QUALITY OF SERVICE IN MOBILE IP NETWORKS WITH PARAMETRIC MULTI-CHANNEL ROUTING ALGORITHMS BASED ON LINEAR PROGRAMMING APPROACH

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By

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Quality of service (QoS) is an essential consideration and an open challenge in computer networking. Providing QoS guarantees becomes even more challenging when the complexities of mobile IP networks are taken into account.

In a Mobile IP Network, when a node moves, it may go away from other nodes, this node movement decreases the available bandwidth, reduces the data transmission rate and increases the propagation delay. These issues affect the network efficiency and make a significant reduction in Mobile IP network performance and utilization. In other words, uncontrolled node movements in a Mobile IP network cause network failure, and non-optimized mobile node movements from a Foreign Network to another Foreign Network lead to an increase in handoff latency.

This work is going to improve network efficiency to guarantee QoS in Mobile IP Network by increasing data transmission rate, avoiding communication failure, and reducing handoff latency. The proposed work has been used to optimize data transmission rate by controlling the node movements and node shiftings in a limited domain, avoid communication failure by preventing nodes from exiting their domain and reduce the handoff latency in Mobile IP networks.

In the proposed approaches, to overcome the mentioned issues in Mobile IP networks when a Mobile Node moves, parametric linear programming and graph theory are employed. To achieve mobility control in Mobile IP networks, a new linear programming formulation for guaranteeing the optimality of data transmission and

network connectivity is proposed. This approach tunes the parameters of the linear programming models that are used in the other algorithms by using a dynamic element.

The proposed algorithms are evaluated by considering different metrics, computation modellings, and measurements on the simulation. The simulation results reveal noticeable data transmission rate improvement over previous routing approaches by optimizing the linear programming models. The proposed node movement control algorithm achieves a 31 percent improvement compared to HMIP and FMIP. Furthermore, Optimized Parametric Topology Control Routing algorithm performs significantly better than Triangular Routing Method and Change Foreign Agent Algorithm. The simulation results show the improvement is about 50 percent reduction of handover latency in different Mobile IP network scenar ios.

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

MENJAMIN KUALITI PERKHIDMATAN DALAM RANGKAIAN IP BERGERAK DENGAN ALGORITMA LALUAN PELBAGAI SALURAN PARAMETRIK BERDASARKAN KAEDAH PEMPROGRAMAN LINEAR

Oleh

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Kualiti perkhidmatan (QoS) adalah satu aspek yang penting dan ia menjadi bertambah sukar apabila kerumitan rangkaian IP bergerak diambilkira.

Dalam satu rangkaian IP bergerak, apabila satu nod bergerak, ia boleh terpisah dari nod-nod yang lain. Pergerakan nod inilah yang akan mengurangkan jalur lebar yang ada, mengurangkan kadar transmisi data dan meningkatkan kelewatan penyebaran. Isu-isu ini menjejaskan kecekapan jaringan dan ia memberi kesan yang ketara kepada prestasi Rangkaian IP bergerak dan penggunaannya. Dengan kata lain, pergerakan nod yang tidak terkawal dalam satu rangkaian IP bergerak membawa kepada kegagalan fungsi jaringan, dan pergerakan nod mudah-alih yang bukan optima dari jaringan asing kepada satu lagi jaringan asing membawa kepada peningkatan kependaman handoff.

Kajian ini akan menambahbaik kecekapan jaringan untuk memastikan kualiti perkhidmatan dalam rangkaian IP bergerak dengan cara meningkatkan kadar transmisi data, mengelakkan kegagalan berkomunikasi, dan mengurangkan kepen daman handoff. Kajian yang disarankan ini telah digunakan untuk mengoptima kadar transmisi data dengan mengawal pergerakan dan peralihan nod dalam domain terbatas, mengelakkan kegagalan komunikasi dengan cara menghalang nod dari keluar dari domainnya dan mengurangkan kependaman handoff dalam rangkaian IP bergerak.

