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TRAFFIC MANAGEMENT ALGORITHMS FOR LEO SATELLITE NETWORKS

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By

FAHRUL HAKIM BIN HUYOP @ AYOB

Thesis Submitted to the School of Graduates Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

February 2016

DEDICATIONS

To my wifey ~ Eida Eidey, Mama dan Papa.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

TRAFFIC MANAGEMENT ALGORITHMS FOR LEO SATELLITE NETWORKS

By

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February 2016

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Faculty : Computer Science and Information Technology

Traffic management for Low Earth Orbit (LEO) satellite networks deals with the process of monitoring the network activities by allocating certain traffic into the right path and increasing the throughput rate for the sake of performance and efficiency. This thesis deals with traffic management by improving some algorithms in routing and congestion avoidance to guarantee the subscribers to have their desired QoS. The problem in network arises during the period of coexistence between UDP and FTP traffic in the same network which could affect their performances. The situation is getting worse when the traffic is not equally distributed across the network which could possibly degrade the network performance especially in the case of the delivery of the high priority traffic. A failure to manage traffic classes by routing them according to their type of service could also bring negative impact to LEO satellite network performance.

In dealing with traffic routing problem, two algorithms, Dijkstra's Shortest Path and Genetic Algorithm (GA) are combined together and enhanced to re-strategize a better routing mechanism for a heterogeneous mix of traffic classes ranging from traditional voice calls to multimedia data services in Low Earth Orbit (LEO) satellite networks. Those two algorithms are combined together due to the strong possibilities of being unable to achieve the optimal results when implemented separately. Three classes of traffic such as low, medium and high priority are defined and to be allocated to the right path from source to destination with the most privileged is given to the high priority traffic.

In satellite network with Multi Protocol Label Switching (MPLS), routing with Extended Dijkstra Shortest Path algorithm is done to improve QoS by minimizing the link shared between UDP and TCP traffic flows. By minimizing the link shared between those traffics, the performance of UDP traffic which carries delay sensitive data could be improved.

Since TCP WestwoodNew is designed to be implemented in wired and wireless network environment, there are few drawbacks when TCP WestwoodNew is implemented in the satellite network environment. As an example, the sender cannot fully utilize the available bandwidth because the rate of the congestion window increment in Slow Start phase of TCP WestwoodNew is rather slow. In this thesis, congestion avoidance algorithm of TCP WestwoodNew is enhanced in order to improve the drawbacks.

In this thesis, several proposed algorithms have been developed to improve the traffic performance in the LEO satellite network. In order to evaluate the proposed algorithm, a series of experiments to implement Discrete Event Simulation (DES) of a LEO satellite network by using ns-2 and C/C++ are conducted. The performances of the proposed algorithms are then compared with the previously developed algorithms. The important parameters measured in the simulation are delay rate, throughput rate and fair traffic distribution rate. From the results, the proposed algorithms have managed to reduce the average delay rate for the high priority and UDP traffic. The results also indicate that there is an improvement of fair traffic distribution rate in the network where most of the Inter Satellite Links (ISLs) are able to maintain the link loading percentage ranging from 25% to 75%. For the TCP traffic performance, there is 5% improvement in terms of throughput rate increment.

Overall, from all the three experiments that have been conducted, the proposed routing algorithms which have been developed to manage the network traffic have proved better than the previously developed algorithms in several perspectives especially for the implementation of real-time applications in LEO satellite networks.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ALGORITMA PENGURUSAN TRAFIK UNTUK RANGKAIAN SATELIT LEO

