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Performance Study of Adaptive Routing Algorithm using Swarm Intelligence

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***Abstract*— *Swarm intelligence (SI) is the collective behavior of decentralized, self-organized systems, natural or artificial. The concept is employed in work on artificial intelligence. The expression was introduced by Gerardo Beni and Jing Wang in 1989, in the context of cellular robotic systems. SI systems consist typically of a population of simple agents or boids interacting locally with one another and with their environment. The inspiration often comes from nature, especially biological systems. The agents follow very simple rules, and although there is no centralized control structure dictating how individual agents should behave, local, and to a certain degree random, interactions between such agents lead to the emergence of "intelligent" global behavior, unknown to the individual agents. Examples in natural systems of SI include ant colonies, bird flocking, animal herding, bacterial growth, fish schooling and microbial intelligence. The application of swarm principles to robots is called swarm robotics, while 'swarm intelligence' refers to the more general set of algorithms. 'Swarm prediction' has been used in the context of forecasting problems.*

In the past few years there has been a lot of research on the application of swarm intelligence to the problem of adaptive routing in telecommunications networks. A large number of algorithms have been proposed for different types of networks, including wired networks and wireless ad hoc networks. In this paper we give an overview of this research area. We address both the principles underlying the research and the practical applications that have been proposed. We start by giving a detailed description of the challenges in this problem domain, and we investigate how swarm intelligence can be used to address them. We identify typical building blocks of swarm intelligence systems and we show how they are used to solve routing problems. Then, we present Ant Colony Routing, a general framework in which most swarm intelligence routing algorithms can be placed. After that, we give an extensive overview of existing algorithms, discussing for each of them their contributions and their relative place in this research area. We conclude with an overview of future research directions that we consider important for the further development of this field.

***Keywords*— *Boids, stigmergy, network routing protocols, swarm intelligence, ant net quality of services.*

I. INTRODUCTION

Modern communication networks are becoming increasingly diverse and heterogeneous. This is the consequence of the addition of an increasing array of devices and services, both wired and wireless. The need for seamless interaction of numerous heterogeneous network components represents a formidable challenge, especially for networks that have traditionally used centralized methods of network control. This is true for both packet-switched and virtual circuit networks, and the Internet, which is becoming an ever more complex collection of a diversity of subnets. The need to incorporate wireless and possibly ad-hoc networks into the existing wire-link infrastructure renders the requirement for efficient network routing even more demanding. Routing algorithms in modern networks must address numerous problems. Two of the usual performance metrics of a network are average throughput and delay. The interaction between routing and flow control affects how well these metrics are jointly optimized. Bertsimas and Gallager note that the balance of delay and throughput is determined by the flow-control scheme – good routing results in a more favorable delay-throughput curve. Quality of service (QoS) guarantee is another important performance measure.

Routing Algorithms with Swarm Intelligence:

Routing algorithms can be classified based on minimal and non-minimal tree. The tree traversal can be advertised based the base node and the cluster node. For each minimal we have to find the shortest- path between two end- nodes. Before that the nodes energy level can be calculated based on their bandwidth, and residual energy.

Minimal routing allows packets to follow only minimal cost paths, while non-minimal routing allows more flexibility in choosing the path by utilizing other heuristics [2]. Minimal routing can further be subdivided into optimal routing and shortest-path routing. In the former, the objective is to optimize the mean flow of the entire network; while in shortest-path routing the goal is to find the minimum-cost path between two nodes [1-7].

Another class of routing algorithms is one where the routing scheme guarantees specified QoS requirements pertaining to delay and bandwidth. These algorithms are usually message based, i.e. they find a feasible path satisfying the QoS constraints based on an exchange of messages between the nodes [11]. These algorithms have the tendency to temporarily overuse network resources until they find the appropriate path. The Dijkstra and Bellman-Ford algorithms [1] are examples. Yet another form of network control, which relies heavily on routing, is that of load balancing [7], [9], [19], [20]. Here the goal is to balance the load throughout all network resources without idleness and overloading.

Swarm Intelligence Routing: Examples

There are a number of proposed swarm-based routing algorithms. The most celebrated one is AntNet [6], [7], an adaptive agent-based routing algorithm that has outperformed the best-known routing algorithms on several packet-switched communications networks. For telephone networks, there also exists a successful application of swarm intelligence dubbed

Ant-Based Control (ABC) [6], [19], [20]. Heusse et al. [8] give another interesting example using a variation of swarm routing based on Bellman's principle of dynamic programming [21]. These algorithms are discussed in further detail below. Other examples also exist and present some interesting variations of swarm-based routing. Oida & Masatoshi [2] present an algorithm dubbed agent-based routing system (ARS) whose main goal is to achieve high utilization of network resources.

The authors propose an extension of the AntNet algorithm with QoS guarantees, imposing certain restrictions on bandwidth and hop-count. [9], take a different agent based approach for load balancing. They propose the use of two classes of agents, dubbed "strategy" agents and "load" agents. The role of the load agents is to find shortest paths based on Dijkstra's algorithm [18]. The strategy agents control the population of the load agents based on network conditions. Varella & Sinclair [20] apply swarm intelligence for virtual-wavelength-path routing. They propose the separation of ants into colonies, with ants being attracted to the pheromone of their own colony and repelled by pheromone of other colonies. Thus, ants of each colony attempt to discover the shortest path independent from the path discovered by other colonies. This leads to a more even load distribution throughout the network. More examples of swarm based routing applications exist in the literature. Bonabeau et al [21] discuss an improvement of ant-based algorithms by dynamic programming. . A. Colorni, M. Dorigo, and V. Maniezzo [18-20] present a number of interesting variations based on ant-like agents. White et al. also discuss various enhancements of routing algorithms in [16-19]. A. AntNet

In the AntNet algorithm, routing is determined by means of very complex interactions of forward and backward network exploration agents ("ants"). The idea behind this subdivision of agents is to allow the backward ants to utilize the useful information gathered by the forward ants on their trip from source to destination. Based on this principle, no node routing updates are performed by the forward ants. Their only purpose in life is to report network delay conditions to the backward ants, in the form of trip times between each network node. The backward ants inherit this raw data and use it to update the routing table of the nodes.

