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Solving routing in telecommunication problems using sensitive ants

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Abstract. Ants, which have a sensitive reaction to pheromone, are considered to be agents for the metaheuristic called *Sensitive ACS (SACS)*. Within *SACS* model, each ant is endowed with a pheromone sensitivity level, which allows certain types of responses to pheromone trails. Such an artificial system, based on emergent behavior promise to generate engineering solutions to distributed systems management problems, for example, in telecommunication networks. A Sensitive Ants Algorithm for Routing (SAR), based on SACS model is developed for solving networks communication problems. The aim of this is to provide a comparison between AntNet Algorithm, based on ACO model and SAR, by giving a formal and comprehensive systematization of the subject.

1 Introduction

Ants are social insects, which have captured the attention of many scientists because of the high structuration level from their colonies. Ant as a single

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individual has a very limited effectiveness. But as a part of a well-organised colony, it becomes a powerful agent. Taking into account that a human brain has about 10 billion neurons and ants only have $250,000$, one may ask how they can perform such amazing tasks when they are in a collective body. Their real power resides in their colony brain. Even though the individuals are limited in number of neurons, a collective of $40,000$ would have approximately the number of neurons that a human brain has [9].

Stigmergy is defined as a particular form of indirect communication in a self-organizing emergent system used by social insects to coordinate their activities [8]. Stigmergic information is local: it can only be accessed by those insects that visit the place in which it was released. In many ant species, ants walking from or to a food source, deposit on the ground a substance called *pheromone*. Generally, insects are known to make more use of pheromones for diverse tasks such as reproduction, alert, identification, navigation and aggregation [8, 9].

Sensitive ants have different degrees of perceiving the presence of pheromone. This is suggested by the Pheromone Sensitivity Level (PSL), whose value is between 0 and 1 [2, 3, 4]. The idea of using ants for solving routing problems is not new: for instance, the ACO metaheuristic provides good results in this area [5]. The paper aims to provide an algorithm where sensitive ants can be used for routing. Numerical experiments indicate the potential of the proposed algorithm.

2 Routing information

Routing can be characterized by the following general way. Let the network be represented in terms of directed, weighted graph: $G = (V, E)$, where each node in the set V represents a processing and forwarding unit and each edge in E is a transmission system with some capacity/bandwidth and propagation characteristics.

Data traffic originates from one node and can be directed to another node (unicast traffic) or to a set of nodes (multicast traffic) and/or to all the other nodes (broadcast traffic). The nodes between sources and destinations are called intermediate or relay nodes. The node, from where the traffic flow originates is also called source, while the nodes to which traffic is directed are the final end-points, or destinations [1, 5, 6].

The characteristics of the routing problem make it well suited to be solved by a mobile multi-agent approach. The ideea of using ants in routing problems is not new, i.e. M. Dorigo and G. Di Caro originally proposed four ACO algorithms for adaptive agent-based routing. They are the following: AntNet, and some improvements of it: AntNet-FA, AntNetSELA and AntHoc Net [5, 6, 7].

3 Sensitive ants model used for routing in telecommunication networks

The Sensitive ACS metaheuristic (SACS) [4] uses different reactions of sensitive ants to the pheromone trail. The model implements both exploration and exploitation search for solving problems with a high degree of complexity.

Within the proposed model, each agent is endowed with a *pheromone sensitivity level* (*PSL*), which is expresed by a real number in the unit interval $[0, 1]$. Agents with low PSL values will normally choose very high pheromone levels moves. They are more independent and they are very good environment explorers [4, 5]. Agents with high PSL value will follow any pheromone trail. They are able to exploit the already indentified paths.

The ACS and SACS models were implemented for solving the *Generalized Traveling Salesman Problem (GTSP)*. The search space was an n-node, undirected graph, $G = (V, E)$ [4]. To favour the selection of an edge, (i, j) with a high pheromone value, τ, and a high visibility value, $\eta = \frac{1}{c_{ij}}$, the transition probability, p^k_{iu} is considered:

$$p^k_{iu} = \frac{[\tau_{iu}(t)] \cdot [\eta_{iu}(t)]^\beta}{\sum_{o \in J^k_i} [\tau_{io}(t)] \cdot [\eta_{io}(t)]^\beta}, \tag{1}$$

where β is a parameter used for tuning the relative importance of edge cost (c_{ij}) in selecting the next node.

The main purpose of *Sensitive Ants Algorithm for Routing (SAR)* is to point out a comparison between multi-agents with random PSL and multi-agents with a fixed (global) PSL. The algorithm refers to finding a minimum-cost path from a certain source to a randomly chosen destination, by using sensitive ants.