Oleh

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Pengurusan trafik bagi satelit Orbit Rendah Bumi (LEO) adalah berkenaan dengan pemantauan aktiviti-aktiviti rangkaian dengan memperuntukkan trafik tertentu kepada laluan yang tepat dan mempertingkatkan kadar *throughput* demi kebaikan prestasi dan kecekapan. Tesis ini menangani pengurusan trafik dengan memperbaiki beberapa algoritma dalam penghalaan dan *congestion avoidance* bagi menjamin pelanggan agar memperoleh QoS yang diharapkan. Masalah dalam rangkaian tercetus di sepanjang tempoh kewujudan bersama antara UDP dan FTP trafik dalam suatu rangkaian yang sama yang boleh menjejaskan prestasi kedua-dua trafik itu. Keadaan tersebut menjadi semakin teruk apabila trafik itu tersebar dengan tidak sekata di seluruh rangkaian yang mungkin boleh menjejaskan prestasi rangkaian terutama bagi kes penghantaran trafik berkeutamaan tinggi. Kegagalan untuk menguruskan kelas-kelas trafik dengan penghalaan yang berdasarkan jenis perkhidmatan juga boleh memberi kesan negatif kepada prestasi rangkaian satelit LEO.

Dalam menangani permasalahan penghalaan trafik, dua algoritma iaitu Dijkstra's Shortest Path dan Algoritma Genetik digabungkan bersama dan dimantapkan bagi penstrategian semula suatu mekanisme penghalaan yang lebih baik bagi percampuran kelas trafik heterogen yang terdiri daripada panggilan suara tradisional ke perkhidmatan data multimedia dalam rangkaian satelit Orbit Rendah Bumi (LEO). Kedua-dua algoritma tersebut digabungkan bersama kerana besar kemungkinan tidak dapat mencapai hasil yang optimum apabila dilaksanakan secara berasingan. Tiga kelas trafik seperti trafik berkeutamaan rendah, sederhana dan tinggi ditakrifkan dan diperuntukkan kepada laluan yang tepat dari sumber ke destinasi dengan keistimewaan diberikan kepada trafik yang berkeutamaan tinggi.

Dalam rangkaian satelit dengan Multi Protokol Pensuisan Label (MPLS), penghalaan dengan menggunakan algoritma lanjutan Dijkstra Shortest Path dilakukan untuk meningkatkan QoS dengan meminimumkan perkongsian pautan antara aliran trafik UDP dan TCP. Dengan meminimumkan perkongsian pautan antara trafik tersebut, prestasi trafik UDP yang membawa data sensitif kelewatan dapat dipertingkatkan.

Oleh kerana TCP WestwoodNew direka untuk dilaksanakan dalam persekitaran rangkaian berwayar dan juga tanpa wayar, terdapat beberapa kelemahan apabila TCP WestwoodNew dilaksanakan dalam persekitaran rangkaian satelit. Sebagai contohnya, penghantar tidak dapat menggunakan sepenuhnya lebar jalur yang ada kerana kadar penambahan *congestion windows* dalam fasa Slow Start TCP WestwoodNew agak lembab. Dalam tesis ini, algoritma *congestion avoidance* TCP WestwoodNew dimantapkan demi untuk mengatasi kelemahan tadi.

Dalam tesis ini, beberapa algoritma yang dicadangkan telah dibangunkan untuk meningkatkan prestasi trafik dalam rangkaian satelit LEO. Dalam usaha untuk membuktikan algoritma yang dicadangkan adalah lebih baik daripada algoritma yang telah dibangunkan sebelumnya, satu siri eksperimen untuk melaksanakan Simulasi Peristiwa Diskret (DES) bagi suatu rangkaian satelit LEO dengan menggunakan ns-2 dan C / C ++ dijalankan. Prestasi algoritma yang dicadangkan kemudiannya dibandingkan dengan algoritma yang dibangunkan sebelumnya. Parameter penting yang diukur dalam simulasi tersebut adalah kadar kelewatan, kadar *throughput* dan kadar pengagihan trafik saksama. Keputusan ini kemudiannya dinilai dan dianalisis. Daripada keputusan, algoritma yang dicadangkan berjaya mengurangkan purata kadar kelewatan bagi trafik berkeutamaan tinggi dan trafik UDP. Keputusan juga menunjukkan terdapat peningkatan pada kadar pengagihan trafik saksama dalam rangkaian di mana kebanyakan Pautan Antara Satelit (ISLs) dapat mengekalkan peratusan muatan pautan antara 25% sehingga 75%. Bagi prestasi trafik TCP, terdapat peningkatan 5% dari segi kenaikan kadar *throughput*.