Dalam pendekatan yang disarankan, untuk mengatasi isu-isudalam rangkaian IP bergerak apabila satu Nod bergerak, pemprograman linear parametric dan teori graf digunakan. Untuk mencapai kawalan mobiliti dalam Rangkaian IP bergerak, satu formulasi pemprograman linear baru untuk menjamin pengoptimaan transmisi data dan

keterkaitan jaringan disarankan. Pendekatan ini menetapkan parameter model-model pemprograman linear yang digunakan dalam algoritmaalgoritma lain dengan menggunakan satu elemen dinamik.

Algoritma yang disarankan dinilai dengan memberi pertimbangan kepada metrik yang berbeza, pemodelan komputasi, dan pengukuran simulasi. Keputusan simulasi menunjukkan peningkatan kadar transmisi data yang ketara yang lebih baik dari pendekatan penghalaan (routing) terdahulu dengan mengoptima model model pemprograman linear. Algoritma kawalan pergerakan nod yang dicadangkan mencapai peningkatan 31 peratus berbanding dengan HMIP dan FMIP. Tambahan lagi, algoritma Optimized Parametric Topology Control Routing menunjukkan prestasi yang jauh lebih baik dari Triangular Routing Method dan Change Foreign Agent Algorithm. Keputusan simulasi menunjukkan bahawa peningkatan adalah dalam bentuk pengurangan kependaman handoff sebanyak 50 peratus dalam senario-senario rangkaian IP bergerak yang berbeza**.**

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ACK	Acknowledgement
ATM	Asynchronous Transfer Mode
AxMN	Auxiliary Mobile Node
BGP	Border Gateway Protocol
CBR	Constraint Based Routing
CoA	Chosen Plaintext Attack
CoCoA	Colocated Care-of Address
CFAA	Change FA Algorithm
CN	Correspondent Node
DCA	Dynamic Channel Assignment
DiffServ	Differentiated services
DPST	Dynamic Priority Spanning Algorithm
FA	Foreign Agent
FACoA	Foreign Agent Care-of-Address
FMIP	Fast Mobile IP
HA	Home Agent
HMIP	Hierarchical Mobile IP
HoL	Handoff Latency
IBSS	Independent Basic Service Set
IEEES02.11	IEEE Standard for WLAN
IETF	Internet Engineering Task Force
IGMP	Internet Group Management Protocol
IntServ	Integrated Services
IP	Internet Protocol

IPV4	Internet Protocol Version 4
IPV6	Internet Protocol Version 6
ISO	International Organization for Standardization
ISOUMR	The input size of optimal unicast multichannel routing
GAN	Global Area Networks
GRE	Generic Routing Encapsulation
GRP	Greedy Randomized Procedure
LAN	Local Area Network
LD	Location Directory
LP	Linear Programming
LPF	Linear Programming Formulation
MAN	Metropolitan Area Network
MDF	Module Definition Form
MDF	Maximum Dynamic Flow
MEMS	Micro Electro-Mechanical Systems
MIP	Mobile IP
MH	Mobile Host
MN	Mobile Node
MANET	Mobile Ad Hoc Networks
MOSPF	Multicast Open Shortest Path First
nAR	new Access Router
NMCA	Node Movement Control Algorithm
oAR	old Access Router
OMMR	Optical Multicast Multichannel Routing
OPTCR	Optimum relative Termination Criterion for MIP

OSI	Open System Interconnection
OSPF	Open Shortest Path First
OUMR	Optimal Unicast Multichannel Routing
P2P	Peer-to-Peer
PAN	Personal Area Network
PESSP	Priority First Search fort Shortest Path
QoS	Quality of Services
RSVP	Resource Reservation Protocol
SAN	Small Area Network
STM	Synchronous Transfer Mode
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol-Internet Protocol
TE	Traffic Engineering
TRM	Triangular Routing Method
TU	Time Unit
UDP	User Datagram Protocol
UMCP	Unicast Multichannel Path
WAN	Wide Area Network
WinQSB	Windows Software
WLAN	Wireless Local Area Network

CHAPTER 1

INTRODUCTION

Today, by using Mobile IP, the connected devices to the network can keep the same IP address, stay connected, and maintain ongoing applications while roaming between IP networks. Considering that Mobile IP is scalable for the Internet as it is based on IP. Note that any media which can support IP, it can also support Mobile IP. In IP networks, routing and data transmission between nodes are based on stationary IP addresses. A device on a network (node) is reachable through normal IP routing by the IP address it is assigned on the network. Thus, we can expect that when a device roams away from its home network, it is no longer reachable by using normal IP routing.

