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Genetic Adaptive Routing Algorithms for Computer Networks

A Thesis Submitted to the Computer Engineering Department
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Degree of
Master of Science in Computer Engineering

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DECLARATION

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ABSTRACT

Traffic routing in computer communication networks is one of the challenging optimization problems. A routing algorithm is employed by a routing strategy that must meet conflicting, independent requirements to select the path from an origin to a destination. A large number of strategies have evolved, two key-strategy categories are the static (fixed) and the dynamic (adaptive) routing.

In this thesis, a new taxonomy of routing is presented and a new scheme of adaptive routing algorithms based on the artificial genetic algorithms is proposed and named the genetic routing algorithms (GRAs). In GRAs traffic is routed by the application of a set of genetic operators that constitute a method to find the least cost route and most-to-all of the alternative routes between a source node and a destination node in a computer network.

Three algorithms are developed which are the Genetic Adaptive Routing Algorithm (GARA) for computer networks, the Synchronous Parallel Genetic Routing Algorithm (SPGRA) for computer networks, and the Asynchronous Parallel Genetic Routing Algorithm (ASPGRA) for computer networks.

Finally results and conclusions, obtained from the simulation programs written using the Borland® C™*, show that the proposed genetic routing algorithms can be used successfully to handle the routing problem. They give attractive adaptive performance that is better than existing methods for networks of moderate number of nodes where all alternative routes can be found.

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INTRODUCTION

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1.1 The Computer Communication Network

The 1970s and early 1980s saw a merger of the fields of computer science and data communications that profoundly changed the technology, products, and companies of the now combined computer-communications industry [1].

A computer communication network is a system that configured by a set of centers and a set of communication links connecting centers. The system configuration can be represented mathematically by a graph as in Figure (1.1), with centers are represented by nodes and edges are represented by links [2].

Fig. (1.1): Links and nodes symbols.

In communication world, any network must continuously grow to meet increasing and variable traffic demand. Network trunk groups are resized periodically to meet forecast traffic demand [3]. In real time operation, however, some origin-destination pair in a network may receive a poorer Grade-Of-Service (GOS) than planned, as in the following situations:

- Traffic demands grow beyond the forecast.
- Traffic overloads result from natural distress.
- Unexpected failures occur in the network elements such as links and transmission facilities.

In such situations, there is traffic overflow in some parts of the network, even though the overall network may have idle capacity. This idle capacity may be the result of the following situations:

- Trunk groups are sized for large future capacities that current use does not yet fill.
- Traffic demands remain below the forecast.
- Trunk groups are sized to accommodate the traffic during the busiest hours of a selected number of busy days, but current traffic below this capacity [3, 4].

The objective of network management controls is to allow the completion of as many calls as possible under given network resource conditions. This is achieved by maximizing the use of available equipment and facilities in any situation through the application of the principles listed below:

- Utilize all available circuits.
- Keep all available circuits filled with traffic that has a high probability of success.
- When most of available circuits are in use, give priority to calls requiring a minimum number of circuits to form a connection.
- Inhibit switching congestion and its spread [3, 4].

Network management controls are classified in two categories, network traffic controls and network configuration control as shown in Figure (1.2), circuit directionalization, circuit turn down, and circuit creation by using digital cross connect systems are categorized as network configuration controls. Network traffic controls are further classified into traffic volume controls and routing controls that we will focus on it [3, 4].

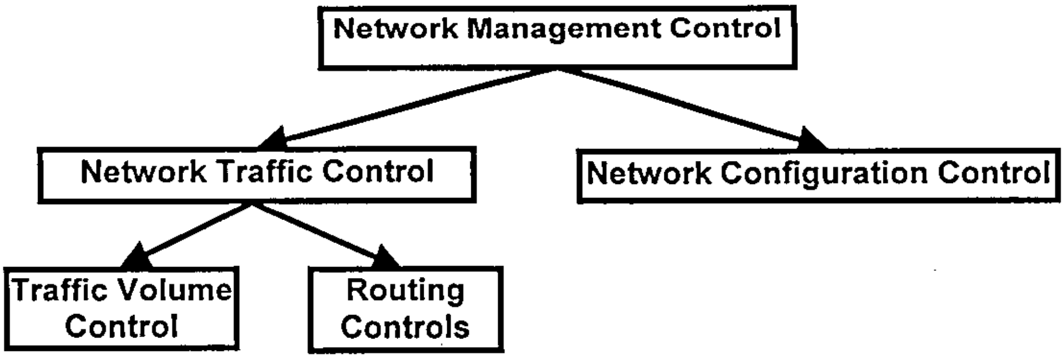

Fig. (1.2): Network management controls.