Secara keseluruhan, daripada ketiga-tiga eksperimen yang telah dijalankan dalam kajian ini, cadangan algoritma penghalaan yang telah dibangunkan bagi menyelenggarakan pengurusan trafik rangkaian telah terbukti lebih baik daripada algoritma yang dibangunkan sebelumnya dalam beberapa perspektif terutama bagi pelaksanaan aplikasi masa nyata dalam rangkaian satelit LEO.

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24 May 2016 *Fahrul Hakim Ayob*

I certify that a Thesis Examination Committee has met on 12 February 2016 to conduct the final examination of Fahrul Hakim bin Huyop @ Ayob on his thesis entitled "Traffic Management Algorithms for Leo Satellite Networks" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

ABE	Available Bandwidth Estimation
ABR	Average Bit Rate
ACK	Acknowledgement (notification packet)
AIMD	Additive Increase Multiplicative Decrease
ATM	Asyncronous Transfer Mode
BWcurrent	current bandwidth
BWE	estimated bandwidth
BWprevious	previous bandwidth
BWratio	bandwidth ratio
CBPs	Call Blocking Probabilities
CBR	Constant Bit Rate
CR-LDP	Constraint-based Routing Label Distribution Protocol
Cwnd	congestion window
DDR	Distributed Datagram Routing
DUPACK	duplicate acknowledgement (notification packet)
ER-LSP	explicit-route on label-switched path
FD	Flow Deviation
FEC	forward equivalent class
FTP	File Transfer Protocol
GA	Genetic Algorithms
GAMEDA	Genetic Algorithms Modified Extended Dijkstra Algorithm
GEO	Geostationary Earth Orbit
GS	Ground Station

IP	Internet Protocol
IPv6	Internet Protocol version 6
ISLs	inter-satellite link
ISP	internet service providers
LAN	Local Area Network
LDA	Loss Discrimination Algorithm
LDP	Label Distribution Protocol
LEO	Low Earth Orbit
LER	label edge router
LSDB	Link State Database
LSP	label switching/switched path
LSPID	label switched path identification
LSR	label switching/switched router
MASMR	Multi-Agent System
Mbps	Megabit per second
MEDA	Modified Extended Dijkstra Algorithm
MEO	Medium Earth Orbit
MLSN	Multi-Layered Satellite Networks
MPIR	Multi-Path Inter-satellite-link Routing
MPLS	Multi-Protocol Label Switched
MPLS-QE	MPLS with QoS Extension
MPLS-TE	MPLS with Traffic Engineering extension
MPLS-TP	transport profile MPLS
MPQR	Multi-Path QoS Routing

MSS	maximum segment size
NAM	Network Animator
NASA	National Aeronatic and Space Administration
NORAD	North America Space Defense Command
ns-2	Network Simulation version 2
OD	origin to destination
OSPF	Open Shortest Path First
PKR	Partially Known Routing
PNNI	Private Network-to-Network Interface
QoS	Quality of Service
RIP	Routing Information Protocol
RTO	retransmission time-out
RTT	round trip time
RVSP-TE	Resource Reservation Protocol traffic engineering
SD	Source-Destination
SDH	Synchronous Digital Hierarchy
SIPN	Satellite IP Network
SMIB	Satellite Management Information Base
SONET	Synchronous Optical Network
ssthresh	slow start threshold
TCP	Transmission Control Protocol
TCPW	TCP Westwood
TCPW-BR	Bulk Repeat TCPW
TLE	Two-Line Elements

UDL	uplink downlink
UDP	User Datagram Protocol
UNI	User-to-Network Interface
VBR	Variable Bit Rate
VoIP	Voice over Internet Protocol
WWW	World Wide Web

