UNIVERSITI PUTRA MALAYSIA

PERFORMANCE ANALYSIS OF SWARM INTELLIGENCE-BASED ROUTING PROTOCOL FOR MOBILE AD HOC NETWORK AND WIRELESS MESH NETWORKS

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By

AYYOUB AKBARI MOGHANJOUGHI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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To my wonderful parents, Jamal & Saadat

...who have raised and encourage me to be the person I am today

To my lovely Sisters, Maryam and Shabnam

...for all the unconditional love, guidance, and support

To my Kindest wife, Atefeh

...in all love, humility, and gratitude

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman: **Associate Professor Sabira Khatun, PhD**
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Ant colonies reside in social insect societies and maintain distributed systems that present a highly structured social organization despite of the simplicity of their individuals. Ants' algorithm belongs to the Swarm Intelligence (SI), which is proposed to find the shortest path. Among various works inspired by ant colonies, the Ant Colony Optimization (ACO) metaheuristic algorithms are the most successful and popular, e.g., AntNet, Multiple Ant Colony Optimization (MACO) and AntHocNet. But there are several shortcomings including the freezing problem of the optimum path, traffic engineering, and to link failure due to nodes mobility in wireless mobile networks.

The metaheuristic and distributed route discovery for data load management in Wireless Mesh Networks (WMNs) and Mobile Ad-hoc Network (MANET) are fundamental targets of this study. Also the main aim of this research is to solve the freezing problem during optimum as well as sub-optimum path discovery process. In this research, Intelligent AntNet based Routing Algorithm (IANRA) is presented for

routing in WMNs and MANET to find optimum and near-optimum paths for data packet routing. In IANRA, a source node reactively sets up a path to a destination node at the beginning of each communication. This procedure uses ant-like agents to discover optimum and alternative paths. The fundamental point in IANRA is to find optimum and sub-optimum routes by the capability of breeding of ants. This ability is continuation of route that was produced by the parent ants. The new generations of ants inherit identifier of their family, the generation number, and the routing information that their parents get during their routing procedure. By this procedure, IANRA is able to prevent some of the existing difficulties in AntNet, MACO and Ad hoc On Demand Distance Vector (AODV) routing algorithms.

OMNeT++ was used to simulate the IARNA algorithm for WMNs and MANET. The results show that the IANRA routing algorithm improved the data packet delivery ratio for both WMNs and MANET. Besides, it is able to decrease average end-to-end packet delay compared to other algorithms by showing its efficiency.

IANRA has decreased average end-to-end packet delay by 31.16%, 58.20% and 48.40% in MANET scenario 52.86%, 64.52% and 62.86% by increasing packet generation rate in WMNs compared to AntHocNet, AODV and B-AntNet routing algorithms respectively with increased network load. On the other hand, IANRA shows the packet delivery ratio of 91.96% and 82.77% in MANET, 97.31% and 92.25% in WMNs for low (1 packet/s) and high (20 packet/s) data load respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master of Sains

ANALISIS PRESTASI KECERDASAH KAWANAN BERASASHAH PROTOKOL PENGHALAAH UNTUK RANGKAIAN AD HOC MUDAH ALIH DAN JEJARING TANPA WAYAR

Oleh

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Koloni semut terdapat dalam masyarakat sosial serangga dan mengekalkan sistem teragih di mana ia mengetengahkan sebuah organisasi yang berstruktur tinggi walaupun mengamalkan kesederhanaan secara individunya. Algoritma semut hasil adalah di kalangan Kecerdasan Kawanan (SI), di mana ia mencadangkan laluan yang paling singkat. Antara teknik-teknik yang diilhamkan dari koloni semut ini, algoritma metaheuristik Pengoptimuman Koloni Semut (ACO) adalah yang paling berjaya dan digemari, contohnya AntNet, Pengoptimuman Koloni Semut Pelbagai (MACO) dan AntHocNet. Namun terdapat beberapa kelemahan termasuk masalah penyejukbekuan terhadap laluan optimum, imbangan muatan, dan untuk menyambung pautan terputus disebabkah oleh pergerakan nod dalam rangkaian mudah alih tanpa wayar.

