A Heuristic Algorithm Based on Ant Colony Optimization for Multi-objective Routing in Vehicle Ad Hoc Netwoks

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***Abstract*—Vehicle Ad hoc NETwork (VANET) provides an opportunity for innovation in the transportation area, enabling services for Intelligent Transportation System (ITS). Because of VANET features, such as highly dynamic networks topology and frequent discontinuity, it is desirable to establish, at a given moment, routes for fast delivery of messages, having a low probability of disconnection. This leads to a multiobjective problem. In this work we propose multiobjective heuristic algorithm, based on ACO (Ant Colony Optimization) to find routes considering the best commitment between the shortest path (number of nodes in a route) and the lowest probability of disconnection. Simulations were done with three different scenarios: static routing, static routing with obstacles, and dynamic routing. Results were very promising, obtained with small computational effort, and allowing the use of the algorithm for real-time optimization.**

***Index Terms*—VANET; Wireless Networks; Intelligent Transportation System; Ant Colony Optimization.**

I. INTRODUCTION

VANET (Vehicular Ad Hoc Network) is a subgroup of MANET (Mobile Ad Hoc Network) in this type of communication network each vehicle represents a node of the network and the communication can occur in two ways: **V2V** (vehicle-to-vehicle), when the communication is between two or more vehicles, or **V2I** (vehicle-to-infrastructure) when the communication is between a vehicle and a device in the highway. In this type of network, vehicles may be a router or a simple node. Figure 1 shows a diagram with the main VANET network elements, and the features of VANET networks are shown below [1]:

- Dynamic topology: the nodes (vehicles) can reach high speeds, however, unlike MANET networks, these movements are accomplished towards well-defined directions, following paths limited by streets and highways;
- Network without infrastructure: vehicular communication is based on Ad Hoc architecture, that is, without a main access point;
- Discontinuous network: as a consequence of the dynamic topology of the network, a node can easily disconnect from the network;
- Unlimited battery: knowing that the vehicle battery is recharged when it is running, the energy of a node can be considered unlimited.

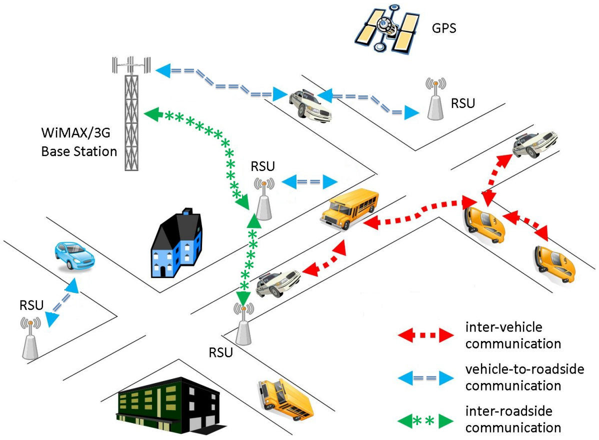


Fig. 1. Main VANET elements. Source: [2].

This type of network enables the development of several applications. Vehicular communication is considered the key for increasing traffic safety and a booster in the development of the transportation sector. The VANETs networks applications can be divided into three main groups [1]:

- Safety: preventing collision and accident reporting;
- Information: notification of traffic congestion;
- Entertainment: video streaming and internet access.

In a real VANET network, it is possible to have obstacles between two or more vehicles. These obstacles fade the signal transmitted and hinder the communication. Therefore, it is necessary to find alternative routes of communication for the vehicles in these conditions. To meet this objective, this paper proposes a multiobjective heuristic routing algorithm for VANET named AntRS. This algorithm is an evolution of another algorithm, AntSensor, proposed by Cunha [3]. AntRS is based on Ant Colony Optimization (ACO), a nature-inspired algorithm with fast response time, low computational effort, and that is particularly useful for routing problems.

A. Related Work

The algorithm ACO-AHR was proposed by Yu Wan-Jun [4]. It is a hybrid algorithm that consists of a reactive part for routing setup and a proactive part for routing maintenance.