The main important key of using Mobile IP is that it can enable users to keep the same IP address while traveling to a different network, ensuring that a roaming individual can continue communication without sessions or connections being dropped.

If in a Mobile IP network, one or more intermediate nodes are suddenly removed or failed, the path between them will be disconnected and the network efficiency will be decreased.

Therefore, we first study the intermediate node failure and changing foreign networks in Mobile IP networks when the Mobile Node (MN) moves. Second, we present a new optimal routing algorithm to control node failure. Throughout this chapter, the premise of the research is set by describing the research problem and defining the scope of the research. Furthermore, research background, motivations, objectives, and the contribution of this work are also presented.

1.1 Background and Motivation

In this thesis, we study the following concepts and methods to construct a new routing algorithm for a Mobile IP network in order to decrease the handover latency including node movement, Linear Programming, topology control, optimal routing, link state routing, unicasting, QoS assurance, data rate, graph theory, and network efficiency. To carry out the research, MATLAB, QSB, and Packet Tracer software are used to demonstrate the proposed algorithm, and to compare it with other available algorithms. By using Linear Programming in a Mobile IP network for topology control, there are many advantages that have not been exploited yet.

A large and growing body of literature has investigated the Mobile IP with different focus areas such as mathematical modeling and optimal routing techniques. For instance, several researchers have been focused on mathematical modeling which enhances the functionality of the current networks and innovating new network technologies to improve the existing services (Lee et al., 2011a; Pei et al., 2006; Mineno et al., 2011; Lee et al., 2016; Oki and Iwaki, 2010). The mathematical modeling for network improvements includes linear programming, fuzzy logic, graph theory, statistical modeling, and differential equations (Mineno et al., 2011; Lee et al., 2016; Heydarian, 2012a; Oki and Iwaki, 2010).

These particular methods are a useful concept which applies to traffic engineering. However, it is important to note that the individual algorithms cannot solve all associated problems and solutions related to networks. This means that other proposed algorithms which have been presented in related work can only be applicable for certain problems, and might not be able to address all the problems.

By considering the previous studies, we apply linear modeling to resolve the problem herein in the context of the multicast protocol. The importance of studying into multicast protocol is because of its application in real-time services, which requires high QoS. The investigations that are carried out in this thesis can be categorized into the following:

1. Mathematical modeling: The aim of conducting mathematical modeling is to optimize the network resources, services, and functions by establishing specific optimal paths. As described in the previous section, linear programming and graph theory are applied in the present research to solve problems in the Mobile IP networks. By adopting these methods, the obtained linear model is proven to be accurate in general, provides a multi-angle solution, and optimal output. The rendered solutions are completely based on concepts and theorems of linear programming. The resources allocation of the network-to-data transmission sessions and real-time applications are conducted based on the optimal linear model.

2. Routing and data transmission: The obtained optimal solution consists of some connections and nodes, which usually can be extracted from established routes. However, there is a need for a new algorithm that can compute in reduced time and low complexity to allocate optimal solution for routes and sessions of a network to enable resource allocation in a short time. Therefore, resource allocation algorithm with polynomial time characteristics is proposed. The algorithm for resources allocation is formulated using a mathematical approach to form certain structures and precise mathematical arguments. During the development of this algorithm, the features of reduced computation time and low complexity are designed based on specific rules and theorems of, particularly integrated algorithms. Hence, the benefit of these integrated algorithms will be demonstrated. The proposed algorithm is tested for comparative analysis in a service at different instances of a network and compared alongside with other readily available algorithms.

The experimental results are based on the computer simulation, and the results are expressed both in the forms of numerical and theoretical aspects. Note that the theoretical calculations and computer simulations are provided by QSB, MATLAB, and Network Simulator software. Note that using MATLAB has several advantages over other methods or languages. For instance, its basic data element is the matrix. A simple integer is considered an matrix of one row and one column. Several mathematical operations that work on arrays or matrices are built-in to the Matlab environment. However, the main reason of using MATLAB in this thesis is the simplicity of Matlab's functionality which can be greatly expanded by the addition of toolboxes such as Mixed-integer linear programming (MILP) solver.

