

# AN INNOVATIVE DESIGN OF AN ANTHOCNET ROUTING ALGORITHM BASED ON DIFFERENT COMPONENTS

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## ABSTARCT:

Mobile ad hoc networks are a class of highly dynamic networks. In previous work, we developed a new routing algorithm, called AntHocNet, for these challenging network environments. AntHocNet has been designed after the Ant Colony Optimization (ACO) framework, and its general architecture shares strong similarities with the architectures of typical ACO implementations for network routing. On the other hand, AntHocNet also contains several elements which are new to ACO routing implementations, such as the combination of ant-based path sampling with lightweight information bootstrapping process, the use of both reactive and proactive components, and the use of composite pheromone metrics. In this paper we discuss all these elements, pointing out their general usefulness to face the multiple challenges of mobile ad hoc networks, and perform an evaluation of their working and effect on performance through extensive simulation studies.

**Keywords:** AntHocNet routing algorithm; bootstrap process; reactive and proactive components; pheromone metrics .

## 1. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) [1] are networks in which all nodes are mobile and communicate with each other via wireless connections. Nodes can join or leave at any time. There is no fixed infrastructure. All nodes are equal and there is no central control or overview. There are no designated routers: nodes serve as routers for each other, and data packets are forwarded from node to node in a multihop fashion. MANETs are useful to bring wireless connectivity in infrastructure less areas or to provide instantaneous connectivity free of charge inside specific user communities and/or geographic areas. However, the control of a MANET is very challenging. Its topology and traffic patterns are determined by the present users, their positions and radio ranges. The effectively available bandwidth is defined by the characteristics of the wireless signal between the nodes, and by the amount of simultaneous contention to access the shared wireless medium. Due to the mobility and the constant arrival/departure of users, all these characteristics, which make up the mode of the network, change over time, and different modes can coexist in different parts of the network.

Routing is at the core of the functioning of a MANET, and the challenges mentioned above call for a fully adaptive, multi-modal routing controller. We believe that the multidimensional complexity of the task makes it necessary to include multiple learning, adaptive, and behavioral components in the design of the routing algorithm. This is the approach we followed in AntHocNet [2][6]. It combines Monte Carlo path sampling and learning using ant agents, which is characteristic of the ACO framework [7], with an information bootstrapping process, which is typical for dynamic programming and some reinforcement learning approaches [8]. Operating the two learning mechanisms at different speeds allows to obtain an adaptivity, robustness and efficiency which neither of the subcomponents could offer on its own. Moreover, the use of both proactive and reactive behaviors allows to both anticipate and respond in timely fashion to sudden disruptive events. AntHocNet's design also

includes the use of multiple metrics (e.g., number of hops and signal quality) in the definition of the pheromone variables used to guide ant decisions.

AntHocNet was inspired by previous work on ACO routing for wired networks [9], but its composite design represents a departure from previous instances of ACO algorithms for routing. The effective integration of a bootstrapping-based mechanisms within a typical ACO architecture is in fact an approach which is innovative in general terms, and not only concerning the application of ACO to network problems. Furthermore, the way we integrated the two mechanisms in AntHocNet is rather general and could be applied with success also to different application domains. Moreover, while the combined use of reactive and proactive ant generation, as well as the use of a composite pheromone metric, are not totally a novelty in ACO routing algorithms, the way these schemes are used is original and general (e.g., see [10{12] for examples of other ACO algorithms for MANETs).

The purpose of this paper is to report an experimental analysis of the role and effect of these different design components of the algorithm. In particular, we show the effect on performance of using bootstrapping and proactive components, of adopting different choices for the composite pheromone metric used to guide ant activities, and of selecting different levels of exploration. Even if this sensitivity analysis is specific for AntHocNet, we believe that to a certain extent the reported results can also provide general insights about all the considered issues, and in particular about the integration of ant-based path sampling with pheromone bootstrapping mechanisms.

The general effectiveness of AntHocNet's integrated approach was assessed in a number of papers [2{6] and a technical report [13]. Over a wide range of scenarios with different characteristics in terms of mobility, data traffic load, modality, etc., AntHocNet always showed excellent performance compared to state-of-the-art MANET routing algorithms such as AODV [14] and OLSR [15]. In this paper we focus on the sensitivity analysis and we do not report any further results concerning AntHocNet's general performance.

