TRAFFIC MATRIX ESTIMATION WITH ENHANCED ORIGIN DESTINATION GENERATOR ALGORITHM USING SIMULATION OF REAL NETWORK

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To my My parents, great mother and father (late), to my beloved wife for all the patience and sacrifices she made and always with me, her advices and support all these years to ensure that I obtained the best education possible, and our children Mohamed, Aya, Basmala, Ryan and Alaa for their prayers. To my supportive brother Sadig. The love and encouraging words from all of you have really inspired me to achieve my goals and dream. Also, to the spirits of my son and brother.

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ABSTRACT

The rapid growth of the Internet has made the issue of ensuring reliability and redundancy a big challenge. Studies of these issues using Traffic Engineering and simulation have been extensively done. In Traffic Matrix Estimation (TME), the Origin–Destination Generator algorithm (ODGen) is limited to the number of hops, where the Expectation Maximization (EM) accuracy is 92%. Most studies have not taken into account real traffic parameters and integration of TME models with routing protocols in their simulation models. Also, there is no a comprehensive model consisting of TME, Border Gateway Protocol (BGP) and Hot Potato (HP) routing in the NS-2 network simulator based on real networks. In this research, Integrated Simulated Model (ISM) is introduced consisting of ODGen-HP algorithm and BGP integrated into the NS-2 network simulator. ISM is then used to simulate the infrastructure of a real production network using actual captured traffic data parameters. Validation is then done against the changes in network topology based on packet loss, delay and throughput. Results gave the average error for packet sent by simulated and production networks of 0% and the average error for packet received by simulation and production networks of 3.61%. The network is modelled with a baseline topology where 5 main nodes were connected together, with redundant links for some nodes. The simulations were repeated for link failures, node addition, and node removal. TME used in ISM is based on ODGen, that is optimized with unlimited number of hops, the accuracy of EM increases to 97% and Central Processing Unit complexity is reduced. HP helps in improving the node which experiences a link failure to select shorter distance route to egress router. In the case of a link failure, HP switching time between the links is 0.05 seconds. ISM performance was evaluated by comparing trace file before and after link failure or by adding nodes (up to 32) or removing nodes. The parameters used for comparison are the packets loss, delay and throughput. The ISM error percentage obtained for packets loss is 0.025%, delay 0.013% and throughput 0.003%.

ABSTRAK

Pertumbuhan pesat Internet telah menjadikan isu kebolehpercayaan dan lewahan satu cabaran besar. Kajian isu-isu di atas menggunakan Kejuruteraan Trafik dan penyelakuan telah dibuat dengan meluas. Algoritma Penjana Asal-Destinasi (ODGen) pada Anggaran Matriks Trafik (TME) mempunyai had pada bilangan lompatan, di mana ketepatan Pemaksimuman Jangkaan (EM) hanya 92%. Kebanyakan kajian tidak mengambil kira parameter trafik sebenar serta integrasi Matriks Trafik TME dengan protokol penghantaran dalam model penyelakuan mereka. Selain itu, tidak wujud model menyeluruh mengandungi TME, Protokol Gerbang Sempadan (BGP) serta Penghalaan Kentang Panas (HP) pada penyelaku rangkaian NS-2 berasaskan rangkaian sebenar. Di dalam penyelidikan ini, Model Penyelakuan Bersepadu (ISM) diperkenalkan merangkumi ODGen, algoritma HP dan BGP diintegrasi dengan penyelaku NS-2. ISM kemudian digunakan untuk menyelakukan infrastruktur Pembekal Perkhidmatan Rangkaian menggunakan parameter hakiki mewakili data trafik sebenar yang diambil. Pengesahan kemudian dibuat terhadap perubahan pada topologi rangkaian berasas kehilangan paket, lengah dan kadar celus. Dapatan menunjukkan purata ralat untuk paket dihantar rangkaian diselaku dibandingkan rangkaian pengeluaran adalah 0% dan purata ralat untuk paket diterima rangkaian diselaku dibandingkan rangkaian pengeluaran adalah 3.61%. Rangkaian dimodel dengan topologi asas dengan 5 nod utama dirangkai dengan sambungan lewah untuk beberapa nod. Penyelakuan diulang bagi kegagalan sambungan, tambahan nod dan penyingkiran nod. TME yang diguna pada ISM adalah berdasarkan kepada algoritma ODGen, dioptimumkan dengan bilangan lompatan tanpa had, ketepatan EM bertambah menjadi 97% dan kerumitan unit pemprosesan utama (CPU) berkurangan. HP membantu memperbaiki nod yang mempunyai kegagalan sambungan sambil memilih jarak lebih kecil kepada penghala egres. Bagi kes kegagalan sambungan, masa pensuisan HP antara pautan adalah 0.05 saat. Prestasi ISM dinilai dengan membandingkan fail jejak sebelum dan selepas kegagalan sambungan atau apabila menambah nod (sehingga 32 nod) atau menghapus nod. Parameter yang digunakan untuk perbandingan adalah kehilangan paket, lengah dan kadar celus. Peratusan ralat ISM yang diperolehi untuk kehilangan paket ialah 0.025%, lengah 0.013% dan kadar celus 0.003%.