CHAPTER 1

INTRODUCTION

Artificial satellites are machines or manmade objects that orbit the earth (Boniface, 2013). These satellites are very important instruments in order to provide human with modern conveniences, such as audio/video broadcasting, communications, navigation, geographical positioning system, weather-climate forecasting, environmental monitoring, earth surface observation, military surveillance equipments and space-science installation facilities. Satellite systems can be seen as integral part of the global network infrastructure due to some advantages such as coverage flexibility, faster deployment and can reduce installation effort upon the scalability of subscribers (Douglas, 2009). Basically, satellite systems can be categorized based on the height of their orbits relative to the earth surface and the following classifications have been done, Low Earth Orbit (LEO), Medium Earth Orbit (MEO) & Geostationary Earth Orbit (GEO) systems (Rishahb, 2012).

GEO satellites are the highest satellites (i.e. 35,786 km from the earth) which are generally used in audio and video broadcasting and some wideband applications (Beal, 2012). Because of its bond to the earth's rotation, therefore they remain fixed in their position in space in relation to the earth's surface. Since its distance is relatively far from the earth, only three GEO satellites are needed for coverage of the entire earth. One of the main benefits of GEO satellite system is that ground stations on the earth needs to point to only the same single location in space in order to receive the signal from a GEO satellite (Zhao, Yi, Hou, & Zhong, 2015). MEO satellites on the other hand, orbit the earth between 9000 and 11,000 km above the earth's surface and are mostly utilized in geographical positioning systems (Wood, 2001). Unlike GEO, MEO satellites are not stationary in relation to the rotation of the earth (Beal, 2012). To effectively cover the entire earth, the MEO system needs between 8 to 20 number of satellites depending on its height (Durofy, 2014). The LEO satellite constellation system is the lowest satellites in the orbit system with the distance approximately between 500 to 2000 km above the earth's surface (Wood, 2001; Henderson, 1999). Since its distance is close to the earth, LEO satellites experience shorter round trip delay with lower power consumption as compared to GEO and MEO which makes it suitable for telecommunication (Wan, Ye, & Song, 2014). The drawback is, the mobility of LEO satellites must be kept high, because LEO satellites are not fixed in space in relation to the earth's rotation. As a result, data being transmitted/received through LEO satellite system must be handed over from one satellite to the other as the satellites move in and out of range of the earth-bound ground stations that are sending/receiving the signals into/from space (Benslama, Kiamouche, & Batatia, 2015). Because of the complex routing strategy due to its number (between 40 and 80 satellites) with unfixed topology has made LEO satellite constellation become one of a main research topics (Wood, 2003; Ekici et al., 2000).

1.1 Research Issues

There are various research issues in LEO satellite networks communication system. Figure 1.1 displays some of the issues. Some studies focus on satellite hardware and architecture which is regarding the instruments of satellite vehicle such as battery, satellite coating material, launch rocket and etc. To meet with today's applications' requirement some policies, regulatory decisions and protocols in satellite communication should be revised. Some studies focus on resource management which caters the issues in routing and satellite signal such as signal loss, Doppler effect, frequency reuse and bandwidth utilization in satellite. Some researchers are interested in the implementation of security in satellite network to ensure the safety of highly sensitive data delivery from source to destination. Routing is an essential research fundamentally and of constant importance. This research concentrates on routing and TCP performance over LEO satellite networks.

