Heterogeneous Sensitive Ant Model for Combinatorial Optimization

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ABSTRACT

A new metaheuristic called *Sensitive Ant Model (SAM)* for solving combinatorial optimization problems is proposed. *SAM* improves and extends the *Ant Colony System* approach by enhancing each agent of the model with properties that induce heterogeneity. SAM agents are endowed with different pheromone sensitivity levels. Highly-sensitive agents are essentially influenced in the decision making process by stigmergic information and thus likely to select strong pheromone-marked moves. Search intensification can be therefore sustained. Agents with low sensitivity are biased towards random search inducing diversity for exploration of the environment. A heterogeneous agent model has the potential to cope with complex and/or dynamic search spaces. Sensitive agents (or ants) allow many types of reactions to a changing environment facilitating an efficient balance between exploration and exploitation.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Coherence and coordination, Intelligent Agents, Multiagent systems; I.2.8 [**Problem Solving, Control Methods, and Search**]: Graph and tree search strategies, Heuristic methods

General Terms

Algorithms

Keywords

ant colony search, metaheuristics, stigmergy, sensitivity, heterogeneous system, search diversification

1. INTRODUCTION

The paper proposes a new metaheuristic technique called *Sensitive Ant Model (SAM)* that combines stigmergic communication and heterogeneous agent behavior. The model of stigmergic communication relies on the *Ant Colony System (ACS)* technique [1]. It is proposed to induce heterogeneity in the *SAM* approach via specific system agent properties. These properties can refer to variable pheromone sensitivity, variable agent life time or the particular heuristics engaged by each agent in the search process. SAM agents are endowed with different pheromone sensitivity levels. Highly-sensitive agents are essentially influenced in the decision making process by stigmergic information and thus likely to select strong pheromone-marked moves. Search intensification can be therefore sustained. Agents with low sensitivity are biased towards random search and are able to sustain diversity for exploration of the environment.

The *SAM* metaheuristic is tested for solving a dynamic drilling problem that can be viewed as an instance of the *Dynamic Generalized Traveling Salesman Problem (GTSP)*. Numerical results indicate that the proposed *SAM* algorithm outperforms the classic *ACS* model suggesting a promising potential for heterogeneous ant-based models.

2. STIGMERGY AND SENSITIVITY

The *SAM* model involves several agents able to communicate in a stigmergic manner (influenced by pheromone trails) for solving complex search problems. Stigmergic behavior is similar to that of *ACS* [1] agents. Agents are heterogeneous as they are endowed with different levels of sensitivity to pheromone. This variable sensitivity can potentially induce several types of reactions to a changing environment. It is expected that a better balance between search diversification and search exploitation can be achieved by combining stigmergic communication with heterogeneous agent behavior.

Within the proposed model each agent is characterized by a pheromone sensitivity level (*PSL*). The *PSL* value is expressed by a real number in the unit interval [0, 1]. Low *PSL* values indicate that agents can choose very high pheromone-marked moves but are more likely to make a decision independent from the stigmergic information available in the environment (as the agent has reduced pheromone sensitivity). These agents sustain search diversification. Agents with high *PSL* values are very sensitive to pheromone traces and therefore likely to be influenced by stigmergic information. Agents of this category are able to intensively exploit the promising search regions already identified.

3. THE SENSITIVE ANT MODEL

The *Sensitive Ant Model* uses a set of heterogeneous agents (sensitive ants) able to communicate in a stigmergic manner and take decisions individually influenced by changes in

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the environment and based on pheromone sensitivity levels specific to each agent. Sensitive ants having maximum PSL value act exactly like 'classical' *ACS* ants. At the opposite side, sensitive ants characterized by a *PSL* level of zero choose the path in a random manner completely ignoring pheromone trails.

A measure of randomness proportional to the level of *PSL* is introduced in the rest of the cases (when $0 < PSL < 1$). It is proposed to achieve this by modifying the transition probabilities using the *PSL* values in a renormalization process. Consider $p_{iu}(t, k)$ the probability for agent k of choosing the next node u from current node i (as given in *ACS* [1]).