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LIST OF ABBREVIATIONS

ISP	-	Internet Service Provider
ICT	-	Information and Communication Technology
IPv4	-	Internet Protocol version 4
IPv6	-	Internet Protocol version 6
DC	-	Data Center
DRC	-	Data Recovery Center
ERP	-	Enterprise Resource Planning
STP	-	Spanning Tree Protocol
TE	-	Traffic Engineering
TME	-	Traffic Matrix Estimation
O-D	-	Origin –Destination
BGP	-	Border Gateway Protocol
IBGP	-	Interior Border Gateway Protocol
RR	-	Route Reflection
HP	-	Hot Potato
ISM	-	Integrated Simulation Model
EM	-	Expectation Maximization

EIGRP	-	Enhanced Interior Gateway Routing Protocol
NS-2	-	Network Simulator v2
NS3	-	Network Simulator v3
OPNET	-	Optimized Network Engineering Tools
OMnetT++	-	Operation and Maintenance New Equipment Training
SSFNet	-	Scalable Simulation Framework Network Models
POP	-	Point of Presence
DV	-	Distance Vector
MIS	-	Management Information System
LAN	-	Local Area Network
WAN	-	Wide Area Network
NSP	-	Network Service Provider
VoIP	-	Voice over Internet Protocol
SLA	-	Service Level Agreement
AS	-	Autonomous System
RRC	-	Route Reflector Client
CPU	-	Central Processing Unit
ER	-	Edge Router
MED	-	Multiexit-Discriminator
TM	-	Traffic Matrix
SD	-	Standard Deviation
ICMP	-	Internet Control Message Protocol

TCP	-	Transmission Control Protocol
UDP	-	User Datagram Protocol
C	-	C language
C++	-	C ++ Language
NAM	-	Tcl/Tk Based Animation Tool
FIFO	-	First in First out
ACK	-	Acknowledgement
Pkt	-	Packet
ELLFD	-	Estimated Link Load from Direction
ELLTD	-	Estimated Link Load to Direction
Mu	-	Mean
Sigma	-	Standard Deviation

LIST OF MATHEMATICAL SYMBOLS

R_a	-	Packet Received time in the Production Network
R_b	-	Packet Received time in the Simulation Network
ES	-	Cell Transmission Time
ρ	-	Link Utilization
P_init_{ij}	-	The End-to-End Probabilities for All Nodes
pps_in_j	-	Total Packets Coming in to Node j
p_{ij}	-	The End-to-End Probability from Node i to Node j
λ_orig_i	-	Traffic Originating at Node i
pps_out_i	-	Total Packets out from Node i
TM_{ij}	-	Traffic matrix Between Node i and Node j
$ELLFD_{ij}$	-	Estimated Link Load from Direction between node i and node j
$ELLTD_{IJ}$	-	Estimated Link Load to Direction between node i and node j
e	-	Epsilon
SD	-	Standard Deviation

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Internet has become an enabler of information in our society and is today a fundamental element of the worldwide communication infrastructure playing a major role in enhancing education, entertainment, business, and social life. This proliferation of content has been followed by a sustained growth of starving Internet consumers. Nowadays Internet traffic is rapidly increasing, not only in volume but also in heterogeneity and complexity of composition. Internet users now demand a faster, a higher-quality, a more reliable, and more secure Internet. Figure 1.1 shows the number of Internet users in fourth quarter of 2013 (2,802,478,934). With this volume of users, many challenging issues and more pressure is faced by the Internet Service Providers (ISPs) to provide quality services with limited resources. At the same time, better traffic monitoring and analysis is needed to ensure the delivery of services to the end users.

