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AN INVESTIGATION AND SIMULATION OF NOVEL DYNAMIC ROUTING METHODS

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Routing in networks is a multi-objective and multi-constraint optimization problem due to the nature of current networks being highly dynamic environments. Currently implemented solutions are single metric solutions where instead an optimal multi-metric solution is needed to solve this problem. This research work investigates novel multi-metric solutions to this optimization problem. Recently, it is found that the employment of a natural optimization process called the ant colony optimization process to the routing problem, resulted in a multi-metric dynamic solution. Latest research work reported two slightly different implementations of this employment. Network agents are used to sensor the status of the network and feedback the network nodes with the necessary information. This is used to update its routing tables based on the network status. These two implementations differ in the method (philosophy) used to update the information in the routing tables held by the network nodes. This research work suggests a new method to update the routing tables held by the nodes in the network. This done by merging modified versions of the previous two methods in order to overcome the disadvantages of each.

A discrete event simulation system is built to test the routing method suggested by this research work together with the previous two routing methods for

comparison purposes. This simulation system represents a prototype for the development of a general network simulation tool. It is capable of collecting various types of simulation statistical data and generating tracing files for detailed studies of the network and for testing purposes. An expandable structured C-pointer based implementation is used to code the system.

The system is tested on various networks and the results of the simulation show improvements on the performance of the network by reducing the overall delay in the network and increasing throughput. Moreover, the use of the suggested routing method results in balancing the load in the network.

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

PENYIASATAN DAN SIMULASI MENGENAI KEBAHARUAN DALAM ALGORITMA PENGHALAAN DINAMIK

Oleh

MOHAMMAD SALEH MUSTAFA

Jun 2001

Pengerusi: **Prof. Madya Abdul Azim Abdul Ghani, Ph.D.**
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Penghalaan dalam rangkaian adalah multi-objektif dan multi-kekangan dalam masalah pengoptimasasian kerana sifat dalam rangkaian semasa bercorak kearah persekitaran yang sangat dinamik. Ketika ini, implementasi penyelesaiannya mempunyai satu metrik tetapi ia memerlukan metrik-multi yang optimal dalam menangani masalah ini. Penyelidikan ini mengkaji kebaharuan dalam penyelesaian metrik-multi dalam masalah pengoptimasasian ini. Setakat ini, penggunaan proses semulajadi pengoptimasasian yang dipanggil proses pengoptimasasian koloni semut, didapati memberikan satu penyelesaian metrik-multi yang dinamik. Hasil kajian penyelidikan yang terbaru, telah melaporkan dua implementasi yang agak berbeza untuk kaedah ini. Agen rangkaian telah digunakan untuk mengesan status rangkaian dan memberikan maklumat tindak balas untuk nod rangkaian bersama maklumat yang diperlukan. Ini digunakan untuk memperbaharui jadual penghalaan yang berdasarkan status rangkaian. Kedua-dua perlaksanaan ini berbeza dari segi kaedah (falsafah) yang digunakan untuk memperbaharui maklumat dalam jadual penghalaan, yang dipegang oleh nod-nod rangkaian. Kajian penyelidikan ini mencadangkan kaedah terbaru dalam memperbaharui jadual penghalaan yang dipegang oleh nod

dalam rangkaian. Ini dilaksanakan dengan menyatukan versi yang diubah bagi kedua-dua kaedah terdahulu untuk menyelesaikan kelemahan mereka.

Satu sistem simulasi berkeadaan diskrit dibina untuk menguji kaedah penghalaan yang dicadangkan dalam kajian ini, bersama-sama dengan kedua-dua kaedah yang terdahulu untuk keperluan perbandingan. Sistem simulasi ini mempamerkan satu prototaip untuk pembangunan peralatan simulasi rangkaian yang umum. Ia berupaya mengumpul pelbagai jenis data statistik simulasi dan menghasilkan fail pencarian untuk satu kajian yang lebih mendalam dalam rangkaian dan untuk kegunaan pengujian. Satu perlaksanaan yang mempunyai struktur petunjuk-C yang mampu dikembang, digunakan untuk mengkod sistem ini.