Let us denote by $sp_{iu}(t, k)$ the renormalized transition probability for agent k (influenced by *PSL*) used in the *SAM* model. In the proposed *SAM* approach renormalization is accomplished via the following equation:

$$sp_{iu}(t, k) = p_{iu}(t, k) \cdot PSL(t, k), \qquad (1)$$

where *PSL(t, k)* represents the *PSL* value of agent k at time t.

In order to associate a standard probability distribution to the system, a *virtual state* denoted by *vs* - corresponding to the 'lost' probability - is introduced. The transition probability associated to the virtual state *vs* is defined as

$$sp_{i,vs}(t, k) = 1 - \sum_{u} sp_{iu}(t, k). \qquad (2)$$

The renormalized probability $sp_{i,vs}(t, k)$ can be correlated to the system heterogeneity at time t.

We may interpret $sp_{i,vs}(t, k)$ as the granular heterogeneity of the agent k at iteration t.

The *SAM* approach has to specify the action associated with the virtual state introduced. If the selected state is *vs* then an accessible state is chosen randomly with uniform probability. This mechanism is called *virtual state decision rule* and it concentrates the essence of the proposed approach.

4. EXPERIMENTAL RESULTS

In this section, the *SAM* metaheuristic is engaged for solving dynamic drilling problem viewed as a dynamic *Generalized Traveling Salesman Problem (GTSP)* instance. The drilling problem considered for numerical experiments refers to the minimization of drilling operation times on large printed circuit boards. Within a dynamic drilling problem the aim is to develop a flexible scheme for drilling the set of considered PCBs (identical except for one variable layer that can be missing or obstructed).

The large drilling problem is a particular class of the *GTSP* involving a large graph and finding the minimal tour for drilling on a large-scale printed circuit board.

The *SAM* algorithm uses m agents that are initially randomly placed in the clusters. Each agent is randomly associated to a PSL value. The selection of the next cluster is guided by the renormalized transition probabilities given by (1). Variable PSL values enable each transition to be more or less biased towards the virtual state i.e. towards a completely random choice of the next move.

At each iteration, only the agent generating the best tour is allowed to globally update the pheromone. The global update rule is applied to the edges belonging to the *best tour*.

Table 1: SAM and ACS Numerical results

Problem	SAM Avg.	SAM Min.	ACS Avg.	ACS Min.
U159	24635.26	**22418**	**24587.5**	23515
D198	**8983.12**	**7693**	9427.56	7848
FL417	**10708.76**	**9737**	11080.4	9918
PCB442	**24722.68**	23091	24908.42	**23006**

Numerical experiments are based on *all* drilling problem instances that can be found in the TSP library [3]. The drill problems with Euclidean distances have been considered. The values of parameters used in the *SAM* algorithm are as follows: $\beta = 5$, τ_0=0.01, $\rho = 0.01$ and $q_0 = 0.9$. The total number of ants considered is 3. The maximal running time is ten minutes.

The results obtained by the proposed *SAM* technique have been compared to the standard *ACS* model [2]. Both models are improved using *2-opt* heuristic [2] as a local optimizer. Table 1 presents the numerical results for the considered approaches.

Experiments indicate that *ACS* is outperformed by the proposed *SAM* technique for the considered set of dynamic problems.

5. CONCLUSIONS AND FUTURE WORK

A new technique called *Sensitive Ant Model (SAM)* that combines stigmergic communication and heterogeneous agent behavior is proposed. *SAM* technique involves several agents able to communicate in a stigmergic manner (influenced by pheromone trails) for solving complex search problems.

The proposed *SAM* metaheuristic proved to be useful for solving the dynamic drilling problem formulated as a dynamic *GTSP* - a well-known $\mathcal{NP}$-hard problem. Experimental results indicate that *SAM* obtains better results compared to the standard *ACS* model for most of the problem instances considered.

Ongoing work focuses on testing the proposed *SAM* metaheuristic for more dynamic problem instances as well as other complex optimization problems.

A challenging and promising future research direction refers to developing a learning scheme to adapt the PSL values of agents during the search process. Furthermore, the hybridization between *SAM* and other techniques for local optimization will be investigated.

6. REFERENCES

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