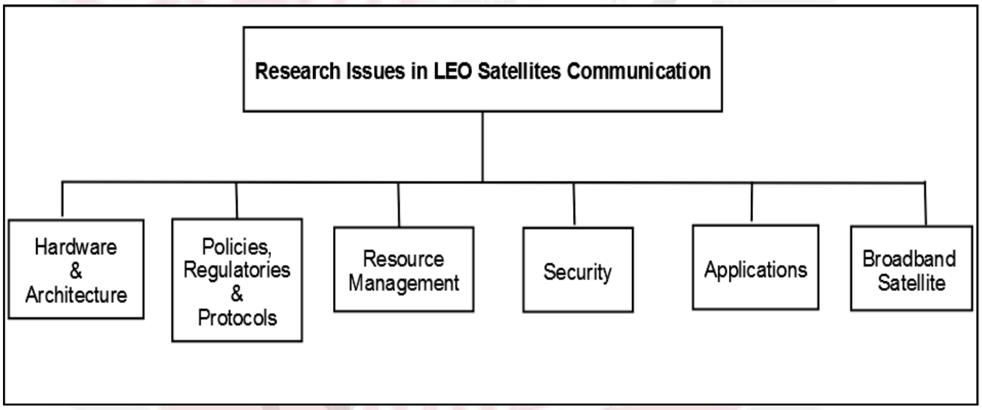

Figure 1.1 : Research Issues in LEO Satellite Communication System

1.2 Routing Algorithm in LEO

Due to the increased number of multimedia applications with various Quality of Service (QoS) requirements, it is essential to have a routing algorithm that is capable of providing a guarantee to the user to meet their expected level of QoS requirements. Since the satellite networks play an indispensable role in providing global Internet access and electronic connectivity, to achieve such global communications, provisioning of QoS within the advanced satellite systems is a must. One of the important mechanisms to implement the QoS is traffic management. Traffic management becomes a prominent factor in the case of satellite network because of limited availability of their resources (Xie, Ma, & Liang, 2012). This research strives to ensure the efforts to manage the network links in order to avoid overloading of some satellite links, while the other links remain underused which would eventually result in network congestion and performance degradation. Traffic management for this research is proposed through routing algorithms, and their related areas which are discussed as follows.

There are two routing algorithms focused in this thesis. The first is Genetic Algorithm (GA) and the second one is the Dijkstra's Shortest Path. GA is an evolutionary theory that has been proven in solving many real-world problems with good solutions including the optimization of network performance (Rao & Wang, 2011b). The Dijkstra's Shortest Path algorithm on the other hand, is a graph search algorithm that solves the single-source shortest path problem for a graph with non-negative edge path costs, producing a shortest path tree (Kawamoto, Nishiyama, Kato, Yoshimura, & Kadowaki, 2013). In networking, the Dijkstra's Shortest Path algorithm is used to determine the right path from origin to destination with the least cost.

Multi-protocol Label Switching with Traffic Engineering (MPLS-TE) which caters the needs of multimedia broadband is a growing implementation in today's service provider networks (Jamali, Naja, & Quadghiri, 2012). Pan et.al (2013) in their research have devised a routing algorithm in LEO satellite networks based on MPLS which takes the limited link time into account and provide traffic engineering for QoS (Pan et al., 2013). The algorithm can fix communication time problem and the total network traffic that caused by satellite handover. But, with the link shared between UDP and TCP traffic flow, the performance of UDP which support real-time application has been degraded. So, this research is to equip the MPLS with more proper QoS extension over the previously developed MPLS routing algorithm as in (Pan et al., 2013) to improve UDP traffic flow in satellite network with the presence of TCP traffic flow.

The Transmission Control Protocol (TCP) congestion control is one of the most important protocol in TCP which utilizes a network congestion-avoidance algorithm that includes various aspects of an Additive Increase/Multiplicative Decrease (AIMD) scheme, with other schemes such as slow start to accomplish congestion avoidance (Forouzan, 2010). With the advent of new breed real-time interactive applications (e.g. VoIP-SKYPE) which hog resources in satellite networks, have exposed to scholars and researchers that the bandwidth estimation method in TCP Westwood could be improved and enhanced in various manner. Hagag in (Hagag & El-Sayed, 2012), for example has suggested TCP WestwoodNew which is an improvement over the previous TCP Westwood in terms of bandwidth estimation which comes out with a better throughput rate and decreases end-to-end delay. Since there is a potential for UDP traffic not yet present in a network, this opportunity should be used to increase TCP traffic flow as maximum as possible. In this case, there is a potential for TCP WestwoodNew to be improved by increasing its throughput.