Sistem ini telah diuji untuk pelbagai rangkaian dan hasil simulasi ini, telah menunjukkan peningkatan dalam prestasi rangkaian dengan mengurangkan kelewatan keseluruhanannya dalam rangkaian dan meningkatkan hasilnya. Tambahan pula, penggunaan kaedah penghalaan yang dicadangkan ini, boleh menghasilkan beban yang sama rata dalam rangkaian.

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CHAPTER 1

INTRODUCTION

1.1 General Overview

Routing in a highly dynamic network environment presents interesting challenges. As a multi-objective, multi-constraint optimization problem, routing is a rich area for research and the evolution of networking technologies constantly reveals new opportunities for routing research and development. Although routing techniques designed for older technologies have sometimes proven adequate for newer techniques, novel routing approaches are often required (Steenstrup, 1995).

Routing is defined as a network function that directs user traffic from source to destination(s) in accordance with the traffic's service requirements and the network's service restrictions (Steenstrup, 1995). Or as an indispensable telecommunication network function that connects a call from an origin to destination(s), and is at the heart of the architecture design, and operation of any network (Ash, 1998). Even though the goal of routing is described by these simple words, achieving the task involves complex designs and procedures. In fact, routing is a complex system that consists of distinct yet interdependent procedures shaped by potentially conflicting objectives, including maximizing network performance while minimizing the cost of resources in the network, constrains imposed by the in use switching technology, the network services provided, and the user services requested.

The kind of routing algorithm to be implemented in a network strongly depends on the nature of that network, which includes the network type, technologies in use, services provided, the rate of dynamism in the network, and many other factors. However, regardless of any particular kind of routing algorithm to be used, it must support the following core basic routing function:

- Assembling and distributing network traffic information.
- Based on user and network state information, generating and selecting routes that are feasible, that satisfy all the user- and network-imposed service constrains, and usually optimal, that are best with respect to a specific performance objective.
- Forwarding the user traffic on the selected routes.

In the design stage of a routing system one should keep in mind that routing is an integrated part of the network system which means, interdependent relationship between routing and the other parts of the system like network flow control, user traffic, ..., etc. that affects both must be considered.

Network design and management are tied up with network routing. Figure 1.1 shows a network model for both. Network design and management functions include real time traffic management, capacity management, and network planning. Real time traffic management insures that network performance is maximized under all conditions including load shifts and failures. It provides monitoring of network performance through collection and display of real-time traffic and performance data, and it allows traffic management controls such as code blocks, call gapping, and reroute controls to be used by network managers when circumstances warrant.