This algorithm is also based on ACO and accounts only for the message time delivery. The deposited pheromone is proportional to the average between the estimated time of a message jump and the time spent to send this message from the origin to the destination. Unlike our proposed algorithm, this algorithm cannot guarantee routes with lower probability of disconnection, it is aimed at finding only the faster routes.

The MRAA algorithm proposed by [5] is based on the ad hoc On-demand Distance Vector protocol (AODV). For the pheromone calculation, this algorithm considers the number of jumps by the message from the source to its destination, the link capacity of the neighbors node and the total time from the source to the destination. This protocol presents some gain related to the AODV only for non stationary networks.

Correia, Celestino and Cherkaoui [6] proposed an algorithm called MAR-DYMO - Mobility-aware Ant Colony Optimization Routing Dynamic MANET On-Demand. In this algorithm the strength of the pheromone deposited is a function of the probability to receive a message sent between two nodes, separated by a distance *D* and the transmission message time. However, for multi hop routing, in which the transmission distance between origin and destination is greater than the range of the antenna, the probability of receiving the message is not a good indication of the quality of the path. In this case the only quality indicator is the transmission time.

RACO – ACO by using Related-nodes [7], is an ACO-based routing discovery algorithm. It uses the same idea of nodes position relationship (related-nodes) by recording multiple information tables of neighbor nodes called Nbtable. The updating frequency of pheromone deposit is defined by the related-nodes in the path. This algorithm presents a better convergence time for large networks. A disadvantage of this algorithm is a network overload caused by the large amount of ants.

B. The Ant Colony Optimization Algorithm – ACO

The Ant Colony Optimization algorithm (ACO) [8] was inspired by the behavior of real ants when searching for food sources. Basically, ACO is an algorithm designed to solve problems that can be represented by a graph, and a possible solution is a specific path in the graph. Ant colonies have a high organization degree capable of self-organizing into groups and develop complex tasks.

Ants communicate each other through pheromone trails left in the surface where they pass. As an example, it is possible to analyze an ants colony that begins searching for food. At first moment, there is no pheromone deposited in the path, and so, ants have no clue to where a food source can be. The first ants that leave the nest go out looking for food wandering randomly, and deposit pheromone along the path they travel. When an ant finds food, it returns to the nest depositing pheromone on the path. Other following ants occasionally will find the pheromone trail and they, in turn, tend to choose the route with the highest pheromone concentration. This leads to an increase of the pheromone concentration in that route, a positive feedback phenomenon. Thus, a path with a high traffic of ants have a high pheromone concentration, while a path with low traffic of ants will tend to extinguish the pheromone by evaporation. As shown by Dorigo [8], in the course of time the ants tend to navigate the shortest route between the colony and the food source.

The ACO algorithm simulates the behavior of an ant colony, creating artificial ants. The amount of pheromone to be deposited for a given route should consider the cost of this route. Like real ants, the probability of an artificial ant to choose a particular path is proportional to the pheromone on it. This probability is given by equation 1, where $P_{i,j}$ is the probability to choose a node j from node i, $\tau_{i,j}$ is the pheromone between the nodes i and j and $\sum_{k=1}^{n} \tau_k$ is the sum of pheromone of the whole path from node i:

$$P_{i,j} = \frac{\tau_{i,j}}{\sum\limits_{k=1}^{n} \tau_k} \qquad (1)$$

Since the choice of a path is probabilistic, wrong decisions can happen. A negative feedback mechanism, by pheromone evaporation, allows ants “to forget” low-quality routes. Pheromone evaporation is given by equation 2, where $\tau_{i,j}$ is the pheromone trails and ρ is a evaporation coefficient:

$$\tau_{i,j} = (1 - \rho)\tau_{i,j} \qquad (2)$$

One of the most known combinatorial problems in the academy, and with large applicability to real-world problems, is the Travelling Salesman Problem – TSP, for which ACO is well suited. The pseudo code of ACO for the TSP is shown in Algorithm 1 [8]:

Algorithm 1 ACO Algorithm for TSP

```
Procedure ACOMetaheuristicStatic
Set parameters, initialize pheromone trails
while ($termination\ condition\ not\ met$) do
    ConstructAntsSolutions
    ApplyLocalSearch                %optional
    updatePheromones
end while
end
```

II. PROBLEM DESCRIPTION

The basic problem approached here by AntRS, is defined as follows: given a network with N vehicles (nodes) randomly scattered in a square area of side L, it is desired to establish the best paths between different vehicles and a reference vehicle. Observing the previously mentioned VANET network characteristics, it is desirable to find the fastest paths between a message source and its destination, reducing the dynamic effect of the network typology on the routing protocol.

Due to the frequent discontinuity in VANET networks, it is necessary to reduce paths with high probability of disconnection. Therefore, it is a multi-objective problem, and the best paths are those that take into account high speed (given by the number of nodes in the path) and low probability of disconnection.

Below, the VANET network characteristics used in this work, following [9]:

- Homogeneous: nodes have the same physical capacity (hardware);
- Flat: there is no hierarchy between vehicles (nodes);
- Dynamic: nodes can change position during communication;
- Symmetric: nodes have the same radio power;

Keeping in mind these VANET network characteristics, and not considering network congestion, the fastest path will be the one with lowest hops number between the source and the destination. The path with the lowest disconnection probability will be the one with more power in communication. However, since the network is homogeneous and symmetric, it is possible to conclude, by the Friis equation [10] (where the power is inversely proportional to the square of the distance between communicating nodes), that communications will be privileged between nodes with smaller Euclidean distance between them, because they tend to stay connected for a longer time.

Notice that this is not a classic TSP problem solved by ACO. Unlike the Traveling Salesman Problem, this network do not have a single connected graph. The current problem is parallel, as if they had several TSP problems solved simultaneously, one for each node.

III. METHOD

The VANET simulation and the implementation of the AntRS algorithm were done using the object-oriented language C++. Some assumptions were done in the algorithm implementation:

- The user defines the number N of vehicles in the network. The simulation starts with these N vehicles randomly distributed over the area;
- Radios have the same power;
- The reference vehicle is randomly positioned in the network;
- There is no data loss due to possible collisions in the RF transmission.

The steps described in Algorithm 2 were the basis for the implementation of AntRS, as follows:

- Once the vehicles randomly scattered, find neighboring vehicles of each vehicle;
- Start sending agents (ants). The first agents choose randomly their route. The next agents will choose their route according to the probability given by equation 3, where α is the pheromone influence factor, β is the number of hops influence factor, γ is the Euclidean distance influence factor, N_{nodes} is the number of agents, and D is the Euclidean distance. The variable values used in the simulation are described in Table I;

$$P_{i,j} = \frac{(\tau_{i,j})^{\alpha} \times (\frac{1}{N_{nodes}})^{\beta} \times (\frac{1}{D})^{\gamma}}{\sum_{neighbors}((\tau_{i,j})^{\alpha} \times (\frac{1}{N_{nodes}})^{\beta} \times (\frac{1}{D})^{\gamma})} \tag{3}$$

- Every time an agent is sent out, the pheromone evaporation rule is applied according to equation 2;
- If the agent is returning to the origin, it is necessary to update the pheromone table according to equation 4, where τ_i is the pheromone amount, K_n is the nodes number coefficient and K_d is the Euclidean distance coefficient.

$$\tau_i = \frac{\frac{K_n}{N_{nodes}} + \frac{K_d}{D}}{K_n + K_d} \tag{4}$$

Algorithm 2 AntRS

```
1:  Set running parameters
2:  Spread the vehicles randomly
3:  for $i = 0 \to N(Vehicles\ numbers)$ do
4:      Find neighbors of vehicle (i)
5:      Create agents (ants)
6:  end for
7:  for $j = 0 \to N$ do
8:      if $Agent\ is\ in\ vehicle\ (N)$ then
9:          $Agent \leftarrow Agentinreturn$
10:         Agent returns to the origin
11:     else if Agent in return then
12:         Update the pheromone matrix
13:     else
14:         Choose next destination
15:         Send agent
16:         Evaporate pheromone
17:     end if
18: end for
```

