Artificial Ant Colonies for Coverage Repair in Wireless Sensor and Robot Networks

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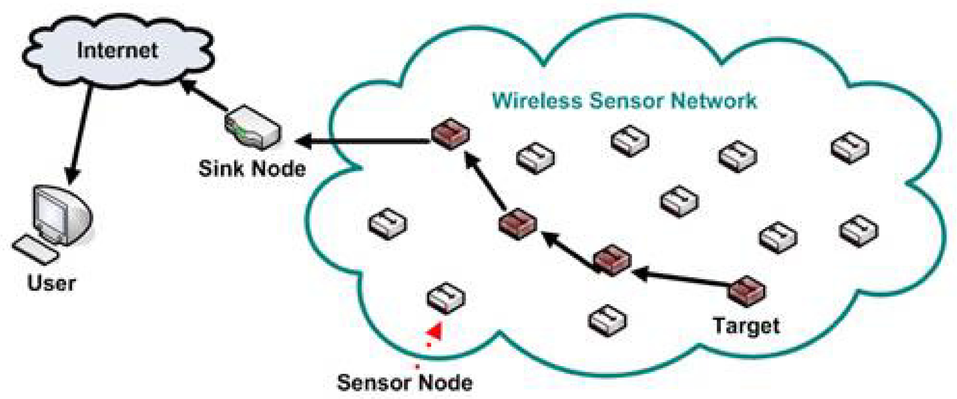
Wireless Sensor and Robot Networks (WSRNs)

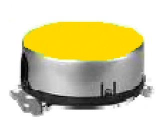


A collection of sensor and robot nodes that communicate via wireless links to perform distributed sensing and actuation tasks.

Mobile robot (able to carry sensors)

Base station (gathers data)

Active sensor (monitoring)



Passive sensor (in "sleep" mode)

Damaged sensor ("sensing hole")

The Carrier-Based Coverage Repair Problem

Active sensors might fail and create sensing holes. Robot replaces damaged nodes with passive (spare) ones. It must find an optimal (shortest) trajectory which starts from and ends at the base station and visits all sensing holes, picking as many passive sensors as needed.

The Traveling Salesman Problem (TSP)

Given a list of cities and their distances, find the shortest closed tour that visits each city exactly once.

TSP is a landmark problem in combinatorial (discrete) optimization.

Our WSRN scenario can be modeled as a generalization of TSP.

Swarm Intelligence

Studies the complex collective behavior of simple, self-organized agents. Ant and termite colonies, bird flocks and fish schools are natural examples of swarm intelligence, which have inspired many computational models for optimization.