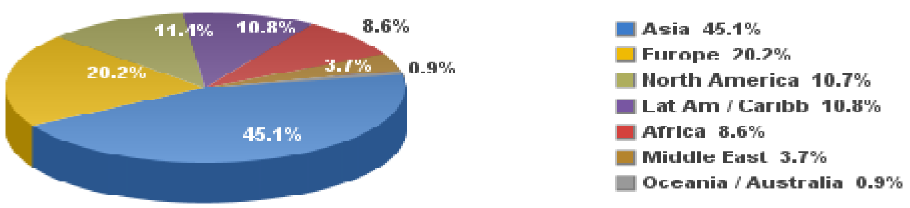

Figure 1.1 Internet users in the world distribution by world regions – 2013 – fourth quarter

Source: Internet World Stats – www.internetworldstats.com/stats.htm (last accessed June 2015)

Currently, many big companies are providing redundant and cheap cloud computing services. These cloud computing services provide a highly flexible environment enabling on-demand network access over the Internet (ISP's), thus allowing small companies to run their business without spending too much money in creating their own infrastructure to run their business applications, as in Management Information System (MIS). One of such infrastructure is shown in Figure 1.2a. In MIS, a Dashboard, as shown in this figure, is an easy to read, often single page, real–time user interface showing a graphical presentation of the current status and historical trends of any cooperation. To overcome the issue of availability of access, companies invest on redundant connections to the Internet ISPs using a dual-homed network (Karol *et al.,* 2007) setup. Figure 1.2b shows a setup of dual-homed network using BGP routing to connect to two ISPs. Dual or multi homed network is applicable in the real enterprise and medium companies world with their own private network (Abdullah *et al.,* 2014).

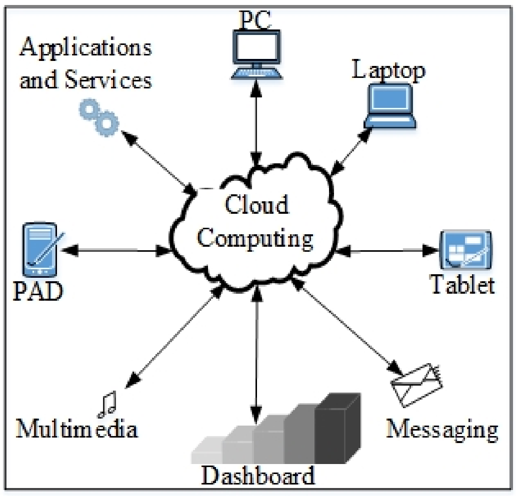

Figure 1.2(a) Company uses the Cloud Computing for their

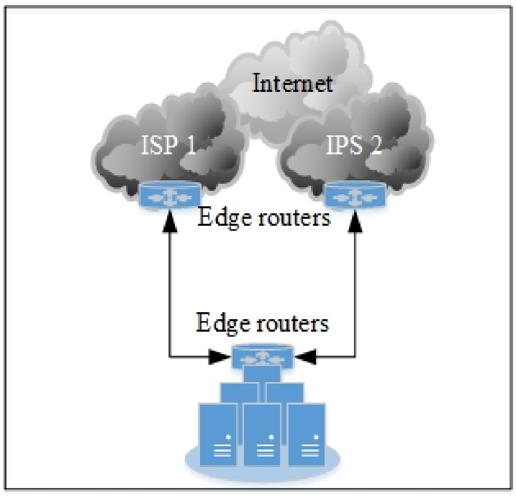

Figure 1.2(b) Company uses the Dual-homed network for redundancy

In the ever challenging world, ISPs will constantly need to study and analyse the existing traffic over existing infrastructures and predict their future demands. This has to be done smoothly and skilfully without any impacts on end users interactions. To achieve these tasks, simulation is normally carried out in order to have minimal or no impact on users (Mahdi and Hussain, 2013). The simulation has to represent the real environment and uses as much as possible real parameters to increase the estimated accuracy. A number of network simulators are available nowadays, either free or commercial.

1.2 Background

Sudan is a developing country with a population of 35.5 million; her advancement in ICT is also evolving. Consequently, the number of Internet users is also growing very fast. Table 1.1 shows the increment of Internet users, from 30,000 to 9.3 million over the periods of 2000 to 2014. This is a sharp increase compared to the decreasing population. This demand adds more pressure to the ISPs and introduces challenges which need to be addressed.