Penemuan hala yang metaherustik dan teragih untuk imbangan muatan dalam Rangkaian Jejaring Wayarles (WMN) dan Rangkaian Ad-hoc Mudah Alih (MANET) adalah tumpuan utama dalam kajian ini. Juga tumpuan utama kajian ini adalah untuk

menyelesaikan masalah penyejukbekuan semasa pengoptimuman serta proses penemuan hala yang sub-optimum. Dalam kajian ini, Algoritma Penghalaan berasaskan AntNet Cerdik (IANRA) telah dilaksanakan bagi penghalaan dalam WMN dan MANET untuk mencari halaan yang optimum dan menghampiri optimum bagi penghalaan paket data. Dalam IANRA satu nod sumber membina laluan ke nod destinasi secara reaktifnya pada permulaan setiap komunikasi. Prosedur ini menggunakan ejen-seperti-semut untuk menemui laluan yang optimum dan alternatif. Aspek asas dalam IANRA adalah untuk mencari hala yang optimum dan sub-optimum dengan keupayaan pembiakan semut. Keupayaan ini adalah sambungan hala yang dihasilkan oleh semut induk. Generasi semut yang baru mewarisi pengenalpasti keluarga mereka, bilangan generasi dan maklumat penghalaan yang diterima oleh induk mereka semasa prosedur penghalaan. Dengan prosedur ini, IANRA berupaya menghindari kesulitan-kesulitan sedia ada dalam algoritma penghalaan AntNet, MACO dan Vektor Jarak Atas Permintaan Ad hoc (AODV).

OMNeT++ telah digunakan untuk mensimulasikan algoritma IARNA bagi WMN dan MANET. Hasil kajian menunjukkan algoritma penghalaan IANRA meningkatkan nisbah penghantaran paket data bagi kedua-dua WMNs dan MANET. Tambahan pula, ia berupaya mengurangkan kadar purata lengah hujung ke hujung dengan mengekalkan sokongan mutu perkhidmatan berbanding dengan algoritma yang lain dengan menunjukkan kecekapannya.

IANRA mengurangkan kadar purata lengah paket hujung ke hujung dengan 31.16%, 58.20% dan 48.40% dalam senario MANET 52.86%, 64.52% dan 62.86% dengan meningkatkan kadar pengeluaran paket dalam WMNs berbanding algoritma

penghalaan AntHocNet, AODV dan B-AntNet dengan muatan rangkaian yang tinggi. Namun IANRA menunjukkan nisbah penghantaran paket 91.96% dan 82.77% dalam MANET, 97.31% dan 92.25% dalam WMN bagi muatan data rendah (1 paket/s) dan tinggi (20 paket/s).

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APPROVAL

I certify that a Thesis Examination Committee has met on September 11, 2009 to conduct the final examination of Ayyoub Akbari Moghanjoughi on his thesis entitled "Performance Analysis of Swarm Intelligence-Based Routing Protocol for Mobile Ad Hoc Network and Wireless Mesh Networks" in accordance with the universities and university colleges Act 1971 and the constitution of the Universiti Putra Malaysia [P.U. (A) 106] March 15, 1998. The Committee recommends that the candidate be awarded the Master of Science.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

_____

AYYOUB AKBARI MOGHANJOUGHI

Date: 2 December, 2009

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LIST OF ABBREVIATIONS

ACO	*Ant Colony Optimization*
AODV	*Ad-hoc On Demand Vector*
AP	*Access Point*
ARS	*Agent-based Routing Algorithm*
BA	*Backward ant*
CBR	*Constant Bit Rate*
DSDV	*Destination-sequenced Distance Vector*
DSR	*Dynamic Source Routing*
DSSS	*Direct Sequence Spread Spectrum*
FA	*Forward ant*
FHSS	*Frequency-Hopping Spread Spectrum*
FSK	*Frequency Shift Keying*
IANRA	*Intelligent AntNet based Routing Algorithm*
IN	*Intermediate nodes*
LFM	*Link Failure Message*
LTS	*Local Traffic Structure*
MAC	*Medium Access Control*
MACO	*Multicast Ant Colony Optimization based Routing*
MANET	*Mobile Ad-hoc Network*
MF	*Mobility Framework*
MIMO	*Multiple-Input and Multiple-Output*
mN	*Mobile Node*
MR	*Mesh router*
OFDM	*Octagonal Frequency-Division Multiplexing*
PSK	*Phase Shift Keying*
QAM	*Quadrature Amplitude Modulation*