1.2 Problem Statement

In a mobile IP network, nodes move randomly and are able to commute between different domains (Lee et al., 2011b; Liu and DiGrande, 2013; Pei et al., 2006; Liu et al., 2016). Although guaranteeing of efficient node mobility without missing QoS criteria is one of the open research challenges, current solutions are not able to thoroughly address all problems related to the node mobility control issue. Therefore, to provide an efficient mobile IP network, these three major problems, optimality failure, communication failure, and handoff latency, should be solved.

1. **Maintain the Optimality of Data Transmission:** When a mobile node (MN) in a Mobile IP network moves, it may go away from other nodes. One of the essential challenges in mobile IP networks is keeping mobility robustness without missing the optimality of data transmission rate. In Mobile IP networks, node movement can decrease data delivery and handoff latency which reduce the network efficiency (Sadhukhan et al., 2013). Furthermore, node movement can violate the optimality of the data transmission rate which can waste the bandwidth and network resources. One of the most relevant existing solutions for providing acceptable data transmission rate over mobile IP networks is Optimal Multicast Multichannel Routing Algorithm that does not provide an optimal mobility range for every single mobile node (Isazadeh and Heydarian, 2008a) and the mentioned deficiency leads to data transmission rate reduction (Heydarian, 2012a). Thus, we introduce an independent parameter that plays a critical role in finding an optimal domain of mobile node movement (valid mobility range) that guarantee the optimization of data transmission rate. This parameter is used to establish a novel routing algorithm that control the node mobility through computing a node movement domain that guarantee an efficient data transmission rate between nodes.
2. **Provide an Optimal Routing Algorithm to Control Mobility of Mobile Nodes:**
   Random node movements in a Mobile IP network can cause network failure. Therefore, the node mobility and shifting of the nodes must be controlled (Tuncer et al., 2013a). The most prevalent method for controlling mobile nodes' movement and avoiding communication failure are Fast Mobile IP (FMIP) and Hierarchical Mobile IP (HMIP) that suffer from two major weaknesses, the first

one is the limitation of scalability of the home network, and the second one is the unavailability of the multichannel routing algorithm (Heydarian, 2012a). Therefore, proposing an optimal multichannel routing algorithm that supports expanding mobility range of nodes provides a reliable and fast network communication. Thus, we introduce a novel multichannel routing algorithm that not only provides an optimal bound of a node movement and transmits data units more rapidly but also moves stationary nodes instead of those nodes which must be stopped that prevents communications failure in a mobile IP network.

3. **Reduce the Handoff Latency**
   When a host or a mobile node exits from home or foreign network, its point of attachment in the mobile network will be changed. This process is called handoff. In a Mobile IP network, when some intermediate nodes fail or are suddenly removed, the links between nodes will be disconnected, and the Handoff Latency (HoL) will be increased. As a result, the network efficiency will be decreased due to the loss of some packets (Tuncer et al., 2013a; Chuang and Lee, 2013a; Zhao et al., 2016). In this case, the movement of the remaining nodes must be controlled to prevent further network efficiency drop. Triangle Routing Method (TRM) as one of the current solutions for decreasing handoff latency depends on the length of the path between mobile nodes. On the other hand, all functions of this method, discovery, registration, and tunnelling are dependent on the length of the paths. In other words, when the size of the network will be expanded, the length of the paths between nodes will be enlarged. Consequently, the HoL will be increased. In this thesis, we propose a novel multichannel routing algorithm which uses a parameter that is able to predict the mobile nodes movement to reduce the handoff latency and number of used links to transmit data in mobile IP networks.

1.3 Research Objectives

To improve the mobile IP network performance by deploying mobile nodes, the objectives of this thesis can be summarized as follows:

1. To propose a new parametric optimal multicast and multichannel routing algorithm that computes a domain for a mobile node which is able to hold the optimality of data transmission and prevent network efficiency failure. Our new algorithm is based on the linear programming formulation and presents an optimal path for transmitting data from a mobile node to another mobile node using multiple single paths. In addition, it computes the maximum bound of Ω until optimal data delivery is stable. In our new algorithm, the Ω is considered as a parameter and plays an important role in controlling the mobility of mobile nodes.

