Bio-inspired routing protocol for mobile ad hoc networks

L.J.G. Villalba  D.R. Cañas  A.L.S. Orozco

Grupo de Análisis, Seguridad y Sistemas (GASS), Departamento de Ingeniería del Software e Inteligencia Artificial, Facultad de Informática, Despacho 431, Universidad Complutense de Madrid (UCM), Calle Profesor José García Santestmases s/n, Ciudad Universitaria, 28040 Madrid, Spain
E-mail: javiergv@fdi.ucm.es

Abstract: A mobile ad hoc network (MANET) is a non-centralised, multihop, wireless network that lacks a common infrastructure. It therefore needs self-organisation. The MANETs are autonomous, adaptive and dynamic. In MANETs, multihop routing allows multiple routes between the source and destination to be established. This study speaks about a bio-inspired routing protocol for these networks based on AntHocNet. The design for the protocol lies in a heuristic, based on swarm intelligence, which takes into account the limited resources and highly dynamic environment, as well as the restriction on the exchange of routing information. So, the key aspects of the proposed protocol are the disjoint-link and disjoint-node routes, separation between the regular pheromone and the virtual pheromone in the diffusion process and the exploration of routes, taking into consideration the number of hops in the best routes which the authors have previously found out. The simulation results show that the protocol has lower overhead and higher delivered packet ratio than AntHocNet. Likewise, these results indicate that the routing satisfies multiple and independent quality of service constraints and can deal with faults, which provides better load balancing.

1 Introduction

A mobile ad hoc network (MANET) [1] is a group of mobile nodes which operate themselves through wireless links. In contrast with the conventional networks, a MANET does not need an infrastructure, since nodes rely on each other to operate themselves, forming what is called multihop communication. Such networks have more problems and disadvantages than a conventional network.

The topology of mobile networks may change quickly and without warning. As a result, errors in the transmission are unpredictable and a lack of security is common, both in nodes and links. We must add that the nodes have limited resources, since an ad hoc network is usually made by battery-powered devices with low capacity, memory and so on.

Basically, routing protocols based in MANETs are classified into three categories: proactive, reactive and hybrid. Proactive routing protocols often need to exchange control packets among mobile nodes and continuously update their routing tables. Each node must maintain the state of the network in real time. This causes high overhead congestion of the network, which requires lots of memory. The advantage of proactive protocols is that nodes have correct and updated information. So, when we need a path, we can find it directly in memory and establish links quickly. These protocols are intended to reduce broadcasting frequency while maintaining the correct information for the routing table. Reactive routing protocols only seek a route to the destination when it is needed. The advantage of these protocols is that the routing tables located in memory are not continuously updated. On the other hand, they have the disadvantage that they cannot establish connections in real time. The aim of these protocols is to save time in the route discovery process, since the reactive protocol is designed to reduce the latency which is critical in this kind of protocols. It also aims to avoid the maintenance of routes to produce long delay.

Hybrids are derived from a mixture of these two protocols, and for this reason, they share some of their advantages. This paper, which shows an innovative routing algorithm, is organised as follows. In Section 2, we present related
works, where we expose some of the bio-inspired protocols based specifically on the ant behaviour, ant colony optimisation (ACO), for *ad hoc* networks. In Section 3, we expose a base protocol which supports our approach, describing and analysing it to make a comparative study. In Section 4, we propose our protocol, explaining the features in detail. Then, in Section 5, the most relevant results are shown. Finally, the paper concludes in Section 6 with overall conclusions, observations and potential advancements for further investigations.

## 2 Related works

MANETs have special characteristics that must be taken into account when a routing protocol is implemented. There are many solutions (RFC 3626 [2], RFC 3561 [3], RFC 4728 [4], RFC 3684 [5], etc.). All these protocols have valid solutions, but they usually have a specific topology and characteristics of certain scenarios as a design basis. They are not always particularly suitable if there are drastic changes in the dynamic topology of the network. There is a group of algorithms or routing protocols called bio-inspired, whose essential characteristic consists of being adaptive, which is especially noteworthy in this kind of network. The concept of swarm intelligence [6] is specifically referred to in the literature. It is based on the application of social behaviour of insects and other animals to solve the problems. The ACO [7] algorithm is the starting point of these algorithms. The ACO algorithms are based on the collective behaviour of ants in search of food to bring back to the nest. Various tasks are performed by proposals of ACO routing, in which proactive, reactive and hybrid protocols are found.