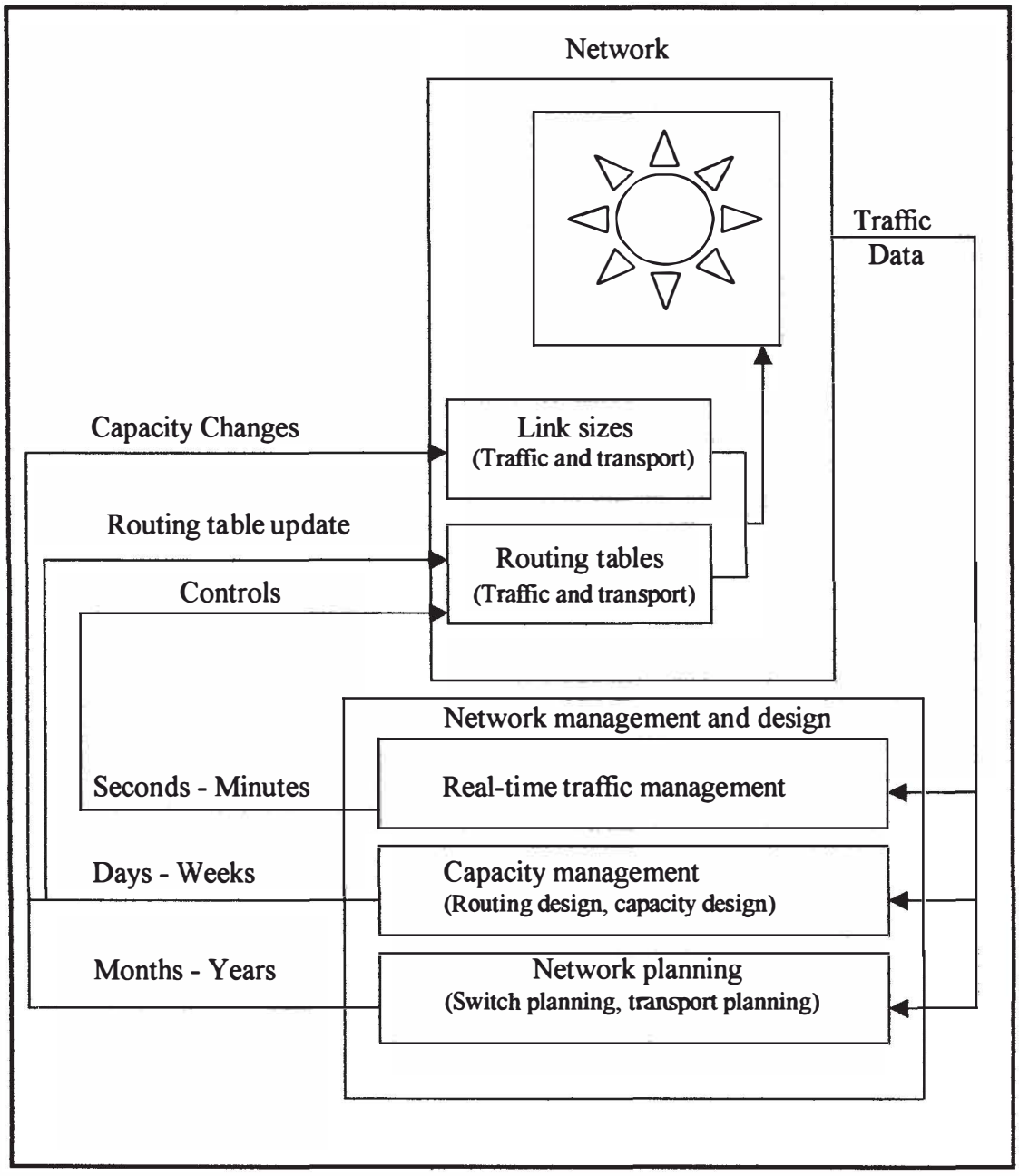

Figure 1.1: Network routing, management and design

Capacity management ensures that the network is designed and provisioned to meet performance objectives for network demands at minimum cost. Network planning ensures that switching and transport capacity is planned and deployed in advance for forecasted traffic growth. These three functions interact as feedback

loops around the network to regulate the service provided by the network through network management controls, capacity adjustments, and routing adjustments.

Generally, all network routing systems respond to the network state changes, however, they do differ in the type of state changes to which they respond and in the speed of their responses. Depending on the kind of response and the speed at which the routing system respond to network state changes, a routing system can be classified as static, quasi-static or dynamic. Static routing is based on expected user and network behaviors, and for this reason routing is an integral part of the network design. This type requires almost no computational resources in the network since it involves no real-time activities except forwarding traffic. If a static routing system is capable of modifying traffic routing in response to exceptional events (such as switch or link failures) or at relatively long time intervals, then it is called a quasi-static routing system.

On the other hand, a dynamic routing system computes routes on demand not only depending on link and switch states, but also on other entities within the network to measure user, resource availability and traffic and network performance as a whole.

The increase use of multimedia personal computers featuring the latest accessories as a result of the continuous revolutions in computing combined with the globally accessible networks, lead to having a large and growing user community with demands for sophisticated communication services. The requirements of these user services can be characterized as low-cost, high quality and distributed

multimedia services. These requirements were addressed by the telephone service providers by developing new technologies such as the Broadband Integrated Services Digital Networks (B-ISDN) to support the multimedia services demanded by the users. Telephone service providers also began to adopt dynamic routing strategies instead of adopting centralized, quasi-static traffic routing strategies to increase the call capacity and robustness in a cost effective manner. On the other hand, the number one environment for the users world wide, the Internet, adopting dynamic routing strategies providing best-effort traffic handling with no service guarantees is now being directed to provide service guarantees, reliable manageable and secured routing strategies.