The rest of the paper is organized as follows. In Section 2 we provide a concise description of AntHocNet (for more details the reader can consult the mentioned references). Section 3 describes the experimental methodology and the general characteristics of the simulation environment.

## 2. THE ANTHOCNET ROUTING ALGORITHM

In MANET jargon AntHocNet is termed a hybrid algorithm since it makes use of both reactive and proactive strategies to establish routing paths. It is reactive in the sense that a node only starts gathering routing information for a specific destination when a local traffic session needs to communicate with the destination and no routing information is available. It is proactive because as long as the communication starts, and for the entire duration of the communication, the nodes proactively keep the routing information related to the ongoing flow up-to-date with network changes. In this way both the costs and the number of paths used by each running flow can reflect the actual status of the network, providing an optimized network response. The reactive component of the algorithm deals with the phase of path setup and is totally based on the use of ACO ant agents to find a good initial path. Routing information is encoded in node pheromone tables. The proactive component implements path maintenance and improvement, proactively adapting during the course of a session the paths the session is using to network changes. Path maintenance and improvement is realized by a combination of ant path sampling and slow-rate pheromone diffusion: the routing information obtained via ant path sampling is spread between the nodes of the MANET and used to update the routing tables according to a bootstrapping scheme that in turn provide main guidance for the ant path exploration. Link failures are dealt with using a local path repair process or via explicit notification messages. Stochastic decisions are used both for ant exploration and to distribute data packets over multiple paths.

In the following we provide a concise description of each of these components. The component dealing with link failures is not described since it is neither central for the algorithm nor relevant for the sensitivity analysis reported here.

### 2.1. Metrics for path quality and pheromone tables

Paths are implicitly defined by tables of pheromone variables playing the role of routing tables. An entry  $T_{nd}^i \in \mathbb{R}$  of the pheromone table  $T^i$  at node  $i$  contains a value indicating the estimated goodness of going from  $i$  over neighbor  $n$  to reach destination  $d$ . Since AntHocNet only maintains information about destinations which are active in a communication session, and the neighbors of a node change continually, the filling of the pheromone tables is sparse and dynamic. Several different metrics, such as number of hops, end-to-end delay, signal quality, congestion, etc., can be used to define the goodness of a path. AntHocNet makes use of a combination of these metrics to define the pheromone variables.

### 2.2. Reactive path setup

When a source node  $s$  starts a communication session with a destination node  $d$ , and it does not have routing information for  $d$ , it broadcasts a reactive forward ant. At each node, the ant is either unicast or broadcast, according to whether or not the current node has pheromone information for  $d$ . If information is available, the ant chooses its next hop  $n$  with the probability  $P_{nd}$  which depends on the relative goodness of  $n$  as a next hop, expressed in the pheromone variable  $T_{nd}^i$ :

$$P_{nd} = \frac{(T_{nd}^i)^\beta}{\sum_{j \in N} (T_{jd}^i)^\beta}, \beta \geq 1 \quad (1)$$

where  $N_d^i$  is the set of neighbors of  $i$  over which a path to  $d$  is known, and  $\beta$  is a parameter which controls the exploratory behavior of the ants. If no pheromone is available, the ant is broadcast. Since it is quite likely that somewhere along the path no pheromone is found, in the experiments we normally use a high value of  $\beta$  to avoid excessive ant proliferation. Due to subsequent broadcasts, many duplicate copies of the same ant travel to the destination. A node which receives multiple copies of the same ant only accepts the first and discards the other. This way, only one path is set up initially. During the course of the communication session, more paths are added via the proactive path maintenance and exploration mechanism discussed in the next subsection.