Notice that in line 4 of the above algorithm, the neighbors of a given vehicle are all those in their range, limited only by the radio power and obstacles. In line 10, the agent (ant) will return from the destination (reference vehicle) to the origin along the same path performed to reach there. In line 12, the Pheromone Matrix is updated according to equation 4. In line 14, the next destination of the agent is chosen probabilistically according to equation 3. Finally, in line 16 the negative feedback rule is applied for evaporating pheromone at the trails, by using equation 2.

IV. EXPERIMENTS

VANETS may contain a large number of vehicles. However, for didactic purposes, our experiments shall be performed with a network composed of ten vehicles. This limitation facilitates the understanding of the underlying details of the algorithm. The experiments were divided into three parts, and the value of the parameters uses are shown in Table I:

- Simulation 1: a static VANET (stationary vehicles) without obstacles;

TABLE I
PARAMETERS USED IN THE SIMULATIONS.

Vehicle number (N)	10
Area (Km^2)	20
Nodes number coefficient (Kn)	1
Euclidean distance coefficient (Kd)	1
Agent number	20
Evaporation coefficient	0.01
Pheromone influence (α)	5
Hops number influence (β)	1
Euclidean distance influence (γ)	10

- Simulation 2: maintaining a static VANET and adding some obstacles between vehicles;
- Simulation 3: a dynamic network (vehicles in motion), some vehicles were kept static, while other move.

V. RESULTS AND ANALYSIS

A. Simulation 1

In this experiment the VANET consists of 10 static vehicles and there are no obstacles between them. The reference vehicle is the number 10. The goal is to find a path from each vehicle (source) to the reference vehicle (destination).

Figure 2 shows the location of vehicles and the connection between them. The lines between each vehicle in the figure indicate neighbor vehicles, that is, those who receive power radiated by another with sufficient level for establishing the communication. The dashed lines without arrows, in all figures in this article, indicate streets where vehicles travel over.

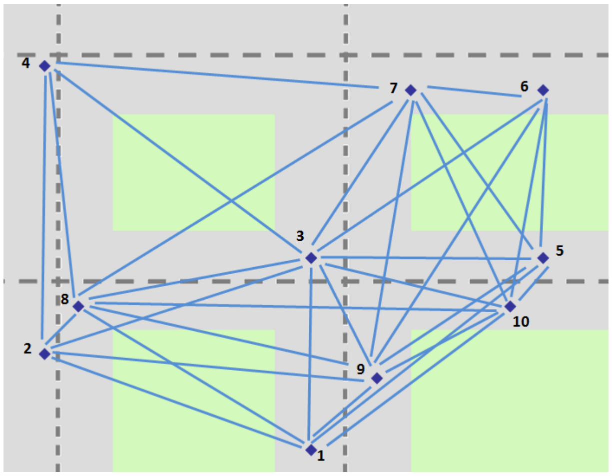


Fig. 2. Vehicles setting in the VANET and their neighbors – Simulation 1.

In Figure 2 it is observed that the network is fully connected, and so, it is possible to find a path to the reference vehicle from any vehicle in the network. For this static situation, the neighbor nodes are:
vehicle 1 → 2, 3, 5, 8, 9 and 10;
vehicle 2 → 1, 3, 4, 8 and 9;
vehicle 3 → 1, 2, 4, 5, 6, 7, 8, 9 and 10;
vehicle 4 → 2, 3, 7 and 8;
vehicle 5 → 1, 3, 6, 7, 9 and 10;
vehicle 6 → 3, 5, 7, 9 and 10;
vehicle 7 → 3, 4, 5, 6, 8, 9 and 10;
vehicle 8 → 1, 2, 3, 4, 7, 9 and 10;
vehicle 9 → 1, 2, 3, 5, 6, 7, 8 and 10;
vehicle 10 → 1, 3, 5, 6, 7, 8, and 9;

Figure 3 shows the best paths found by the AntRS algorithm in this network without obstacles.