The model's main purpose is to improve routing in telecommunication networks. The network is represented by a weighted graph $G = (V, E)$, where each node represents a processing and forwarding unit for every ant passing by, and each edge in E is a transmission system with propagation characteristics. Ants are used to explore the search space so that data packets can reach the destination taking into account the improvements made by the ants. When all the routing tables are updated with the minimum costs, the algorithm stops.

Two classes of ants are used for this purpose: the first one is the management ants. Here, three types of ants are considered: $\mathsf{exploration}$ ants, which have the role to explore the unoriented graph and find more candidate routes between the nodes. Another type of ants are the $\mathsf{message}$ ants or $\mathsf{response}$ ants (they work as backward ants). Error ants appear if one node or edge is deleted. The second class are the $\mathsf{exploitation}$ ants, which only take into account the improvements made by management ants, and because of this, they only choose the edges with the low cost. They are also called data packets [5, 6].

At iteration $t+1$ every ant moves to a new node and the parameters controlling the algorithm are updated. Each edge is labelled by a trail intensity; let $\tau_{ij}(t)$ be the trail intensity for the edge (i, j) at iteration t. At each time unit evaporation takes place and its value is between 0 and 1. Every ant decides which node is the next move with a probability, which is based on the distance to that node and on the amount of trail intensity on the edge connecting the nodes. The inverse of distance from a node to the next node is called visibility and is denoted by the formula: $\eta = \frac{1}{c_{ij}}$, where c_{ij} is the cost on the edge (i, j). To favour the selection of an edge that has a high pheromone value, τ, and high visibility value, η, a transition probability is proposed:

$$p_{iu}^{k} = \frac{[\tau_{iu}(t)] \cdot \eta_{iu}(t)^{PSL}}{\sum_{o \in J_i^k} [\tau_{io}(t)] \cdot \eta_{io}(t)^{PSL}}. \tag{2}$$

(2) expresses the probability of ant k from the node i to choose the next node u; PSL represents the pheromone sensitivity level for an ant. It is used for tuning the relative importance of the quantity of pheromone on the edge. J_i^k are the unvisited neighbors of node i.

The algorithm can be resumed as follows: from each network node, ants are randomly launched towards specific destination nodes. The agent generation processes happen concurrently and asyncronously; the best (minimum) path is searched from a certain source to a randomly chosen destination, using ants. Destination is chosen randomly. The agents moving from their source to destination node are called *forward ants*. Every forward ant has a taboo list: where it has the source node, the destination node, the PSL value and the intermediate nodes, between its source and destination; the pheromone trail is updated on every edge taking into account the evaporation rate and the number of ants which pass on the edge in that moment of time. When an ant arrives at destination it is deleted and a *backward ant* (response ant) is created, which goes back following the same path as before, but in the opposite direction. If an ant does not reach the destination and the maximum Time-To-Live (TTL) has expired, then it is also destroyed. The pheromone on the trail is updated as follows:

$$\tau_{i,j}(t+1) = (1-\rho)\cdot\tau_{i,j}(t) + \ln(N_{i,j}(t)+1), \tag{3}$$

where $N_{i,j}$ is the number of ants which pass on the edge (i,j) at iteration t; ρ represents the evaporation rate; if an ant arrives at destination, it is deleted and a backward ant (response ant), $B_{d\to s}$, is created and goes back to the same path $P_{s\to d} = [s, v_1 v_2 \ldots, d]$ as before, but in the opposite direction.

In AntNet technique [6], the routing decision policy is adopted by forward ants in choosing the next node (hop). Therefore, the ant's decision is influenced by the entries in the pheromone table, the status of the local link queues (heuristic values), and it depends on the memory of the already visited nodes. At each intermediate node k, the forward ant $F_{s\to d}$ heading to its destination d must select the neighbor node $n \in N_k$ to move to. The probability p_{nd} assigned of each neighbor n of being selected as next hop is:

$$y = \begin{cases} p_{nd} = \frac{\tau_{nd}+\alpha\cdot l_n}{1+\alpha(|N_k|-1)} & \text{if } \forall n \in N_k \wedge n \notin V_{s\to k} \\ p_{nd} = 0 & \text{otherwise,} \end{cases} \tag{4}$$

where τ_{nd} are the values of the pheromone stochastic matrix τ_k corresponding to the estimated goodness of choosing n as the next hop for destination d; l_n is a $[0,1]$ normalised value proportional to the length $q_{n'}$; $V_{s\to d}$ is the list of the nodes visited so far and $\alpha \in [0,1]$ weighs the relative importance of the heuristic correction with respect to the pheromone values stored in the pheromone matrix [5].