Table1.1 : Sudan internet usage and population growth

Year	Users	Population
2000	30,000	36,841,500
2003	300,000	35,035,677
2009	4,200,000	34,206,710
2014	9,307,189	35,482,233

Source: Internet World Stats
http://www.internetworldstats.com/af/sd.htm (last accessed) June 2015)

The need for global IPs for Internet users and companies is becoming a challenge with limited availability of IPv4 addresses. Figure 1.3 shows the increase in demand for year 2014. Migration to IPv6 is a challenge because most people are experts in IPv4. Thus, ISPs must increase the user knowledge through workshops.

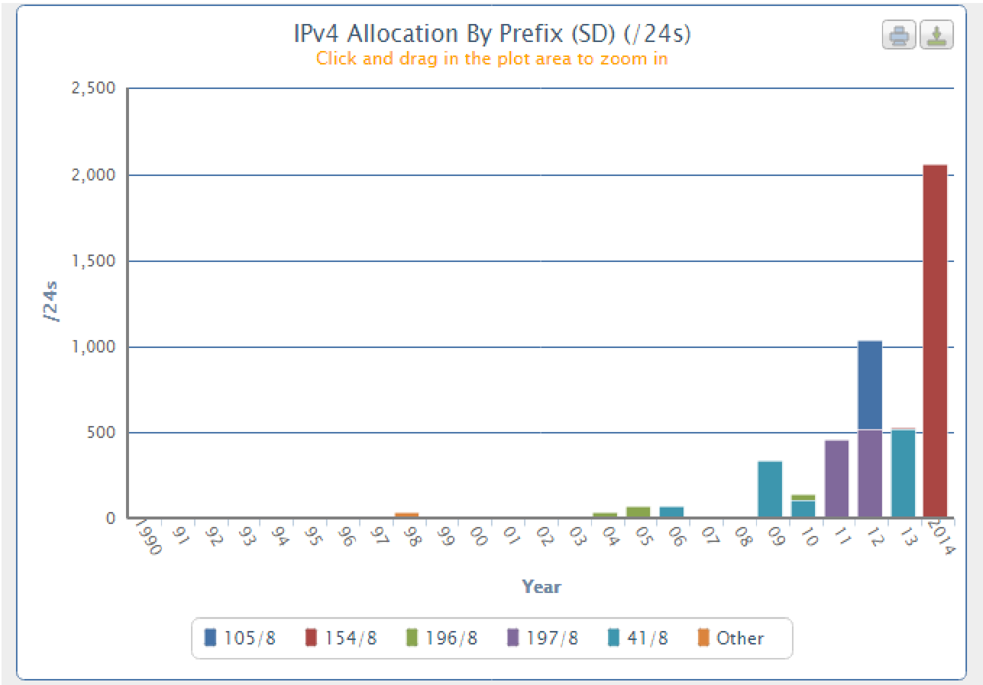

Figure 1.3 IPv4 allocations by prefix in Sudan (SD)

Source: Internet Numbers Registry for Africa
http://www.afrinic.net/en/services/statistics/country-stats (last accessed June 2015)

In this research, the ICT services provided by Sudan's Internet Service Provider for the population is used for the case study; in addition, these services are also aimed to be enhanced and developed for optimum provision of services. This Sudan ISP (also referred to as 'Corporation'), has more than sixty four (64 egress points) sites, represented by different industrial cities, complexes and companies, that are located around the country.

The management of the Corporation decided to centralize the ICT departments into one body, in order to reduce investment, budget and to finally ensure that the technical and supervisory control that are currently outsourced to other commercial companies are now directly taken care of by the Corporation. Thus the Corporation can apply and implement the future ICT infrastructure based on their strategic plan.

1.3 Motivation

The Corporation dream is not impossible. However, at the same time, it is not an easy task and risks have to be managed properly in the migration effort. Some challenges are more related to management issues and culture. Technical issues, which are the main focus of this research, involve migrating from the current static routed configuration environment to the enhanced dynamic routed environment.