1.3 Problem Statements

Challenging issues in LEO satellite network involves in dealing with traffic management by constructing proper routing algorithms to guarantee the subscribers to have their desired QoS. The problem in network arises during periods of heavy load particularly if the traffic demands cannot be predicted in advance. The situation is getting worse when the traffic is not equally distributed across the network which could possibly degrade the network performance. A failure to manage traffic classes by routing them according to their type of service also could bring negative impact on LEO satellite network performance. The details on the problems are described as follows:

- There are many routing algorithms based on GA and Dijkstra's shortest path have been developed by researchers in order to balance the traffic workload across the network. These algorithms which are based either on GA or Dijkstra's in searching the right path from source to destination do have their own strengths and weaknesses. Although there are various GA techniques that have been proposed to optimize the searching of the best route and to maintain the traffic distribution across the network, it still cannot guarantee that the selected route is a hundred percent the best solution because GAs may have a tendency to converge towards local optima. This situation happens very often when the populations have a lot of subjects with different constraints. Many traffic types in satellites are cases of this type. Another problem is certain optimisation problems which are known as the variant problems cannot be solved by means of GA. This occurs due to poorly known fitness functions which generate bad chromosome blocks despite the fact that only good chromosome blocks crossover. The problem of greedy algorithm such as Dijkstra's Shortest Path on the other hand is that there are no set of solutions to be opted in finding a collection of alternative path to route various classes of traffic. So the searching of the right path for each traffic class cannot be optimized. This could result in the failure to maintain the equal traffic distribution across the network.

- The link shared between real-time application and non real-time application in satellite networks which carry UDP and FTP traffic respectively reduce UDP traffic performance significantly that might be unacceptable by standard users. This is because UDP packet loss occurs more frequently and successively when the flow control of TCP congestion windows are synchronized. The drawback of the previous algorithm is that, it does not make any attempt to isolate UDP and TCP traffic flows into different paths in order to minimize the tendency of FTP and UDP traffic from flowing into the same path. Failing to do so, it could significantly affect UDP traffic performance which carries delay sensitive data such as voice communication, etc.

- With the increasing popularity of Internet applications which implement UDP protocol such as VoIP and streaming high quality video with massive size of bytes transferring, the networks become more congested due to continuous and constantly flowing traffic. The situation becomes worse when the TCP traffic flow that brings traditional applications such as email and web browsing are severely affected by this. Since TCP WestwoodNew is suggested to be implemented in wired and wireless network environment only, There are few drawbacks when TCP WestwoodNew is implemented in satellite network environment. For example, the sender cannot fully utilize the available bandwidth because the rate of the congestion window increment in Slow Start phase of TCP WestwoodNew is rather slow. The other problem is, since packet losses often occur due to link errors in satellite environment, TCP WestwoodNew tends to decrease its throughput drastically without committing a proper available bandwidth estimation.

1.4 Research Objectives

The main objective of this study is to develop proper algorithms that can improve traffic performance for LEO satellite networks. In this thesis the privilege is given to high priority traffic (delay sensitive traffic) that carries real-time application data. To achieve the main objective of this study, the following procedures are taken.

- To develop an enhanced algorithm for optimizing the searching for the right paths from source to destination in satellite network by combining the strengths of two algorithms GA and Dijsktra shortest path. Dijkstra shortest path algorithm is used to determine the correct path. GA on the other hand, is used to optimize the link usage with the distribution of traffic workload evenly across the network. Moreover, with GA, it could provide alternative routes for different kind of traffic classes in order to improve the performance of high priority traffic by preventing some of the links from becoming idle. In this case, the high priority traffic class is given the privilege to be assigned with the shortest path from source to destination. Longer paths on the other hand, are reserved for medium and low traffic classes.