1.2 Statement of Problem

Ultimately, global user interconnectivity will not be provided by a single homogeneous networking substrate. Instead, multiple independently managed, interconnected service providers offering different services and using different switching technologies will almost certainly provide it. The principle problem for a routing system operating in such an environment will be efficient distributions, management, and synthesis of the large volume of diverse information used in routing traffic across the internetwork. In fact, this is likely to be one of the most challenging communications problems posed by the large, heterogeneous, and dynamic internetworks of the future (Steenstrup, 1995).

Currently, present routing methods use a single dynamic metric and static multi-metric information for finding the shortest path between two nodes in the network. A Dynamic multi-metric routing method is required to consider different

parameters affecting the choice of a route in the network. In other words, there is a need to compute paths in a network using dynamic link metrics. Dynamic link metrics could be cost metrics that depend on a link dynamic state, e.g., congestion on the link. On the other hand, the required new routing method, compared to current methods, has to maintain high performance under different network loads.

1.3 The Methodology

A research focusing on routing methods was conducted and it was found that a dynamic and distributed multi-metric method exists and being used in front of our eyes by very simple yet cooperative insects in the nature, ants. In fact a natural optimization process named after the ants called the ants optimization process translates the natural process obtained from the study of real ants to an optimization process that can be applied to solve many continuous and combinatorial problems. One of these problems is the famous shortest path problem solved by applying a system called the ants system derived from the ant optimization process. The ant system is a generalized and problem dependent system.

A variation of the ant system is used to implement dynamic routing for telecommunication networks in which two different methods for updating the routing tables are used in these implementations. The first method used was the epochal method while the second is the incremental method (see Chapter 4). In the two cases, the results showed improvement on the network performance compared with the routing methods currently used. The research focuses on studying these methods, and looking for any applicable improvements. As a result of that, a new method that combines the epochal and incremental methods into one method where they work

simultaneously is suggested. This research work then creates a simulation system to test these three methods for comparison.

1.4 Scope of the Thesis

The scope of this thesis is investigating current routing algorithms employed in packet-switched networks and looking for problems associated with the field, in particular, the need of a dynamic multi-metric routing method that maintains its performance under different network traffic loads. The scope of this research work is then extended to the study of the performance evaluation of network routing method using simulations.

Consequently, the research work of this thesis is conducted in the area of network routing and simulations. More precisely, packet-switched routing techniques and their performance study using discrete-event simulations.

1.5 Objectives of the Thesis

The main objectives of this thesis are:

- To propose a new dynamic routing method that improves network performance and overcomes the problems associated with routing in telecommunication networks.
- To create a simulation system and use it to test the suggested routing method together with other routing methods for comparison purposes.

These objectives are achieved through the different stages of this research work and are documented in the chapters of this thesis.

1.5 Outline of the Thesis

The thesis consists of six chapters of which this is the first chapter. A comprehensive literature about traffic flows and routing in telecommunications networks is presented in chapter 2. This includes a classification of the different types of routing algorithms, a brief description of each category and some of its implementation examples focussing more on dynamic routing systems.

Chapter 3 introduces a theoretical background about a new optimization process that is inspired from the intelligence created in very simple individuals of insects in the nature that are ants. The material includes literature on the study of these insects and the principle of stigmergy. The amazing method that ants use to solve the shortest path problem is introduced. The chapter also includes the related literature to a novel optimization process (the ant colony optimization process). A discussion of the different versions of the resultant ant colony system is presented. The different implementations of the ant colony system applied to various continuous and combinatorial problems are listed. Finally the chapter ends with introducing the implementations of the ant colony system applied to telecommunications networks.

Chapter 4 has two main parts:

- Applying the ant colony system to the problem of dynamic routing: in this part a new updating method to the information in the routing tables is adopted. The new method is the result of merging two previously applied methods called epochal updating and incremental updating methods. The resultant method is called For/Backward updating method.

- The architecture, design and implementation of a simulation system to simulate dynamic routing using the above mentioned methods. The discussion includes a description of the components of the system, the system's input and the simulation process through presenting the main functions involved using text, pseudocode and flowcharts whenever needed. The chapter ends with presenting the different types of the system's output.

The simulation system is used to simulate different networks with different combinations of routing updating methods, traffic patterns, and geographical traffic patterns. Some of the results are their discussion are presented in Chapter 5.

Finally, Chapter 6 includes a general summary of the thesis and its conclusions. The chapter is ended with a long list of suggested future work for which a research work can be established.