Since proactive ACO routing protocols are included, probabilistic emergent routing algorithm [8] has a low delivered data packet ratio in scenarios with high mobility; it has a high overhead caused by control messages being sent several times in broadcast mode. Another protocol is ant routing algorithm for MANETS [9] which, according to the authors, reduces the overhead of discovery and maintenance of the routes; but, they do not discuss how they control the generation of control messages in a dynamic environment. However, it has the common characteristic of achieving a low latency in the route discovery process, with the information of the routing table receiving correct updates. We also mention reactive protocols called ant-colony-based routing algorithm (ARA) [10]. This approach made use of the process of flooding to update pheromone tables in all nodes. This process has greater scope in the transmission of packets than a simple broadcast, but leads to high overhead. ARA is not scalable and does not detect loops. Ant colony-based multipath quality of service (QoS)-aware routing [11] protocol is robust and can withstand better QoS, but is similar to reactive protocol, which has a high latency in the discovery of routes. As hybrid ACO routing protocols are included, ant *ad hoc* on-demand distance vector [12], in which the latency of route discovery is reduced, because the process of route discovery is reduced. Hybrid ACO routing algorithm for MANET [13] is a highly scalable protocol, with the disadvantage that, when the number of nodes is low, the continuous movement of the peripheral nodes incites to discover new routes causing more delay than other hybrid protocols, and AntHocNet [14–16] protocol is based on the approach made in this article. This protocol does not take into account disjoint-link/node routes and has a high overhead in the process of exploring new routes. The disadvantage of the previously reviewed protocols is not using disjoint routes, whether link or node.

## 3 AntHocNet

AntHocNet [15, 16] is a hybrid ACO routing algorithm. Data from 2004 and 2005 have had numerous extensions and a great impact, being a pioneer algorithm in this field. This protocol is applied to multipath and dynamic networks, that is, creating multiple paths to transmit data from source to destination in the same data session. AntHocNet follows a structure similar to AntNet-fast ant (AntNet-FA) [17], but it differs from AntNet-FA given that topologies of static networks are applied and convergence is slow. So, what all ants have to do is choose the path. AntHocNet, meanwhile, takes into account the dynamic topology and other characteristics of *ad hoc* networks. When the network topology changes, then it must be restored quickly and this is achieved through a new route discovery process. If multiple resources are used to accelerate this process, the exchange of information is enhanced. This can cause the network to collapse. Therefore we have a problem that if we do not want to overload the network, we increase the convergence time (time required for the network to become stable before a link failure) of the ACO algorithm, and if we want to reduce the convergence time, we overload the network. The previous problem means that AntNet-FA algorithm does not directly apply to MANETs, so it needs a modification to accelerate its convergence time without overloading the network. In this way, AntHocNet emerges as a reactive, adaptive, multipath and proactive algorithm (hybrid). It is reactive because it has agents operating on-demand to set up routes to destinations.

- It is proactive because it has agents collecting information and these agents can discover new routes which serve as alternatives if a link fails.
- It is a multipath because it provides different routes to send information to the destination.
- It is adaptive because it adapts to traffic conditions and networks.

In the operation of AntHocNet, the following stages or phases are distinguished:
• Routing information setup: The source node sends reactive agents to discover the first available route to the destination.

• Data routing: Data are sent through the nodes to the destination using the route information and can use a multihop technique, which involves sending data through intermediate nodes. These nodes act as routers.

• Path maintenance and exploration: Information about existing routes is proactively updated and the discovery of new ones is possible.

• Management of link failures: Management failures occur when a node is outside the scope of the network or does not receive control messages which are responsible for informing a node of its closest neighbours (who are one hop), and so on. This phase deals with such failures.

4 AntHocNet-based improved routing (AntOR): routing approach

The proposed protocol, AntHocNet-based improved routing (AntOR), is a hybrid ACO routing protocol that takes Ducatalle algorithm [18] as its starting point, and demonstrates the following qualities and abilities, which are different from AntHocNet:

• disjoint-link and disjoint-node protocol;

• separation between the pheromones in the diffusion process;

• use distance metric in path exploration.