Each forward ant keeps a list of the nodes it has visited. Upon arrival at the destination  $d$ , it is converted into a backward ant, which travels back to the source retracing the path. At each intermediate node  $i$ , coming from neighbor  $n$ , the ant updates the entry  $T_{nd}^i$  in the  $i$ 's pheromone table. The way the entry is updated depends on the path quality metrics used to define pheromone variables. For instance, if the pheromone is expressed using the number of hops as a measure of goodness, at each hop the backward ant increments an internal hop counter and uses the inverse of this value to locally assign the value  $\delta_d^i$  which is used to update the pheromone variable  $T_{nd}^i$  as follows:  $T_{nd}^i = T_{nd}^i + (1 - \delta_d^i) \cdot 2$  [0; 1]: For different metrics, the calculation of  $\delta_d^i$  is more complex but follows the same logic. For instance, if delay is used, the ant needs to incrementally calculate at each node a robust estimate of the expected delay to reach the destination.

### 2.3. Proactive path maintenance and exploration

During the course of a communication session, source nodes periodically send out proactive forward ants to update the information about currently used paths and try to find new and better paths. They follow pheromone and update pheromone tables in the same way as reactive forward ants. Such continuous proactive sampling of paths is the typical mode of operation in ACO routing algorithms. However, the ant sending frequency needed to faithfully keep track of the constant network changes is in general too high for the available bandwidth. Moreover, to find entirely new paths, excessive blind exploration through random walks or broadcasts would be needed. Therefore, we keep ant sending rate low but ant actions are integrated with a lightweight process combining pheromone diffusion and bootstrapping. This process provides a second way of updating pheromone on existing paths, and can give information to guide exploratory ant behavior.

Pheromone diffusion is implemented using beacon messages broadcast periodically and asynchronously by the nodes to all their neighbors. In these messages, the sending node  $n$  places a list of destinations it has information about, including for each destination  $d$  its best pheromone value  $T_{m^nd}^n$ . A node  $i$  receiving the message from  $n$  first of all registers that  $n$  is its neighbor. Then, for each destination  $d$  listed in the message, it derives an estimate of the goodness of going from  $i$  to  $d$  over  $n$ , combining the cost of hopping from  $i$  to  $n$  with the reported pheromone value  $T_{m^nd}^n$ . We call the obtained estimate  $B_{nd}^i$  bootstrapped pheromone, since it is built up bootstrapping on the value of the path goodness estimate received from an adjacent node. The bootstrapped pheromone can in turn be forwarded in the next message sent out by  $n$ , giving rise to a bootstrapped pheromone field over the MANET. This is the typical way of calculating estimates followed by all approaches based on dynamic programming such the class of distributed Bellman-Ford routing algorithms [16] and the reinforcement learning algorithms derived from Q-learning [8]. However, due to the slow multi-step forwarding, bootstrapped pheromone does not provide the most accurate view of the current situation and has difficulty to properly track the distributed changes in the network. Generally speaking, bootstrapping alone is not expected to work effectively in highly non-stationary environments. However, here the bootstrapped pheromone is obtained via a lightweight, efficient process, and is complemented by the explicit Monte Carlo path sampling and updating done by the ants. In this way we have two complementary updating frequencies in the path updating process. Bootstrapped pheromone is used directly for the maintenance of existing paths. That is, if an entry  $T_{nd}^i$  is present in the routing table,  $B_{nd}^i$  is used as a replacement of it. For path exploration, bootstrapped pheromone is used indirectly. If  $i$  does not yet have a value for  $T_{nd}^i$  in its routing table,  $B_{nd}^i$  could indicate a possible new path from  $i$  to  $d$  over  $n$ . However, this path has never been sampled explicitly by an ant, and due to the slow multi-step process it could contain undetected loops or dangling links. It is therefore not safe to use for data forwarding before being checked. This is the task of proactive forward ants, which use both the regular and the bootstrapped pheromone on their way to the destination. This way, promising pheromone is investigated, and can be turned into a regular path available for data. This increases the number of paths available for data routing, which grows to a full mesh, and allows the algorithm to exploit new opportunities in the ever changing topology.

#### 2.4 Stochastic data routing

Nodes in AntHocNet forward data stochastically according to the pheromone values. When a node has multiple next hops for the destination  $d$  of the data, it randomly selects one of them, with probability  $P_{nd}$ .  $P_{nd}$  is calculated like for reactive forward ants, using Eq. 1. According to this strategy, a mesh of multiple paths is made available to route data. The number of paths to use is automatically and dynamically selected in function of their estimated quality.