Table 1.2 : The scope of involvement: current versus future states

Current State	Future State	Scope of involvement
A few sites has own independent ICT department	Centralize the ICT	Management
Running cost is very high	Initial cost is high (DC, DRC)	Management
A variety of network topologies	Apply new topology to achieve all corporation needs in next 15 years	Technical
A variety of ERP applications	Apply centralized ERP for the corporation	Management
ICT does not support the decision makers such as Dashboard	Fully support the decision makers on click	Management
Manually maintaining the routing protocol (Static)	Apply suitable dynamic routing	Technical
Network High availability, Available through Passive Link controlled by Spanning Tree Protocol (STP).	Network Connectivity must be fully utilized for maximization performance	Technical

1.4 Research Questions

Based on the literature reviewed and existing setup requirements as applicable to this case study, the following questions are generated:

1. How can Traffic Matrix Estimation (TME) method that is based on combination of end-to-end recovery (probability) and method of generating traffic matrix be classified?
2. How can the selected method be enhanced and implemented; and the results validated?
3. Based on the survey, which tools can be used to make the computation complexity easy?
4. How can an existing method that is easy to modify, enhanced and aligned with the research needs be selected?
5. How can the traffic generated between each O-D pair in a flow structure, including offset time, source, destination, protocol, type and length, in text file be save?
6. How can the network simulators be classified; and suitable ones that is cheap (possibly free) and has inherent libraries in modeling dynamic routes such as Border Gateway Protocol (BGP), Interior Gateway Protocol (IBGP) and Route Reflection (RR) be selected for the purpose of this research?
7. How to inject the real data captured from case study network or outcomes from TME text file into selected simulator and disable their traffic generator functionality?
8. How can the result from selected network simulator be validated, and which tools should be used?
9. How can the Hot-Potato routing algorithm be implemented; and their outcomes validated?

10. How can the TME outcomes as input parameters to support Hot-Potato in generating Hot-Potato routing changes plan be used and validated?

11. How can the BGP which run in selected simulator to use Hot-Potato routing protocol instead of the default routing in Interior Border Gateway Protocol (IBGP) within the cluster that uses Route Reflection (RR) setup be enforced?

12. How can the outcome when disabling the default routing in IBGP and use Hot-Potato Routing validated?

13. Since there is no work that integrates TME, HP and BGP, to the best of our knowledge in a simulator environment, how do we synchronize between them and validate the outcome based on the three metrics packet: loss, delay and throughput?

14. How can the impact of link failure in the network when using such integrated model be reduced?

15. How can the scalability when adding new nodes and increase the performance when adding new links when using the integrated model be extended?

1.5 Problem Statements

The problem of the Corporation is to move from the current network configuration which uses static routing protocol to future state network that is based on Traffic Engineering (TE). In TE, the ODGen algorithm TME is limited to the number of hops, the Expectation Maximization (EM) accuracy is 92% and the complexity of calculations that consumes the CPU time (ODGen problem runs in about 19 seconds for each iteration). Thus, there is a need to minimize the real experimental risks as much as possible by using a suitable network simulator NS-2 is normally used to simulate the real network based on the topology and link probabilities. However, networks parameters representing the real network traffic are not used in NS-2. The error percentage observables with BGP simulated in NS-2 with three matrices are 22% for packet losses, 12% average delay and 22% throughput. There is lack of such comprehensive model consisting of TME, BGP and HP in NS-2 based on real network from previous studies and analysis. Previous work such those found in (Teixeira *et al.* 2008), only HP functionality were tested in BGP and which were used to generate the traffic matrix in order to study the network impacts.

1.6 Research Objectives

The ultimate aim of this research is to assist in providing the best solution to migrate from the current ISP network setup based on static routes to network based on enhanced auto dynamic updates. To enhance this auto dynamic update, the research views the issues based on traffic engineering problems utilized by TM (TME). The proposed Border Gateway Protocol (BGP) which provides scalable internetworking and redundant for ISP's to be implemented will use Hot-Potato (HP) routing protocol to get the dynamic updates, wherein in turn, HP will get their parameters from TME which are based on the real network setup and traffic data. Specifically, the following are the objectives of the research:

1. Enhanced the Origin – Destination Generator algorithm (ODGen) by increasing the accuracy, simplify the calculation and visualization of the traffic in the NS-2 network simulator instead of using their interior traffic generators based on the real network.
2. Develop an Integrated Simulation Model (ISM) which consists of TME, BGP and HP by using NS-2 simulation based on the real network to study the impacts and visualize- the changes in real network topologies based on Packet loss, Delay and Throughput.