4.1 Disjoint-link/node protocol

In such protocols there are two kinds of routes: disjoint-node and disjoint-link. The first corresponds to routes in which nodes are not shared and the latter refers to routes in which links are not shared. Every disjoint-node is also a disjoint-link, but not vice versa.

Both types of disjoint routes have the following advantages:

1. A failure in one node only affects a path, not the entire network.

2. Load balancing is better because there are not repeated routes on the disjoint property.

However, the use of such routes does also have its disadvantages, for example

1. More resources are needed because they do not share links and nodes.

2. These routes are more difficult to detect, because we limit the nodes that can be explored.

Our approach does not use disjoint-partial routes as in [19]. Disjoint-link and disjoint-node are different from the disjoint-partial because they may have both nodes and links in common. Disjoint-partial routes are less restrictive, allowing computing of more routes, providing better tolerance to link failures as a result of quick and efficient recovery from broken routes. Also, in general, they are easier to detect. But they have the disadvantage of using some intermediate node of the main route (hybrid approach between disjoint-link and disjoint-node), so whether an intermediate node fails a new route has to be discovered. Therefore the routes which are only disjoint-link or disjoint-node prevent better link failures because they have alternatives so that nodes and links are not repeated. This is one of the reasons not to use disjoint-partial routes. Next, we will show how to calculate disjoint-node and disjoint-link with regard to AntOR algorithm.

4.1.1 Disjoint-node routes: As mentioned above, a disjoint-node route is one in which nodes are not shared in the same data session. Fig. 1 shows an example of disjoint-node routes. The procedure for calculating disjoint-node route is different from how we calculate disjoint-link. In the case of disjoint-node, the intermediate nodes which have been visited are marked, so we do not repeat them. This table shows information regarding the previously visited nodes, which is stored ‘locally’. This aims to perform a proactive process for the exploration of new routes. In Fig. 2 a flowchart shows the functionality of this method.

4.1.2 Disjoint-link routes: As previously mentioned, a disjoint-link route is one in which no links are shared on a same data session. Fig. 3 shows an example of disjoint-link route, which recognises the difference between disjoint-link route and non-disjoint-link route. The basic idea for finding and representing disjoint-link routes is to mark each disjoint-link with a label indicating what the source of the data session is. In Fig. 4, we present a diagram showing how this process functions. We can see that the mechanism is very simple.

![Figure 1](https://example.com/figure1.png)
When two or more data sessions sharing links in its information retransmit, the procedure to calculate disjoint-link routes is similar: each link which is visited is marked according to the session that it belongs to. As a result, there will be no conflict or problems since the sessions do not rely on each other.

4.2 Separation between the pheromones in the diffusion process

In Ducatelle’s approach [18], the same route can have both regular pheromone values and pheromone virtual values simultaneously. Regular pheromone values are used to determine the routes through which data travels. On the other hand, virtual pheromone values indicate the routes that can possibly be ‘good’ to relay the data.

In AntOR, a route cannot have both a regular pheromone value and a virtual pheromone simultaneously; this technique improves the efficiency of the algorithm. To carry out this separation, the equation (1) of Ducatelle’s route exploration is changed [18].

\[
P_{in}^d = \frac{\max(t_{in}^d, k_{in}^d \beta_2)}{\sum_{j \in N_i} \max(t_{ij}^d, k_{ij}^d \beta_2)}
\]

where \(P_{in}^d\) is the likelihood that node \(i\) chooses the next hop \(n\) with destination node \(d\); \(\max(a, b)\) function returns the maximum of two values \(a\) and \(b\); \(t_{in}^d\) corresponds to the regular pheromone value; \(k_{in}^d\) corresponds to the virtual pheromone value; \(\beta_2\) is a protocol configuration parameter. It is used in the proactive process for new routes exploration. When this parameter has a low value, all alternative routes to a destination can be chosen with equal probability \(N_i^d\). This is a one-hop neighbour of node \(i\).
The result of this modification of (1) is shown in the following one.

\[ P_{\text{in}}^k = \frac{(\psi^k_{\text{in}})^{\beta_k}}{\sum_{\tau \in N^k} (\psi^k_{\tau})^{\beta_k}}, \quad \psi \in \{ k \text{ virtual } \tau \text{ regular} \} \quad (2) \]

where \( \psi \) corresponds to a regular or virtual pheromone value, but never corresponds to both simultaneously.