- To develop an algorithm which could improve the QoS in LEO satellite network by reducing the average end-to-end delay and increasing throughput rate of the highly sensitive delay real-time traffic. This can be done through the minimization of link shared between UDP and TCP traffic flow over the network so that the performance of UDP traffic could be improved.

- To propose an enhancement of some modules in TCP WestwoodNew such as congestion avoidance and packet loss control algorithm in order to improve the TCP traffic flow which carries the data for traditional applications such as email and web browsing over a heavy congested satellite network with the present of the UDP traffic flow. This can be done by increasing the throughput rate without compromising packet delay and packet drop rate. For this effort, within a very short period of time, the performance of TCP traffic flow could be enhanced to allow more transmission of TCP packets from source to destination when there is an opportunity during the UDP traffic is not yet present in the network.

1.5 Research Scope

This research consists of three (3) major parts involving an improvement of routing algorithms and congestion control in LEO satellite network with Iridium satellite constellation. The first part suggests an improvement of routing in the network for the sake of high priority traffic. The proposed algorithm is the combination of Dijkstra's shortest Path Algorithm and Genetic Algorithms (GA). The second part focuses on the development of a routing algorithm to provide more QoS in a switched satellite network with MPLS capability. This involves the Modification of Dijkstra's Shortest Path Algorithm to minimize UDP and TCP traffic flows from sharing the same links. The last part is an enhancement of TCP congestion control based on the previously developed algorithms such as TCP WestwoodNew to improve the performance of TCP traffic in satellite network. The effectiveness of the proposed algorithms will be compared with the previously developed algorithms such as MPQR, Pan's algorithm and TCP WestwoodNew.

1.6 Organization of the Thesis

This thesis is divided into six chapters, according to the second writing style in UPM thesis preparation guide year 2010. The contents of each chapter are described as follows:

Chapter 2 presents the review of important literature for the studies. These include reviews on journals and papers particularly on Dijkstra's shortest path algorithm and GA in optimizing and searching the right path for traffic routing in satellite communication. The architecture of MPLS and traffic engineering is discussed including application programming interface (API) that is going to be used in ns-2 for simulation. Previous papers on satellite with MPLS capability are presented as well. This chapter also explains in detail about the congestion avoidance algorithm which is implemented in TCP-Westwood and TCP-WestwoodNew.

Chapter 3 focuses on methodology on how the experiments are conducted. In this chapter, the methodology and the basic problem formulation in solving the traffic management issues are discussed and followed by detailed explanation of methodological works of three separate experiments on satellite simulation. The topological concept of satellite network used in this thesis is also being explained.

Chapter 4 is the first research contribution. This contribution proves that the combinatorial algorithms under the name GAMEDA could be established and performs better in terms of providing QoS in traffic routing than that of GA or Dijkstra's Shortest Path Algorithm alone in several aspects. This chapter also gives an account of how the research is conducted and describes the research methodology such as research instrument, algorithm procedures, implementation and analysis. The data analysis part is discussed at the end of this chapter.

Chapter 5 discusses on the second research contribution that proves the suggested algorithm which is implemented along with MPLS could improve some of the QoS requirement in the LEO satellite communication. This chapter also highlights the design and the implementation of MPLS simulation in LEO satellite network which supports label swapping operation, LDP (label distribution protocol), and CR-LDP (constraint based routing-LDP). In order to prove the advantage of MPLS traffic engineering (MPLS-TE) with QoS in satellite communication network, the basic MPLS function defined in MPLS standards such as label distribution schemes, flow aggregation, explicit routing is simulated. The data analysis part is discussed at the end of this chapter.

Chapter 6 focuses on the third research contribution. This chapter proves the modification of congestion avoidance algorithm in TCP WestwoodNew could increase the TCP traffic performance by increasing its throughput and the number of congestion window in heavy congested satellite network. The modifications of the previously developed algorithm and the methodology of conducting the research are shown. The data analysis part is explained at the end of this chapter.

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