1.7 Scope of Work and Assumptions

This research involves four phases. The first is development of simulation environment (using NS-2) phase. In this phase parameters representing the actual data packets are injected into the real production network in the NS-2 model. Next, is the TME phase, which is to develop and enhance the existing TME model. The enhanced TME model will include the combination of the end-to-end probability path and traffic matrix algorithms based on Expectation Maximization (EM) whose parameters are based on the real production network traffic. In Phase Three, the Hot Potato (HP) integrated with TME will provide the dynamic updates for IBGP when using Route Reflection (RR) method. The last, is the ISM phase, where here TME, HP with BGP functions are all integrated within an open source network simulator. The four phases are illustrated in Figure 1.4.

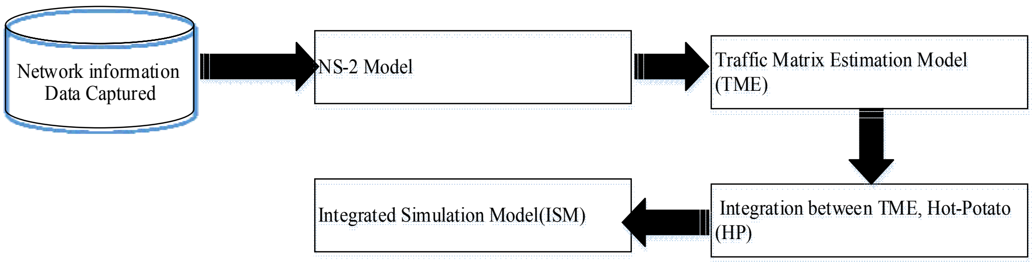

Figure 1.4 The steps to develop the ISM

The scope of this research is as follows:

1. Dataset are captured from the Corporation in Sudan which is collected at router-to-router level through a modified sniffer program.
2. The simulation uses NS-2 Network simulator.
3. In generating the TME model, the following are used:

    i. The R tools are to be implemented with EM algorithm for the Gaussian mixture model.

    ii. Dijkstra's Minimum Weight Path Algorithm to compute the shortest paths.

    iii. The weights used by Dijkstra's Algorithm and Hot-Potato Algorithm are the Enhanced Interior Gateway Routing Protocol (EIGRP) metric.

4. The work does not include Traffic Matrix optimization.

1.8 Contributions of Research

1. ODGen is enhanced by unlimited number of hops, the accuracy of EM increases from 92% to 97% and computations (in which the average of 10 execution elapsed time equal to 0.07 seconds) is simplified.
2. Injecting the real network traffic in NS-2 instead of using readily available NS-2 internal traffic generators. The results shows that the characteristics of injected traffic and the real traffic are very similar with an average error packet time send 0% and error packet time received 3.61% with 0% packet loss when comparing between them. Thus we are using parameters representing real traffic instead of NS-2 packet traffic generators based on certain distribution function.
3. Development of an Integrated Simulation Models based on NS-2 using real traffic parameters. With the ISM, various scenarios, such as link or node removal and addition can be studied and its impact evaluated. The model, wherein Hot Potato learns the weight from TME optimizes further the switching time for BGP from primary link to the alternative to 0.05 seconds.

1.9 Organization of the Thesis

This thesis includes six chapters and the appendices.

Chapter 2 discusses four main topics. Firstly, NS-2 model based on the real network parameter methods are discussed. This is followed by traffic matrix estimation methods. Thirdly, Hot Potato routing functions in simulators network is described. This is finally followed by a discussion on Border Gateway Protocol functionality on network simulators. At the end of the chapter, the research questions that are generated from these reviewed literatures are discussed.

Chapter 3 shows the steps involved in the research methodology as applicable to this study. Likewise, the models and the proposed data collection strategies are explained.

Chapter 4 explains further on generating NS-2 traffic model based on real network parameter. Development and enhancement of the traffic matrix estimation model based on a production network is elaborated. This chapter also discusses the data collection, experimental setup and implementation of the production network to test the accuracy of the NS-2 model and the TME.

Chapter 5 deals with the TME outcome for Hot-Potato routing algorithm and how IBGP could get dynamic update from Hot-Potato protocol. This chapter also discusses the experimental setup and implementation of the production network to test the effectiveness of the ISM in dealing with link or node failure, as well as the addition of new node or link.

Chapter 6 concludes the thesis by discussing the achievements. The future work also described.

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