Then, an example to compare the difference of (1) and (2) is shown. There are four nodes (A, B, C and D) in the scenario. As node A wants to send data to the destination node D, node A needs to choose the most appropriate route. Fig. 5 shows the scenario from the point of view of Ducatelle equation or (1), where the two routes from A have regular and virtual pheromones. Therefore to calculate the probability of choosing the alternative route 1, the following equation is used

\[ P_{\text{D}AC}^D = \max(\tau_{\text{D}AC}^{\beta_k}, k_{\text{D}AC}^{\beta_k}) \frac{\max(\tau_{\text{D}AB}^{\beta_k}, k_{\text{D}AB}^{\beta_k})}{\max(\tau_{\text{D}AB}^{\beta_k}, k_{\text{D}AB}^{\beta_k}) + \max(\tau_{\text{D}AC}^{\beta_k}, k_{\text{D}AC}^{\beta_k})} \quad (3) \]

On the other hand, Fig. 6 shows the same scenario but from the perspective of AntOR. In this case, the alternative route 1 has only regular pheromone and the route 2 has only virtual pheromone. Thus, the probability of choosing the alternative route 1 is given by next equation

\[ P_{\text{D}AC}^k = \frac{(\tau_{\text{D}AC}^{\beta_k})}{(\tau_{\text{D}AC}^{\beta_k} + (k_{\text{D}AB}^{\beta_k}))} \quad (4) \]

These two equations (3) and (4) use the pheromone in a different way to calculate the alternative routes. In the case of (3) a route can have regular and virtual pheromones simultaneously. In the case of (4) the same route has regular or virtual pheromone, but not both at the same time.

### 4.3 Use distance metric in path exploration

Our approach takes into account the number of hops for the routes which have been found to be the best. There is a hop limit on the nodes. This hop limit is established according to previously calculated routes that have a smaller distance in hop number. Fig. 7 shows an example of how this mechanism which we have mentioned in our approach works.

Once you have established the main route, sending proactive control packets to explore new routes can be...
chosen from two alternatives: (a) alternative route 1 and (b) alternate route 2. In this proactive process, route 1 will be chosen because it has a hop count less than the main route because the main route consists of three hops. Thus, the control messages that they choose route 2 will never reach their destination because they are scheduled at most to visit three nodes.

5 Illustrative results

In this section, we show the most relevant results from what we discovered in the simulation.

5.1 Parameter setting

To evaluate the behaviour of the protocol network simulator 3 (NS-3) has been used [20]. We compared AntOR-DLR (disjoint-link route version) with AntHocNet. So, we have used common parameters for both the protocols, as is shown in Table 1. Table 2 shows the internal characteristics of both protocols that are compared. Finally, in Table 3 we indicate the parameters of the scenario, where you can see mobility as an important characteristic: random waypoint (RWP). We also used a highly dynamic scenario (maximum speed of nodes is 10 m/s) because it is attempting to analyse the worst case. Next, we show the obtained results by comparing both protocols using the same scenario, according to different performance parameters.

5.2 Performance metrics

The most important performance metrics that were used to assess this approach are

- Throughput: Volume of work or information flowing through a system. It is calculated by dividing the total number of bits delivered to the destination by the packet delivery time.
- Delivered data packet ratio: Relationship between number of packets sent and the number of packets delivered successfully.
- Average end-to-end delay: Measure of accumulative effectiveness of experienced delays by packets going from source to destination.
- Overhead in number of packets: Relationship between the total numbers of transmitted control packets by the nodes of network and the number of delivered data packets to their destinations.
- Overhead in number of bytes: Relationship between the total number of transmitted control bytes and delivered data bytes.