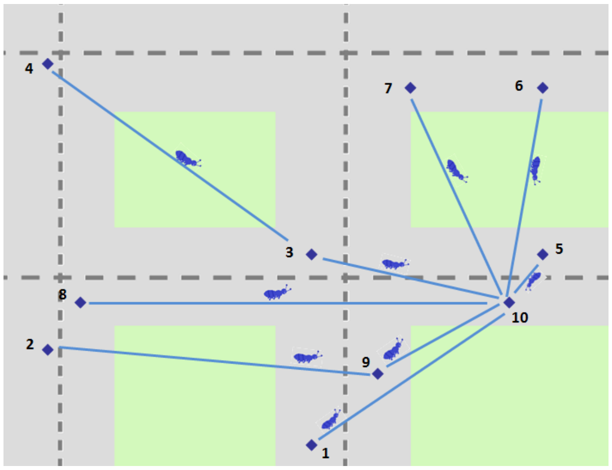


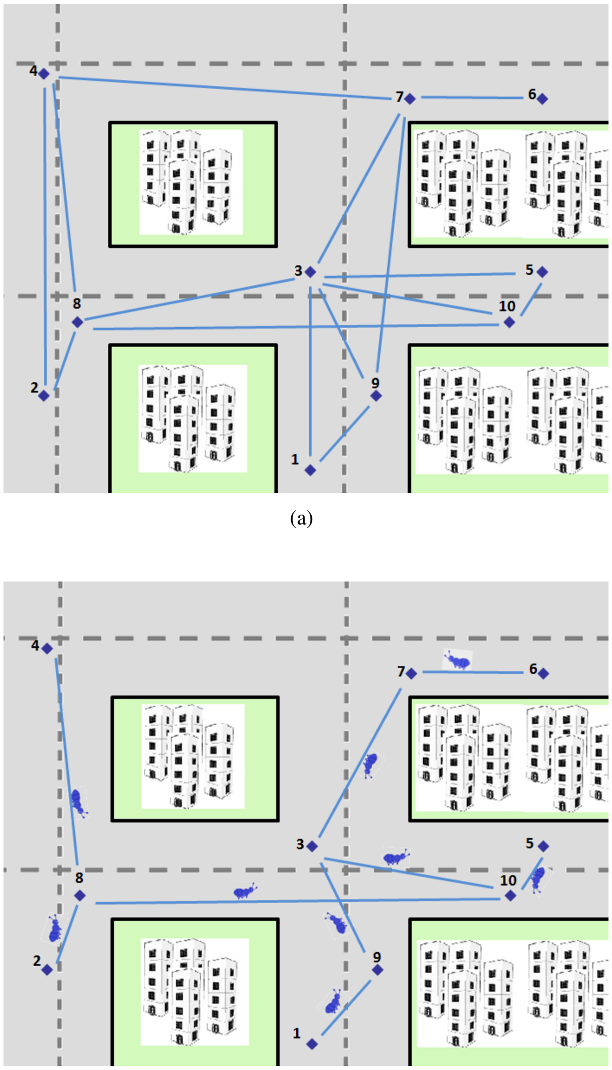
Fig. 3. Best route – static vehicles and communication without obstacles.

Analyzing the results of this simulation, it is observed that the vehicle 4 is not neighbor of the reference vehicle (vehicle 10). Therefore, it must communicate with intermediate vehicles to achieve the reference and, in this case, the shortest route to the reference vehicle has two hops. There are three ways of achieving this goal, through vehicles 3, 7 or 8. The route chosen by vehicle 4 was the route 4–3–10, because it satisfies mutually the two algorithm goals: route with the lowest number of hops and favors communication with closer vehicles.