An example of an AntNet routing table is in table I. The entries of the routing table are probabilities, and as such, must sum to 1 for each row of the network. These probabilities serve a dual purpose: (1) the exploration agents of the network use them to decide the next hop to a destination, randomly selecting among all candidates based on the routing table probabilities for a specific destination (2) the data packets deterministically select the path with the highest probability for the next hop.

TABLE I. ANTNET ROUTING TABLE

		Next Hop	
		B	C
Destination	E	0.15	0.85
	F	0.75	0.25

AntNet: Using SI Routing

AntNet [29] is a SI routing algorithm for packet switched IP networks. It was, together with Ant Based Control (ABC) [11], one of the first routing algorithms that followed the SI approach, and many of its mechanisms have been adopted later by other algorithms. AntNet takes its inspiration from the shortest path behavior of ant colonies and from the related ACO framework for optimization. The task of finding the shortest path between a nest and a food source is mapped onto the task of finding the shortest path between source and destination nodes in the network. The agents solving this task are artificial ants that travel to assigned destinations.

Each node in the network maintains a probabilistic routing table, which plays the role of artificial pheromone: ants are stochastically forwarded through the network using the information in these routing tables, and the tables are in turn updated using feedback from the ants about the quality of the paths they have followed. Here, we first give a brief description of the algorithm as a prototypical example of what SI routing algorithms look like. Then, we use this example to derive some basic principles that are present in most SI routing algorithms.

Ant Colony Optimization is a model in which multiple agents (ants) parallelly try to achieve a specific task by cooperating among themselves. A natural ant generates chemical substance and deposits on its way to the food source. Since an artificial ant (packet) cannot generate chemical substance, it is modeled to carry memory with it. While moving, the ant can change the pheromone trails (probabilistic value) associated with the problem.

AntNet is an ACO algorithm proposed by R. Schoonderwoerd, O.E. Holland, J.L. Bruten for data communication networks. Routing is determined by agents implementing forward and backward network exploration. The philosophy behind this technique is that backward ants utilize information gained by forward ants on their trip from source to destination [10]. The forward ants are not responsible for routing updates; their sole purpose is to collect raw data about network conditions and report results to backward ants. It is this data that the backward ants use to update appropriate routing tables of respective nodes (colonies).Brief description of the AntNet is given below: A forward ant is launched, at regular intervals, towards a destination _d' from source _s' to find a feasible path from _s' to _d'.

1. At each node, each forward ant which is going towards destination d, selects the next node to move on.
2. A cycle is detected when the forward reaches a node which is already present in its memory. If a cycle is detected the nodes which are forming a cycle are removed from the memory.
3. When the forward ant reaches the destination node, the Ant agent generates a backward ant, transfers all of its memory to it and the forward ant is killed.
4. The backward ant retraces the same path the forward ant traversed but in the reverse direction.
5. The backward ant updates the routing table at every node in the path.

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$$r' = \begin{cases} \frac{T}{c\mu}, c \geq 1, if \frac{T}{c\mu} < 1 \\ 1, otherwise \end{cases}$$

Table (I) shows an example of AntNet routing table.

The routing table of every node is the same as *AntNet*. The update philosophy of the routing table is slightly different though. There is only one class of ants, which is launched from the sources to various destinations at regular time intervals. The ants are eliminated once they reach their destination. Therefore, the probabilities of the routing tables are updated as the ant visits the nodes, based on the life of the ant at the time of the visit. The life of the ant is the sum of the delays of the nodes = Σ *I T Di* . The delays *Di* are given by *c e d S Di* = · − · , where *c*, *d* are design parameters and *S* is the spare capacity of each node in the telephone network. Then a step size is defined for that node, according to: *b T a* δ *r* = + ,where *a* and *b* are both design parameters. This step size rule is chosen heuristically. It assigns a greater step size to those ants who are successful at reaching the node faster.

The routing table is then updated according to: *r i t r*

$$r^{i}_{i-1,s}(t+1) = \frac{r^{i}_{i-1,s}(t) + \delta r}{1 + \delta r}$$

$$r^{i}_{n,s}(t+1) = \frac{r^{i}_{n,s}(t)}{1 + \delta r}, n \neq i-1$$

where s is the source node, i is the current node and i-1 the previous node.

TABLE IV. ABC ROUTING TABLE

		Next Hop	
		B	*C*
Destination	*E*	0.65	0.35
	F	0.55	0.45

II. CONCLUSION

In this paper, we have presented an overview of swarm intelligence applied to network routing Inherent properties of swarm intelligence include massive system scalability emergent behavior complex global intelligence emerging from simple, local interactions, autonomy and stigmergy. Fortunately these are the properties that are also highly desirable in computer networks. Swarm Intelligence proposes a new way of thinking the solution of the non-linear complex problems. Swarm intelligent based approaches hold great promise for solving numerous problems of ad-hoc power aware networks. Swarm intelligence however is a new field and much work remains to be done.

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