### 3. EXPERIMENTAL METHODOLOGY AND CHARACTERISTICS OF THE SIMULATION ENVIRONMENT

For the study of the performance of AntHocNet, we use simulation experiments. This is the most common approach in MANETs, since the complexity of this kind of networks makes analytical evaluations difficult and limited in scope, while the high costs involved in purchasing and configuring hardware limit the use of real test beds. As simulation software, we use QualNet [17], a commercial simulation package which comes with correct implementations of the most important protocols at all layers of the network protocol stack.

All the simulation tests reported in this paper last 900 seconds, and each data point represents the average taken over 10 runs using different random seeds. The tests are carried out in open space scenarios (see [13] for evaluations of AntHocNet in a structured urban scenario). 100 nodes move in an area of 2400 800 m<sup>2</sup>. The movements of the nodes are defined according to the random waypoint mobility model [18]. Nodes pick a random destination point in the area, and move to that point with a randomly chosen speed. Upon arrival, they stay put for a fixed pause time, after which a new random destination and speed are chosen. In our experiments,

the node speed is chosen uniformly between 0 and 10 m/s, unless stated otherwise. The pause time is always 30 seconds.

Radio signal propagation is modeled with the two-ray ground reflection model, which considers both the direct and the ground reflection path [19]. The transmission range of each node is 250 meters. At the physical and medium access control layers of the network protocol stack, we use the IEEE 802.11b protocol in DCF function with 2 Mbits/s bandwidth. At the application layer, data traffic is generated by 20 constant bit rate (CBR) sources, sending packets of 64 bytes. The CBR sessions start at a random time between 0 and 180 seconds after the start of the simulation, and go on until the end of the simulation. The data rate is 4 packets per second, unless stated differently. CBR uses the UDP protocol at the transport layer. All these settings reflect choices widely adopted in MANET research. Concerning the AntHocNet parameters, if not stated differently, the value of  $\alpha$  in Eq. 1 is set to 20, the maximum number of entries in the pheromone diffusion messages is set to 10, and the sending interval for the proactive ants is 2 seconds.

To evaluate the performance of the routing algorithms, we measure the average end-to-end delay for data packets and the ratio of correctly delivered versus sent packets (delivery ratio). These are standard measures of effectiveness in MANETs. Other metrics which we consider are delay jitter and routing overhead. Delay jitter is the average difference in inter-arrival time between packets. This is an important metric in quality-of-service networks and in MANETs provides also a measure of the stability of the algorithm's response to topological changes. Routing overhead is a measure of efficiency. We calculate it as the number of control packet transmissions (counting every hop) per data packet delivered. Due to space limitations we do not show the results for jitter and overhead. In any case, for all the tests of Section 4, the results for jitter and overhead always follow the same trends of those for delivery ratio and end-to-end delay.

#### 4. CONCLUSION

MANETs are extremely dynamic network environments. Their multi-modality represents an important challenge for algorithms at all levels of the network protocol stack, and specifically for routing. We addressed these challenges with AntHocNet, a routing algorithm designed after ACO ideas. AntHocNet was introduced in previous work and showed superior performance compared to other state-of-the-art algorithms over a wide range of MANET simulation scenarios [2, 6, 13]. In this paper we discussed AntHocNet emphasizing its innovative design, especially with respect to previous ACO algorithms for routing. In particular, we pointed out the fact that AntHocNet is based on the integration of reactive and proactive components, and on the integration of the typical ACO path sampling mechanism with the learning of routing information using an information bootstrapping process. In a detailed experimental study we have investigated the role and the importance of these and other different components of the algorithm, studying their effect on the overall performance. The effectiveness of the use of a composite design to deal with the multiple challenges of MANETs, and in particular the effectiveness of combining ant-based Monte Carlo sampling with pheromone bootstrapping, has been confirmed by the experimental results. Moreover, the experimental analysis has pointed out the need for adopting low-overhead and low-interference strategies for exploration and data forwarding, as well as the importance of defining a composite pheromone metric taking into account different multiple aspects of the network environment.

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