4 Numerical experiments

SAR paradigm presents a simulation on a routing network, which is represented by a connection-less graph $G = (V, E)$. The number of nodes is denoted by N. NFSNet, one of the graphs used for the simulation, is a WAN composed of 14 nodes and 21 bi-directional links with a bandwidth of 1.5 Mbit/s [5].

SAR showed good performance under the NSFNet graph. All reported data are averaged over 10 trials. The best results were rather obtained using sensitive ants, with a random PSL, than ants with a global PSL. Costs on the edges were computed taking into account only the propagation delays:

PSL	No of steps	No of ants	No of packets	No of delivered packets
random	**2524.8**	**274.5**	**277.8**	**255.4**
0.2	2653.4	291	290.7	266.9
0.5	2795.8	304.6	306.8	283.8
0.7	2781.5	302.8	306	282.3
0.9	2912.2	316.8	323.1	300.1
1	3024.8	335.3	327.5	304.9

Table 1: NFSNet: Comparative results for different PSL values in SAR

costs range from 4 to 20 msec. TTL was set at 255 sec. As it can be seen from Table 1, better results were obtained using a random PSL value, so sensitive ants (with PSL values between 0 and 1) are better than ants which have a global PSL value, i.e., 0.2, 0.5, 0.7, 0.9 or 1. In ACO metaheuristic, every ant has the same global value for the PSL. Time of the simulation is proportional with the number of steps; a step occurs at every 15 msec. As it can be seen from Table 3 the percentage of delivered packets obtained using the SAR paradigm is bigger than the percentage of delivered packets from the AntNet results. From this point of view, SAR obtained better results. However, AntNet was always, within the statistical fluctuations, among the best performing algorithms. AntNet showed a robust behaviour, being able to rapidly reach a good stable level in performance. Moreover, the proposed algorithm has a negligible impact on network resources and a small set of robustly tuneable parameters. Its features make it an interesting alternative to classical shortest path algorithms.

PSL	No of Steps	Time (sec)
random	**2524.8**	**37.8**
0.2	2653.2	39.7
0.5	2795.8	41.9
0.7	2781.5	41.7
0.9	2912.2	43.6
1	3024.8	45.3

Table 2: Time results of SAR on NSFNet WAN

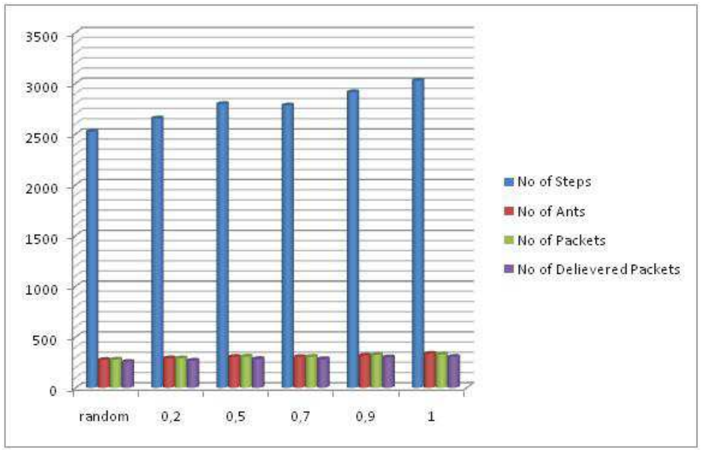

Figure 1: NFSNet: A comparison between different PSL values

Application	Percentage of delivered packets
SAR	92.25 %
AntNet	90 %

Table 3: Delivered packets on SAR vs AntNet

5 Conclusions and future work

The Sensitive Ants Paradigm for Routing (SAR), based on the model SACS is presented. SAR obtained good results in routing taking into account the NSFNet graph which was also used by M. Dorigo et al. in AntNet paradigm. From AntNet statistics some numerical results can be pointed out: the number of generated ants is $567,000$, the number of received ants is $107,000$ and number of dropped ants is $429,000$ [9]. The computational results concerning the SAR model show that sensitive ants achieve better results than ants with global PSL because ants with a random PSL value are able to make a more efficient exploration of the proposed WAN. These results may be improved by considering different parameter settings.

Future work focuses on the improvement of the proposed SAR model, by quantifying specific roles of the stigmergetic communication in ant colonies in order to bring better results in routing research.

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