1.2 Artificial Genetic Algorithms and The Routing Problem

Traffic routing is an indispensable communication network function. It connects a call from origin to destination as one of the functions of the network layer (layer 3 in the ISO-OSI reference model). To do this, a path or route through the network must be determined; generally, more than one route is possible [1 and 13]. A large number of strategies have evolved for dealing with the routing requirements. Two key-strategy categories are the static (non-adaptive) and the dynamic (adaptive) routing [5]. A routing strategy employee a routing algorithm to perform the routing function that can be stated as follows:

> **"Given a network of nodes connected by bi-directional links, where each link has a cost associated with it in each direction, define the cost of a path between two nodes as the sum of the costs of the links traversed. For each pair of nodes, find the path with the least cost [1] and most-to-all of the alternative nodes?"**

The routing algorithms for communication networks must meet conflicting, independent requirements. Route assignment must minimize cost while satisfying traffic requirements and keeping network delays within permissible values.

Artificial genetic algorithms are heuristic optimization techniques that provide a robust search procedure for solving difficult problems and appears ideal to face the routing problem with the capability of handling discrete values, multiobjective functions, and multiconstraint problems. So, the idea of controlling traffic using genetic algorithms has bean arisen. Hence traffic is routed by the genetic routing algorithms (GRAs) which are based on the application of a set of genetic operators that constitute a method for selecting the path from an origin to destination [6].

Since, computer networks provide suitable environment for parallel and distributed processing. Also, genetic Algorithms (GAs) are good candidates for effective parallelization, given their inspiring principle of evolving in parallel population of individuals [7]. So, the ideas of parallel genetic routing algorithms (PGRAs) have been innovated with its synchronous and asynchronous approaches [8, 9].

1.3 Thesis Outline

In this thesis, a new scheme of computer communications routing algorithms that uses the artificial genetic algorithms approach is proposed and named the Genetic Routing Algorithms (GRAs) for computer networks.

Firstly, the various classical routing algorithms and strategies that are used in computer networks are investigated, classified with a new proposed taxonomy and compared with their advantages and disadvantages. Secondly, the principles of the artificial genetic algorithms are presented. Thirdly, the proposed genetic routing algorithms are discussed. The following genetic routing algorithms are developed:

(1) The **Genetic Adaptive Routing Algorithm (GARA)** for computer networks was realized. In GARA a source node works individually and sequentially to get the least cost route and most-to-all of the alternative routes between a source node and a destination node in a computer network [6].

(2) The **Synchronous Parallel Genetic Routing Algorithm (SPGRA)** for computer networks was realized. In the SPGRA a source node and its neighboring nodes work synchronously in parallel to find the least cost route and most-to-all of the alternative routes between the source node and the destination node [8].

(3) The **Asynchronous Parallel Genetic Routing Algorithm (ASPGRA)** for computer networks was realized. In the ASPGRA, a source node and its neighboring nodes work asynchronously in parallel to find the least cost route and most-to-all of the alternative routes between the source node and the destination node.

Simulation programs are developed using the Borland™ C language compiler to simulate, study, analyze, and measure the performance of the proposed algorithms; namely the GARA, the SPGRA, and the ASPGRA, compared with the famous Dijkstra's routing algorithm by applying them to three arbitrary chosen computer networks.

1.4 Thesis Structure

This thesis is organized as follows:

Chapter (2) reviews the classical computer networks routing algorithms and strategies.

Chapter (3) illustrates the principles of the artificial genetic algorithms.

Chapter (4) discusses the Genetic Adaptive Routing Algorithm (GARA), with its simulation results.

Chapter (5) discusses the Synchronous Parallel Genetic Routing Algorithm (SPGRA), with its simulation results.

Chapter (6) discusses the Asynchronous Parallel Genetic Routing Algorithm (ASPGRA), with its simulation results.

Chapter (7) shows the final conclusions and the future works.

Appendices I and II list the source code of the simulation programs for the Dijkstra's algorithm, and the Genetic Routing Algorithms.

Chapter 2

ROUTING IN COMPUTER NETWORKS

Chapter 2

ROUTING IN COMPUTER NETWORKS

2.1 Introduction

The main function of the network layer, which is layer 3 of the ISO-OSI (International Standards Organization-Open System Interconnection) Reference-Model, is routing packets from the source machine to the destination machine. Routing is one of the complex and crucial aspects of packet switching network design. The algorithms that choose the routes and the data structures used are a major area of network layer design [13]. This chapter classifies routing algorithms and strategies. Then it surveys them emphasizing on their key characteristics together with their advantages and disadvantages.