B. Simulation 2

In this simulation the VANET consists of 10 static vehicles, and the reference vehicle is the number 10, as before. However, in this simulation there are obstacles in the communication paths. Figure 4 displays this VANET. The presence of an obstacle between two vehicles decreases the signal strength received by them, decreasing the reliability of the communication between them. Vehicles which a stablished communication with each other are shown in Figure 4(a) as continuous lines.

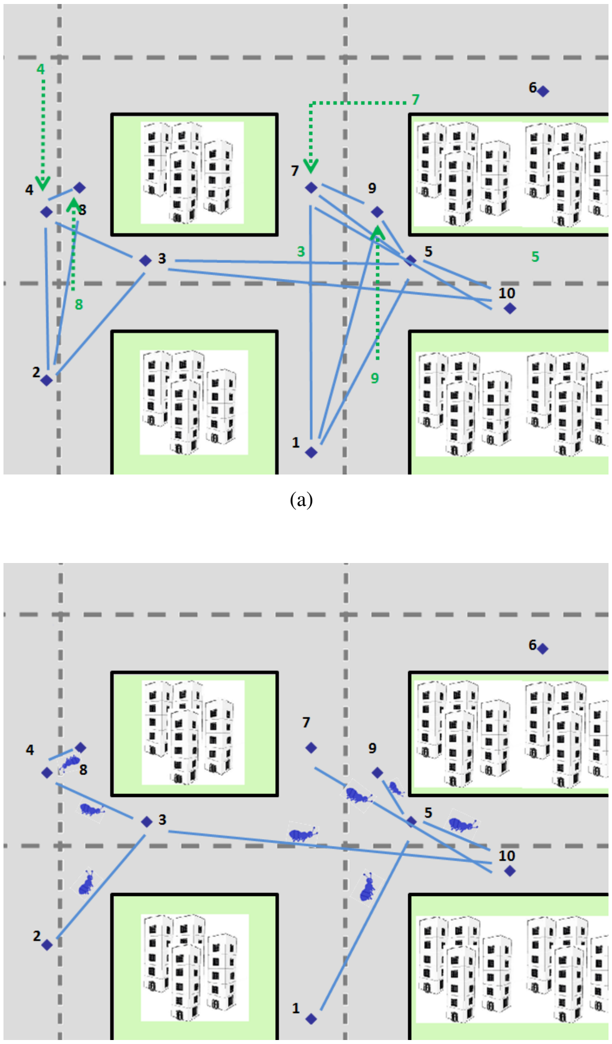
In Figure 4(b), it is observed that the vehicle 1 favors communication with closer vehicles, increasing the probability of maintaining the route connection. Vehicles 4 and 6, even far away from the reference vehicle, can find routes to it, circumventing the obstacles (Figure 4(b)).



(a)

(b)

Fig. 4. Static vehicles and communication with obstacles.



(a)

(b)

Fig. 5. Dynamic vehicles and communication with obstacles Displacement 1.

C. *Simulation 3*

In this experiment the VANET is dynamic, composed by 10 moving vehicles, and there are obstacles between some of them. We started the simulation with the vehicles in the same positions of previous simulations and, then, some vehicles are moved. During the movement of the vehicles, three time steps were analyzed to understand the behavior of the algorithm reaction to the mobility of the network:

The first time step is the beginning of the simulation when the vehicles have the same settings and positions as in Simulation 2. Therefore, the routes are the same as described in Figure 4(b).

In the second time step the vehicles are in the positions shown in Figure 5(a). The displacement of vehicles are shown in dashed arrows in the figure, and the arrows indicate the direction.

In this situation there were neighborhood changes. The vehicles neighboring relation is shown by solid lines in Figure 5(a), where it is observed that vehicle 6 is isolated from the network. So it cannot exchange messages with the network.In the Figure 5(b) is evident that vehicle 6 did not find a route communication with the reference vehicle (vehicle 10). The routes found by each vehicle in the VANET are represented by solid lines in Figure 5(b).

In the third time step the vehicles are in the positions shown in Figure 6(a).

It is observed in the Figure 6(a) that vehicle 6 reconnects to the VANET network by establishing a communication through vehicle 9, constructing the route 6–9–7–10 (Figure 6(b)).The routes found for each vehicle in the VANET are represented by solid lines in this figure.