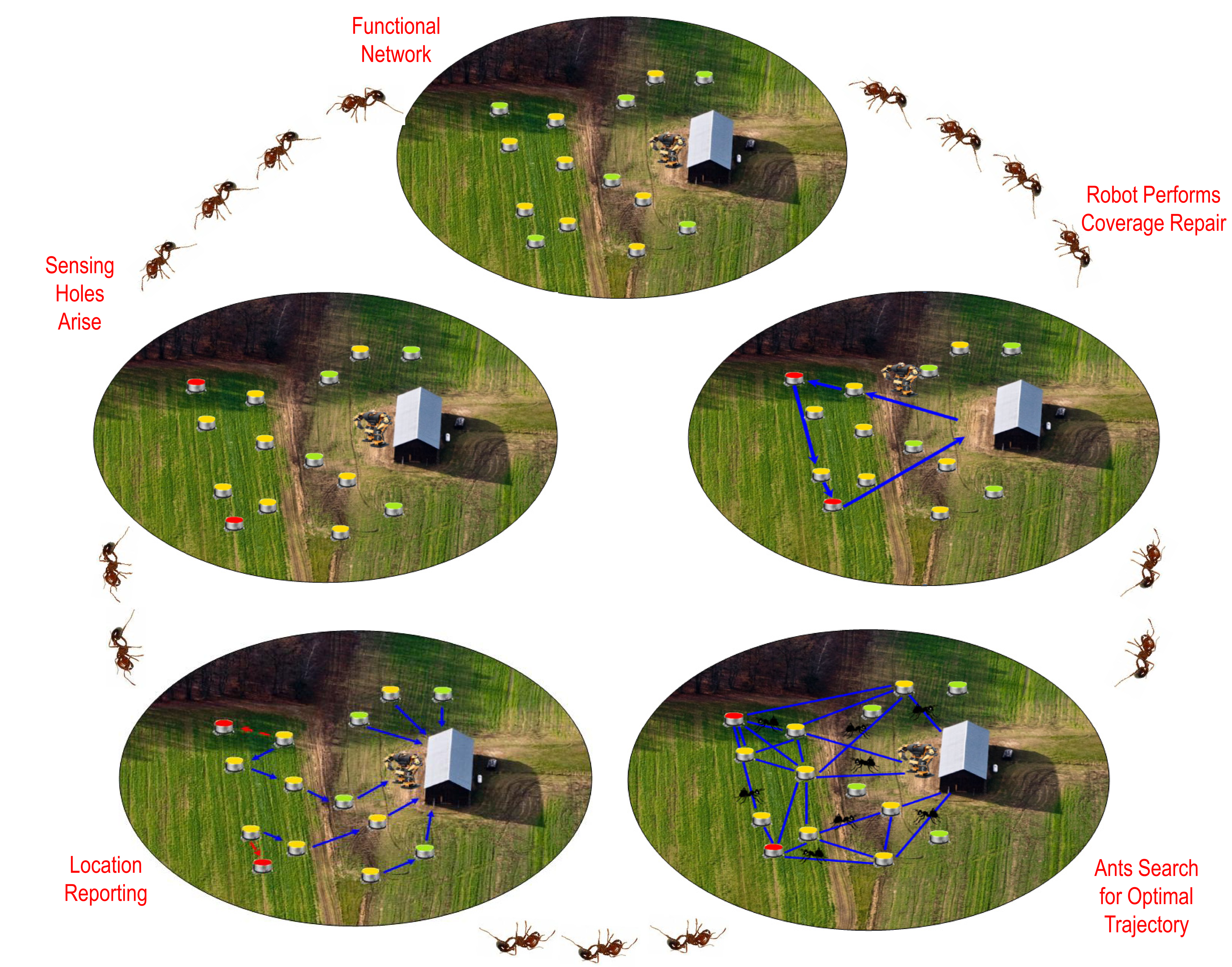
Particle Swarm Optimization

Firefly Optimization

Honey Bee Optimization

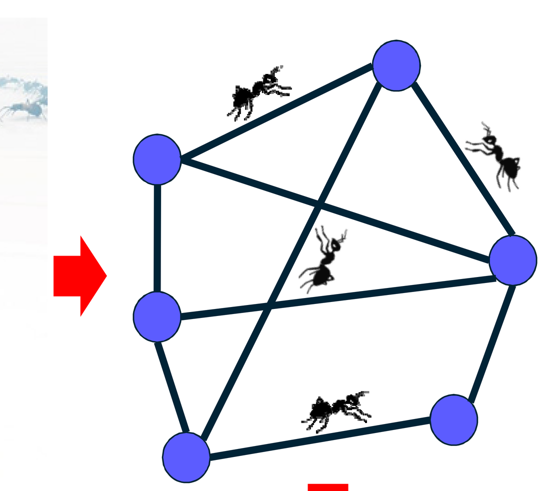
Ant Colony Optimization

Artificial Ant Colonies Find an Optimal Robot Trajectory for Coverage Repair



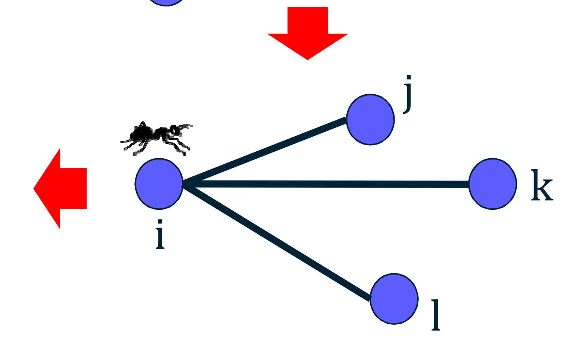
How Do Artificial Ants Manage to Find Shortest Paths in a Graph?

Natural ants deposit a chemical substance on the ground named **pheromone** as they forage. The accumulation of pheromone serves as an indirect communication mechanism (**stigmergy**) that makes future ants more prone to follow the most visited paths.