2.2 Traffic Routing Strategy Evolution

Figure (2.1) shows stages of the traffic routing strategy evolution [3].

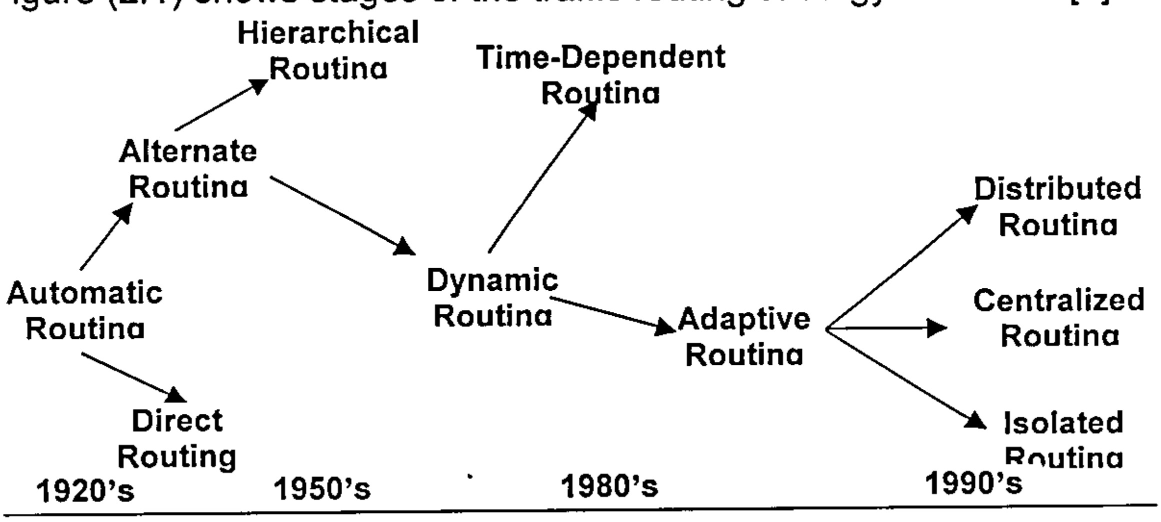

Fig. (2.1): Traffic routing technological evolution.

2.3 Characteristics of Routing Strategies

The routing function should satisfy the following:

- Correctness,
- Simplicity,
- Robustness,
- Stability,
- Fairness,
- Optimality, and
- Efficiency [1].

2.4 Routing Performance Criteria

A route is selected according to some performance criterion such as:

1. The minimum-hop route, which is the route that passes through the least number of nodes through the network.
2. The least-cost route, which is the route that has the least cost associated with its links. Costs are assigned to links to support one or more design objectives [1, 14, and 15].

2.5 Routing Decision Time

The routing decision time for packet-datagram networks is made individually for each packet. While for virtual-circuit networks, a routing decision is made at the time the virtual-circuit is established [1, 14, 15].

2.6 Routing Decision Place

It designates the node(s) in the network that makes the routing decision. It can be a central node, a source node, or distributed group of nodes [1, 14, and 15].

2.7 Network Information

The network information required as input to do routing include:

- The network topology
- Link cost
- Geographic distance
- Measured delay
- Communication cost, and
- Traffic load
- Number of hops
- Mean queuing delay
- Average traffic
- Bandwidth [1, 4, 13, and 15].

2.8 Network Information Source

There are many methods to update information such as:

1. None: no information to update such as in flooding and some random strategies.

2. Local: it is used with distributed routing, in which each node makes the routing decision uses only local information such as the cost of each outgoing link.
3. Adjacent nodes: each node collect information from adjacent (directly connected) nodes.
4. Nodes along route: a node can collect information from all nodes on any route of interest.
5. All nodes: in centralized routing the central node collects information from all nodes [1, 14, and 15].

2.9 Network Update Timing

For fixed routing there is no information to update. For an adaptive routing strategy, the information is updated from time to time to enable the routing decision to adapt to changing conditions. Methods for updating include:

1. None: if no information is used.
2. Continuous: If only local information is used, an individual node continuously knows its local status.
3. Major load change: This used for information source categories (adjacent nodes, all nodes).
4. Topology change: This is used for all types of strategies [1, 14].

2.10 The Optimality Principle

It states that "if router Y is on the optimal path from router X to router Z, then the optimal path from Y to Z also falls along the same route" [13]. The Sink Tree is the set of optimal routes from all sources to a given destination that form a tree rooted at the destination. It is not necessarily unique and has no loops. Routing algorithms search for the sink trees for all routers in a network [13]. Figure (2.2) shows an example of a sink tree.

