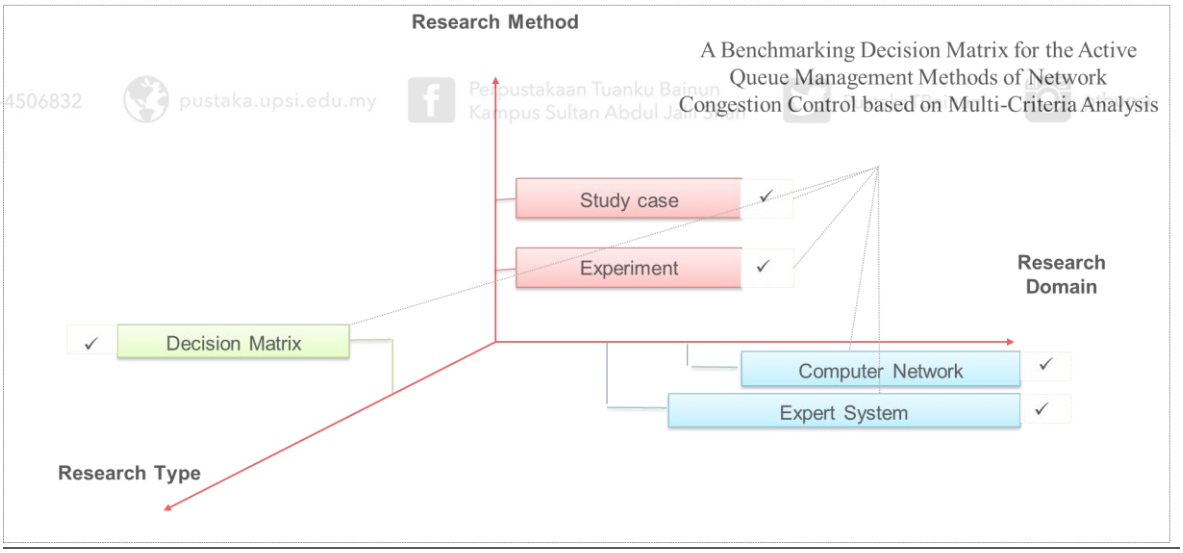

Figure 1.3. Research Scope

This study is an entry-disciplinary involving a decision matrix in order to benchmark the AQM methods that considered one the computer networks field. The study is designed to address the benchmarking problem of AQM methods. In the case study, sub process focuses on the congestion control at a single router buffer, based on the discrete time

queue approach. Other congestion control mechanisms in the network can be implemented at several levels in the network, such as the TCP congestion (Chitra & Padamavathi, 2010) or node congestion are outside the scope of this thesis. The selected case study is based on RED method and its extension. The sub process is used in experiments to generate the data that used to proof of concept of our proposed system.

The outcomes of the research indicate the research type. The output from this study is a decision matrix; a decision matrix is improving the process of benchmarking of AQM methods.

Our research domain contain tow sub domain: computer network and expert system where used the integrated MCDM method (AHP and TOPSIS) from expert system to benchmark the AQM methods which is belong to computer network.

1.8 Significance of the study

The significance and benefits of this research is to select the best active queue management (AQM) method which is important to improve the performance of the computer networks as a whole (Chitra & Padamavathi, 2010; Hamdi et al., 2018; Seifaddini et al., 2013).

Accordingly, the benefits of this study are listed as follows:

- Assist the developers of AQM methods to take right decision of selecting the best AQM method to prevent the router congestion.
- Assist the developers of AQM methods to develop a new AQM method with high quality and high performance.

- The proposed benchmarking process for AQM methods can assist the developers of AQM methods to benchmark their developed AQM methods with the existing once.

1.9 Organization of research

This thesis is composed of five chapters. The general information and background of the research, research problem, research questions and research objective of this study, the relationship between research questions, research objective with research problem (specific problem, and general problem), research scope and the significant of this research is provided in **Chapter One**. The rest of this research is organized as follows:

Chapter Two: "Literature review" Provide an in-depth investigation on AQM benchmarking approaches. Through this chapter, the main criteria for benchmarking are identified and described in details. This chapter also presents the popular MCDM methods, and explains the main two MCDM methods: AHP method and TOPSIS method. The main purpose of this chapter is figure out the research gap and challenges as well as to propose the recommended solution.

Chapter Three: "Research Methodology" presents a detailed description of the proposed process that is developed for AQM methods' benchmarking and comparison. The process is designed in four phases, namely, Preliminary Study Phase, identification phase, design phase and validation phase. Through the phases, this chapter will discuss in fill detail how the four research objectives will be achieved.

Chapter Four: "Results and Discussion" presents the results and discussion based on the proposed method. This chapter illustrates how the results of the proposed process resolve the problems that mentioned in the problem statements and presents the results of the validation process.

Finally, **Chapter Five** "Research Conclusion and Future Work" presents the research goals, research contributions, research limitation and shortages, future works and research conclusion are also suggested in this chapter.