QoS	*Quality of Service*
RREP	*Route Reply*
RREQ	*Route request*
RRRA	*Reactive Route Repair Ants*
S-ACO	*Simple Ant Colony Optimization*
SI	*Swarm Intelligence*
TTL	*Time To Live*
Wi-Fi	*Wireless Fidelity*
WiMAX	*Worldwide Interoperability for Microwave Access*
WMNs	*Wireless Mesh Networks*

LIST OF SYMBOLS

$\mathcal{P}_{\mathbf{O.P}}$	Optimum path
$\mathcal{P}_{\mathbf{N.O}}$	Non-Optimum path
$\mathfrak{R}_{O.P}$	Optimum route
$\mathfrak{R}_{N.O}$	Non-Optimum route
l_l	Length of longest path
l_s	Length of shortest path
r	Length ratio
$\mathbf{P}_{i\gamma}(t)$	probability of the ant arriving at destination
$\varphi_{i\gamma}(t)$	total amount of pheromone on the path from node i by γ generation of FA
μ	number of ants cross the path per second
$\rho_{j,i}$	probability of choosing the route when ant arrive from node *i* to node *j*,
$\Delta\rho$	Effect of ant movement at the entrance of probability table
$\aleph_i^k$	The neighbourhood of ant$k$ when in node i.
F_d^s	Forward ants from source node to destination
$\mathbf{P}_{nd}$	The probability of next hop selection by artificial ants
t	Service time per node
x	Travelling time of FAs on the selected path
$\mathcal{B}_{jd}^i$	Boostrapped pheromone from i to d via adding cost of hopping from i to j
$\mathcal{V}^i$	Virtual pheromone table for node i

CHAPTER 1

INTRODUCTION

1.1 Background

Wireless and mobile communication networks have allured significant interests in recent years because of their raised flexibility and minimization of costs. Wireless networks have unique characteristics compared to wired networks. In this case nodes mobility may cause topology changes frequently. Mentioned changes in topology of wireless networks might occur between the wireless devices or mobile nodes and wired access points (Base Station). Therefore mobile network can be classified into infrastructure less (without base station) and infrastructure base (defined coverage area with access point) networks.

In order to facilitate communication within wireless networks and to provide better load management, usually routing protocols are used to discover routes and manage the network flow congestion among nodes in a network. Hence for mobile networks, design of a routing protocol is a major technical challenge due to the dynamism of the network. Currently there are many routing algorithms which are proposed to find shortest path for data transmission, but only few of them support quality of service requirements in network.

The multi-path routing protocol is to perform better load management and to provide high fault tolerance. Multiple paths are selected between source to destination and

packets flow in one of these selected paths. Whenever this path is broken due to channel quality or mobility, another path in the set of existing paths can be chosen. Among multi-path based routing algorithms, Ad-hoc On Demand Vector (AODV) is popular algorithm [Mir 2006]. AODV is improvement of Destination-sequenced Distance Vector (DSDV). AODV establishes a required route only when it is needed as opposed to maintaining a complete list of routes, with DSDV. Another successful example of multi-path routing algorithms for wireless networks is known as AntNet that is a direct extension of the Simple Ant Colony Optimization (SACO) algorithm. AntNet is even closer to the real ant colonies behaviour that inspired the development of the ACO metaheuristic than the ACO algorithms for Nondeterministic Polynomial-time hard ($\mathcal{NP}$ -hard) problems. In real ants' behaviour, they initially explore the area surrounding their nest in a random manner for searching food. During the trip, the ant deposits a chemical pheromone trail on the travelling path. The concentration of pheromone deposited on paths, are increased by selection probability by ants as usual.

Here, focus is given to solve the route freezing problem in AntNet algorithm and fair bandwidth allocation to data transmission by applying several kinds of intelligent mobile agents (artificial ants) and decrease path discovery duration by ants breeding strategy. In this case simple definition of Genetic Algorithm (GA) is utilized to choice the best fitness of travelled paths information. Selected information is transferred to new generated agents through parent ants. The algorithm can be able to detect optimum path to next hop. In this research the new routing algorithm, IANRA is applied to two kind of wireless networks which are Wireless Mesh Networks (WMNs) and Mobile Ad-hoc Networks (MANET).