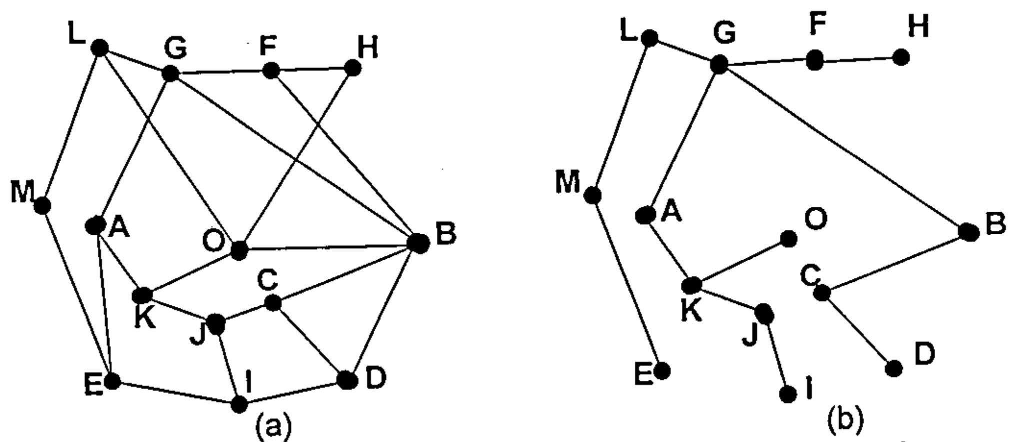

Fig. (2.2): (a) A subnet. (b) A sink tree for router L.

2.11 Classification of Routing

According to the previous sections, a modified classification of routing is proposed as shown in Figure (2.3).