2. To propose an enhanced version of parametric optimal multicast multichannel routing algorithm that spreads the mobility domain of a home network in order to prevent a mobile node join a foreign network and keep connectivity that lead to reduce the handoff latency and avoid communication failure. In this mobility

control algorithm, to maintain a stable link between nodes, the stationary nodes are moved instead of mobile nodes that should be stopped. Furthermore, by providing a multichannel path between nodes, if some single channel paths are dropped, the data transmission between nodes is keep remained using the other reminder single channel paths.

3. To propose a new optimal routing algorithm for controlling node failure and changing foreign networks in mobile IP networks when the mobile node moves through a linear programming approach to reducing the handoff latency. The new algorithm is based on a parametric post-optimality routing method for recomputing defected unicast multichannel paths for retransmitting data between nodes and preventing more handoff latency. In our new algorithm, we apply the parameter Ω on the optimal unicast multichannel algorithm formulation to measure the coordinates of the location of mobile nodes.

1.4 Research Scopes

This thesis focuses on the following scopes in order to solve the addressed problems in the previous section.

- Designing, constructing and presenting formal methods for achieving the optimal communication algorithms. To enable data transmission via mathematical models of network topology and nodes, new algorithms are designed based on linear programming and graph theory;
- To avoid network breakdowns, to innovative and efficient routing algorithms, with specific focuses on the QoS, virtual routes, and connection based services. Furthermore, the traffic engineering is conducted dynamically in the Mobile IP network via constrained-based routing techniques;
- Minimizing and maximizing network functionalities to produce better results in the Mobile IP networks.

A high-performance computer with mathematical tools is required to realize the solutions for problems 1, 2, and 3. Also, the high-performance computer is necessary due to the application of linear modeling and the usages of multicast and multichannel states.

Furthermore, in this research work, the optimal data transmission models, constrained routing techniques, MATLAB, QSB and OPNet software are also required. It is important to realize the proposed theories as the optimal solution to solve problems, the required tools and software are essential to conducting the computations and simulations

1.5 Contributions

The main contribution of this thesis can be explained as follows:

1. A new dynamic element is combined with parametric linear programming via Simplex and other software tools to create a control algorithm for dynamic nodes;
2. To achieve optimal mobility and connectivity in a network, formulations of the network resources (links, nodes, and bandwidths) and the topology components (node movements and nodes/links failure) are conducted as part of the parametric linear programming and graph theory approach;
3. A construction of new optimal dynamic routing algorithms for routing and also efficient handover with low latency between FA to FA in a Mobile IP network;

1.6 Thesis Organization

This thesis is organized into seven different chapters. Chapter One gives the introduction to the research work. It states the study research background, problems that arise in the Mobile IP network and node movement when users are transferring data that derive this research to be conducted, the scope of research, the methodology used, and the contributions of this study. The rest of this thesis is organized as follows:

- **Chapter2,** presents the background and the review of theliterature, studying terminologies, existing algorithms, and significant challenges in the area of Mobile IP networks including routing protocols;
- **Chapter 3,** presents the implementation of research framework and the methodology of this thesis such as problem formulation, and previous approaches and models;
- **Chapter 4,** proposes our new algorithm to achieve optimal data transmission in Mobile IP networks by managing mobility, connectivity, and topology control.
- **Chapter 5,** In this chapter, we present our approach to control the node movement and altering the FAs in Mobile IP networks by optimally managing the topology control via our new algorithm.
- **Chapter 6,** presents our new Optimal Dynamic Routing Algorithm (OPTCR) algorithm to solve the two main critical problems in Mobile IP network. The first significant issue is a latency while dynamic nodes are doing handover or moves. The second challenge is a lack of efficiency in current routing algorithms for dynamic nodes.
- **Chapter 7,** summarizes the major contributions of this thesis and finally, we will suggest the directions for the future work of this thesis.

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