VI. CONCLUSIONS AND FUTURE WORK

VANET is a type of Ad Hoc network and a subgroup of MANETs networks. Because their particular characteristics, especially the dynamic topology and frequent discontinuities

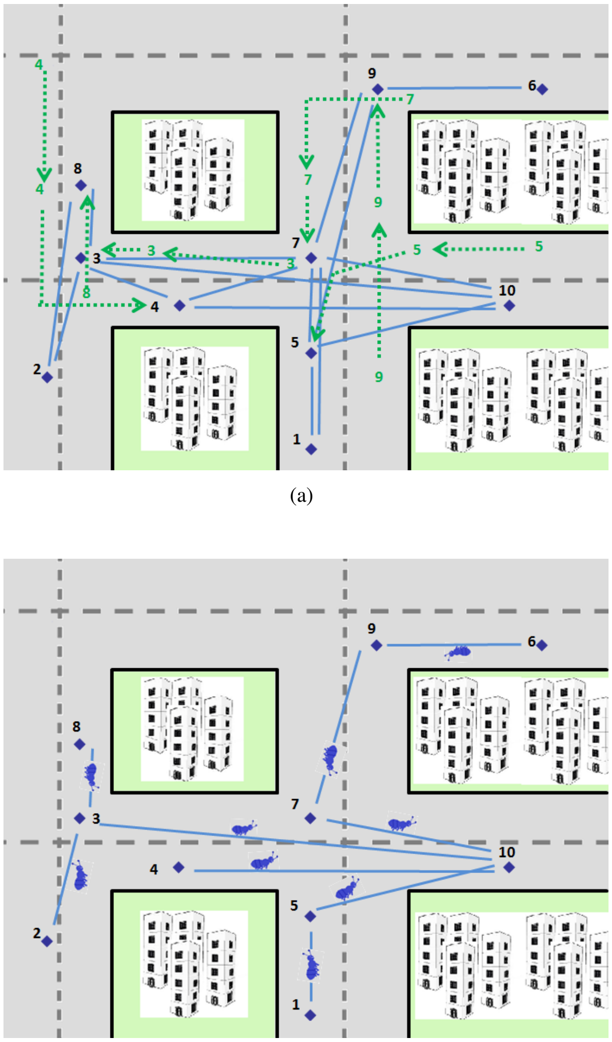


Fig. 6. Dynamic vehicles and communication with obstacles Displacement 2.

in the network, it is desirable to establish fast routes to delivery messages with a low disconnection probability.

In this paper we proposed AntRS, a heuristic multi-objective algorithm based on Ant Colony Optimization, for finding routes with the smallest cost between simultaneous vehicles and a reference vehicle. The two goals considered were the shortest path, computed by the number of hops between the source and the destination, and preference for communication between closer vehicles, that is, with smaller Euclidean distance between them.

As shown in the previous section, the results are good and promising. The algorithm converged to good solutions for the different scenarios tested in the simulations. The routes chosen for each vehicle tend to use closer vehicles, as desired. With this behavior the route remains connected for a longer time. Even when two vehicles are in opposite directions, they will remain longer receiving a signal from each other and the established communication will lasts longer.

Another feature of the proposed algorithm is that the selected routes tend to use a low number of nodes. When a message is received, each vehicle should analyze the message destination and, if necessary, to calculate the next destination (as Algorithm 2). This processing time may add a delay to the message. Therefore, reducing the number of nodes involved in the transmission of a message from source to destination, will also reduce the total delivery time of the message. As shown by the results of the simulations, the routes found by the algorithm tend to meet these two objectives.

The proposed algorithm AntRS, showed a good adaptability to the obstacles present between vehicles, finding alternative routes to transmit data, circumventing the obstacles. Therefore, it has a good response to the network mobility.

As future work will include comparison of the proposed routing algorithm (AntRS) with other existing routing algorithms, specially for high-density and dynamic networks.

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