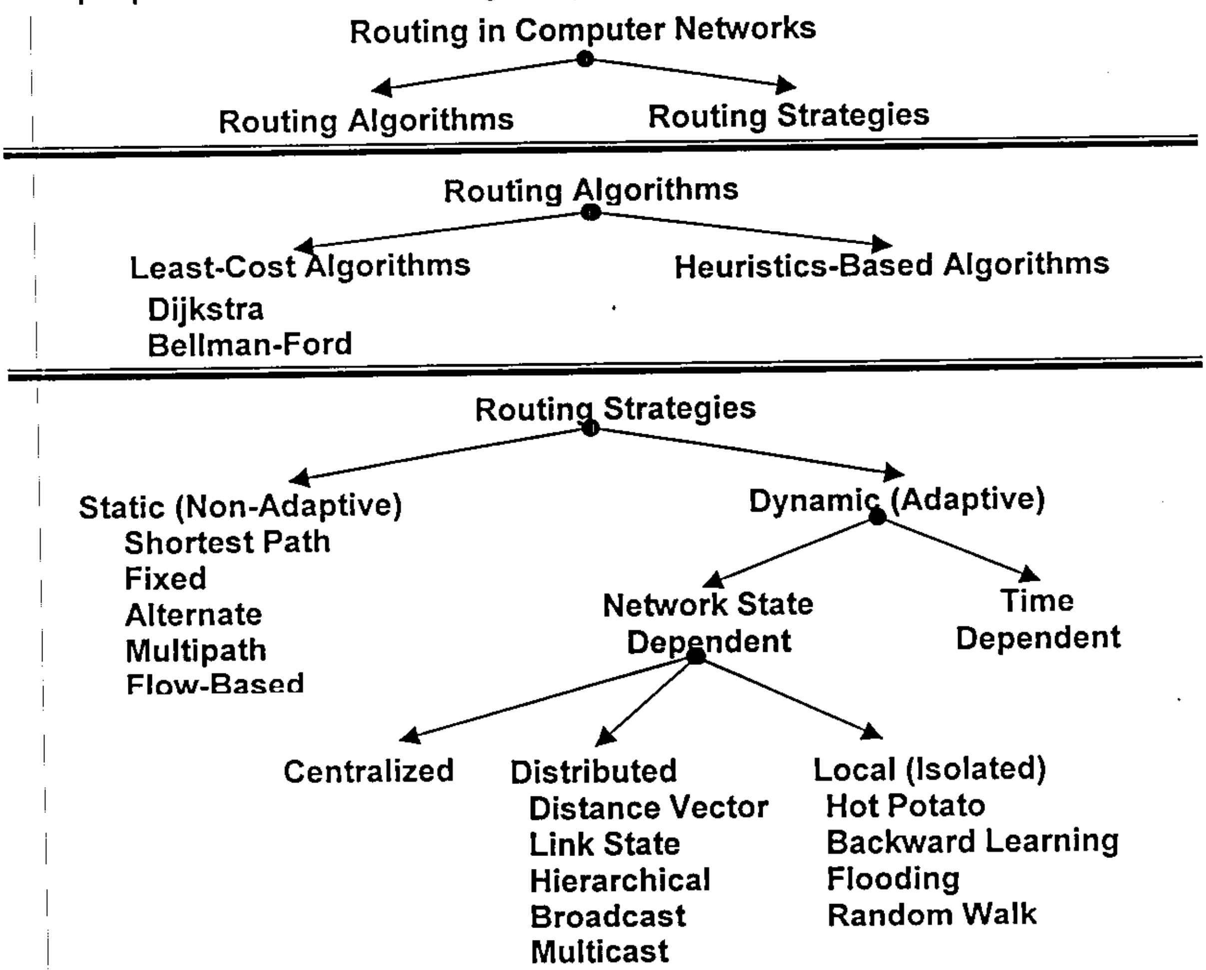

Fig. (2.3): Classifications of routing

A **routing strategy** is that part of the network layer software that is responsible for deciding which output line an incoming packet should be transmitted on [13]. It employees one of the **routing algorithms** to finds out the best routes. The different classes will be discussed in the next sections.

2.12 The Least-Cost Algorithms

The least-cost routing algorithms are employed by a routing strategy and include Dijkstra's algorithm and Bellman-Ford algorithm. The least cost routing problem can be stated as:

> **"Given a network of nodes connected by bi-directional links, where each link has a cost associated with it in each direction, define the cost of a path between two nodes as the sum of the costs of the links traversed. For each pair of nodes, find the path with the least cost?"** [1].

2.12.1 Dijkstra's Routing Algorithm

It is due to Dijkstra (1959), and can be stated as "Find the shortest paths from a given source node to all other nodes by developing the paths in order of increasing path length". The algorithm proceeds in stages. It can be formally described as follows:

N = set of nodes in the network
s = source node
M = set of nodes so far incorporated by the algorithm
d_{ij} = link cost from node i to j; $d_{ii} = 0$; $d_{ij} = \infty$ if the two nodes are not directly connected; $d_{ij} \geq 0$ if the two nodes are directly connected
D_n = cost of the least-cost path from node s to node n that is currently known to the algorithm

The algorithm has three steps; steps 2 and 3 are repeated until M=N.

initialize:

1. Let M = {s} (i.e., the set of nodes so far incorporated consists of only the source node)
   $D_n = d_{sn}$ for $n \neq s$ (i.e., the initial path costs to neighboring nodes are simply the link cost)
2. Find the neighboring node not in M that has the least-cost path from node s and incorporate that node into M; this can be expressed as
   Find $w \notin M$ such that $D_w = \min_{j \notin M} D_j$

Add w to M

3. Update least-cost paths:

$D_n = \min [D_n, D_w+d_{wn}]$ for all $n \notin M$

If the latter term is the minimum, the path from s to n is now the path from s to w, concatenated with the link from w to n [1].

2.12.2 Bellman-Ford Routing Algorithm

It is due to Ford (1962), it can be stated as "Find the shortest paths from a given source node subject to the constraint that the paths contain, at most, one link; then find the shortest paths with a constraint of paths of, at most, two links, and so on". It can be formally described as follows:

s = source node

dij = link cost from node j; dij = 0; dij = ∞ if the two nodes are not directly connected; dij≥0 if the two nodes are directly connected

h = maximum number of links in a path at current stage of the algorithm.

$D_n(h)$ = cost of the least-cost path from node s to node n under the constraint of no more than h links.

The algorithm has the following steps, step2 of which is repeated until none of the costs change:

1. Initialize:

$D_n^{(0)} = \infty$ for all $n \neq s$

$D_s^{(h)} = 0$, for all h.

2. For each successive $h \geq 0$:

$D_n^{(h+1)} = \min_j [D_j^{(h)} + d_{jn}]$

The path from s to i terminates with the link from j to i.

Figure (2.5) shows an example of the two least cost algorithms using sample network in Figure (2.4) [1].

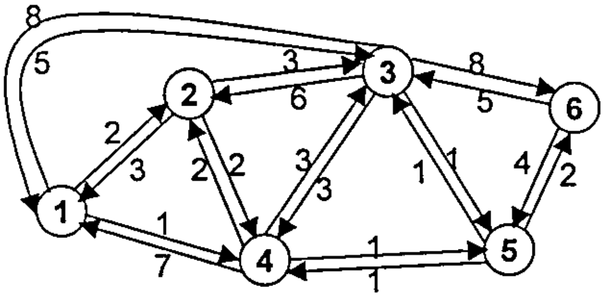

Fig. (2.4): Example of a network topology.