Table 2 Parameters of configuration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$</td>
<td>0.7</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.7</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>20</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>2</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>20</td>
</tr>
<tr>
<td>maximum number of destinations in the HELLO message</td>
<td>10</td>
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<tr>
<td>HELLO emission interval</td>
<td>1 s</td>
</tr>
<tr>
<td>PFA emission interval</td>
<td>2 s</td>
</tr>
<tr>
<td>maximum number of retry for restoring the route</td>
<td>5</td>
</tr>
<tr>
<td>RFA emission interval</td>
<td>5 s</td>
</tr>
<tr>
<td>maximum number of broadcast allowed by RRFA message</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3 Parameters of stage

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>beginning of time CBR client:</td>
<td>0 s</td>
</tr>
<tr>
<td>ending of time CBR client:</td>
<td>30 s</td>
</tr>
<tr>
<td>beginning of time CBR server:</td>
<td>0 s</td>
</tr>
<tr>
<td>ending of time CBR server:</td>
<td>30 s</td>
</tr>
<tr>
<td>number of data sessions:</td>
<td>4</td>
</tr>
<tr>
<td>position model:</td>
<td>list</td>
</tr>
<tr>
<td>mobility model:</td>
<td>RWP</td>
</tr>
<tr>
<td>velocity:</td>
<td>minimum 0 and maximum 10 m/s</td>
</tr>
<tr>
<td>pause time:</td>
<td>5 m/s</td>
</tr>
</tbody>
</table>

Table 1 General features of the simulations

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>number of nodes:</td>
<td>between 20 and 100</td>
</tr>
<tr>
<td>dimensions of area:</td>
<td>1400 × 1400</td>
</tr>
<tr>
<td>transmission range (open area):</td>
<td>300 m</td>
</tr>
<tr>
<td>physical layer:</td>
<td>configured for IEEE 802.11b</td>
</tr>
<tr>
<td>sent data ratio:</td>
<td>constant WiFi-6 mps</td>
</tr>
<tr>
<td>time simulation:</td>
<td>30 s</td>
</tr>
<tr>
<td>number of trials:</td>
<td>3</td>
</tr>
</tbody>
</table>
5.3 Throughput

Fig. 8 shows that throughput in AntOR in extreme situations (space networks or very dense) is higher than AntHocNet’s throughput. In average situations, the values are made equal. Similarly, a robustness of the protocol is shown since the curve displays a greater stability against variations in network conditions.

5.4 Delivered packet ratio

Fig. 9 shows that delivered packet ratio is similar to throughput seen previously, but with the use another scale. This is because the delivered packets influence in both the metrics, and we can also see how AntOR is scalable, obtaining a good ratio with 100 nodes.

5.5 Average end-to-end delay

Fig. 10 shows that average end-to-end delay of AntOR in sparse network is superior to finding in AntHocNet. However, the value of this delay is not very high. For denser networks, AntOR is practically made equal to AntHocNet. Although the latter has better values of delays in sparse networks, it seems to be more unstable against increasing nodes than AntOR.

5.6 Overhead in number of packets

Fig. 11 shows that the overhead in the number of packets of AntOR is lower than AntHocNet, which proves that the changes made are correct. The disjoint-link capacity means less proactive forward ant (PFA) control messages are sent. With better tolerance of link failures, thanks to the existence of alternative routes, fewer repair route forward ant (RRFA) control message in the route repair process needs to be sent.

5.7 Overhead in number of bytes

Fig. 12 appreciated that in the case of sparse networks, the overhead in the number of bytes (which is a more representative parameter) is similar in both the protocols, while in the case of denser networks, there is a reduced overhead than with AntHocNet.

6 Conclusions

We have presented a routing protocol for MANETs called AntOR that is classified as a hybrid ACO routing protocol (based on the algorithm of ant colony) and can be
considered as a variant of the AntHocNet protocol, which improves the performance in important parameters such as delivered packet ratio, the overhead in the number of packets and the overhead in the number of bytes. The protocol is stable in the carried out simulations, which suggested its scalability. Even more outstanding characteristics of this variant approach of AntHocNet can be noticed. Several are mentioned below:

- use disjoint-link/node routes;
- the separation between the pheromones in the diffusion process;
- the new route exploration process takes into account the hop number of the best routes found previously.

These latest characteristics and qualities have as a goal, the reduction of the overhead in the number of bytes and the increase of delivered packet ratio of AntHocNet, whose aspects have been achieved with this approach.

There are several possible lines of work which could be developed further. Among them are the following:

- Specify new simulation scenarios to validate the obtained result.
- Analyse other performance metrics such as jitter.
- Implement the disjoint-node version (it has implemented disjoint-link version).
- Make a comparison with more reference protocols.
- Implement disjoint-partial route version by comparing this approach with the proposed approach.

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8 References