An artificial ant walks along the graph edges and incrementally builds a tour (solution). All the ants do the same. Then the pheromone values associated with the graph edges (or nodes) are updated according to some rule.

In the same way that chemical pheromone evaporates over time, so it does the artificial pheromone in order to prevent stagnation of the algorithm in locally "good" paths.



The ants apply a probabilistic rule to decide which node to visit next.

$$p_{ij} = \frac{(\tau_{ij})^{\alpha} \cdot (\eta_{ij})^{\beta}}{\sum_{n \in N_i} (\tau_{in})^{\alpha} \cdot (\eta_{in})^{\beta}}$$

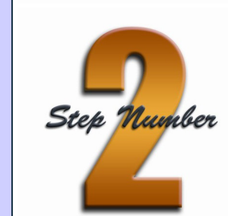
$\tau_{ij} =$ pheromone concentration at edge (i, j)

$\eta_{ij} =$ heuristic desirability of traversing edge (i, j)

Addressing Scalability Concerns

When the network is very dense (the graph size is very large), computing the optimal robot trajectory will take a longer time. To accelerate convergence, we use a recent exploration strategy that splits the search process carried out by the ants into two steps:

A subset of the total ants will look for partial solutions (tours) to the original problem in a limited timeframe.



The remaining ants will exploit the findings in step 1 to build full, improved tours. They can profit from either the best partial solutions or of the pheromone values generated by the previous ants.

Experimental Results

We empirically compared our ant-colony-based approach with competitive algorithms in literature such as Simulated Annealing and a hybrid method called GRASP-VND.

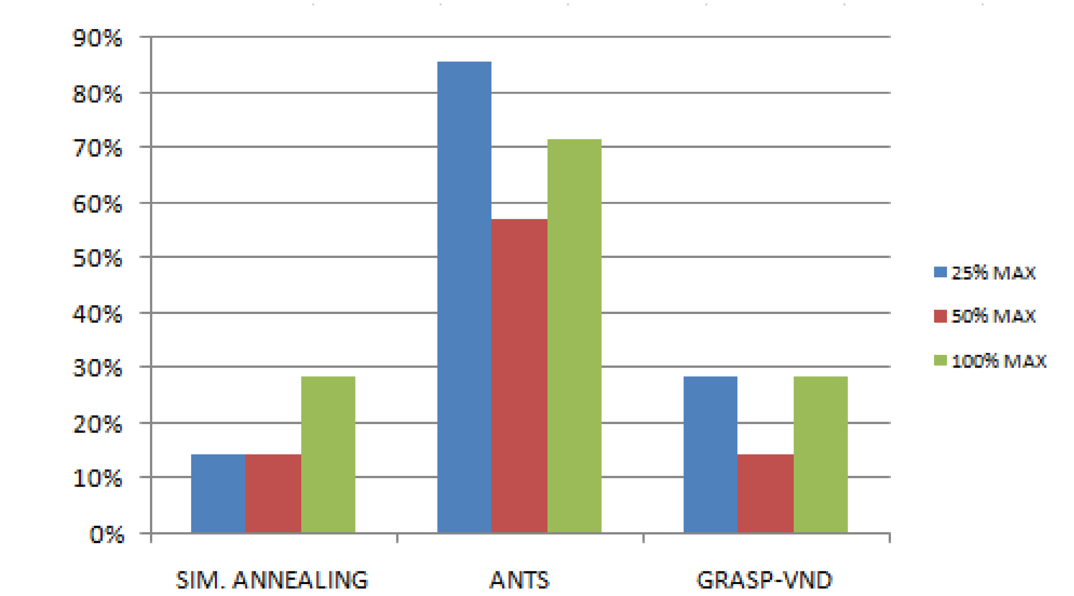


Figure 1: Percentage of tested files in which the best solution (shortest tour) was found by every algorithm under different maximum robot capacities.

Furthermore, the two-step exploration strategy achieved solutions of the same quality (from the statistical viewpoint) than those obtained with the original algorithm but in just 40% ~ 55% of the computational time initially required.

Conclusions

We have modeled the coverage repair scenario in WSRNs as a novel combinatorial optimization problem, coined as "*the one commodity traveling salesman problem with selective pickup and delivery*". Our approach uses artificial ants as search agents and outperforms existing methods in literature.

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