Ant colony based optimization algorithm for the Mobile ad hoc Network Routing Problems based on SMR Protocol (ACO-SMR)

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Abstract

Mobile ad hoc networks (MANETs) consist of a collection of wireless mobile nodes which dynamically exchange data among themselves without the reliance on a fixed base station or a wired backbone network. All nodes are mobile and can be connected dynamically in an arbitrary manner. Multi hop, mobility, large network size combined with device heterogeneity, bandwidth and battery power constrain make the design of adequate routing protocols a major challenge. Because of these characteristics, path connecting source nodes with destination may be very unstable and go down at any time, making communication over ad hoc networks difficult. Earlier research has proposed several uni-path routing protocols specifically on MANET. In single routing, only a single route is used between a source and destination node. Single path routing protocols cause increases the call blocking probability and decreases overall network utilization. Additionally, single path protocol can increase end-to-end delay and packet loss rate. To alleviate these problems, new multipath routing algorithm for MANETs is proposed, which combines the idea of ant colony optimization with Split Multipath Routing (SMR) protocol. Ant colony optimization Split Multipath Routing (ACO-SMR) is based on swarm intelligence and especially on the ant colony based meta heuristic. The proposed algorithm will improved the performance of the network such as delay and packet delivery ratio than traditional routing algorithms.

Keywords: ant colony optimization, uni-path routing protocols, multipath routing, SMR, ad-hoc networks.

1. INTRODUCTION

Mobile ad hoc networks (MANETs) consist of a collection of wireless mobile nodes which dynamically exchange data among themselves without the reliance on a fixed base station or a wired backbone network. All nodes are mobile and can be connected dynamically in an arbitrary manner. There is no static infrastructure such as base station. Because of these characteristics, path connecting source nodes with destination may be very unstable and go down at any time, making communication over ad hoc networks difficult. Routing is one of the key issues in MANETs due to their highly dynamic and distributed nature. Routing Protocols can be divided into two categories as shown in the table 1, based on when and how the routes are discovered.

<table>
<thead>
<tr>
<th>Table 1: Different Types of Routing Protocols</th>
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<tbody>
<tr>
<td>Pro-active Routing or table-driven Protocols</td>
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<tr>
<td>Reactive Routing or On-demand routing Protocols</td>
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<tr>
<td>Hybrid (Pro-Active/On-demand)</td>
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In pro-active or table driven routing protocols each node maintains one or more tables containing routing information to every other node in network. All nodes update these tables so as to maintain a consistent and up-to-date view of the network. When the network topology changes the nodes propagate update messages throughout the network in order to maintain consistent and up-to-date routing information about the whole network. These routing protocols differ in method by which the topology change information is distributed across the network and the number of necessary routing-related tables. Unlike pro-active, Reactive or On-demand routing protocols take a lazy approach to routing. In contrast to Pro-active Routing protocols all up-to-date routes are not maintained at every node, instead the routes are created as and when needed. When a source wants to send to a destination, it invokes the route discovery mechanism to find the path to the destination. The route remains valid till the destination is reachable or until the route is no longer needed. Protocols such as DSR [1, 2] and AODV [3] are members of the re-active protocol class. Hybrid protocols combine the advantages of pro-active and reactive routing. The routing is initially established with some pro-actively prospected routes and then serves the demand from additionally activated nodes through reactive flooding. The ZRP [4, 5, 6] is an example of a hybrid routing protocol.
Clearly, routing in MANETs must take into consideration their important characteristics such as node mobility. Work on single path (or unipath) routing in MANETs has been proposed in [7, 8, 9]. Multipath routing allows the establishment of multiple paths between a single source and single destination node. Multipath routing is typically proposed in order to increase the reliability of data transmission (i.e., fault tolerance).

In this paper, we propose the Ant Colony Optimization based Split Multipath Routing Protocol (ACO-SMR). SMR is similar to DSR, and is used to construct maximally disjoint paths. Maximally disjoint paths have as few links or nodes in common as possible. The aim is to find more stable paths so that the route discovery frequency can be decreased and the network performance will be improved. The routing algorithm is based on swarm intelligence and especially on the ant colony based meta heuristic. The proposed algorithm will improved the performance of the network such as delay and packet delivery ratio than traditional routing algorithms.

The rest of this paper is organized as follows: In Section 2 we describes the basics and background of ant behavior, Section 3 covers the ant colony based routing algorithms, Section 4 describes the problems with unipath routing protocols, in section 5 we describes the proposed ant colony optimization split multipath routing algorithm and conclusion and future work in section 6.

2. BASICS AND BACKGROUND

2.1. UNDERSTANDING ANT BEHAVIOUR

The basic idea of the ant colony optimization meta-heuristic is taken from the food searching behavior of real ants[10]. When ants are on the way to search for food, they start from their nest and walk toward the food. When an ant reaches an intersection, it has to decide which branch to take next. While walking, ants deposit pheromone, which marks the route taken. The concentration of pheromone on a certain path is an indication of its usage. With time the concentration of pheromone decreases due to diffusion effects. This property is important because it is integrating dynamic into the path searching process. Figure 1 shows a scenario with two routes from the nest to the food place. At the intersection, the first ants randomly select the next branch. Since the below route is shorter than the upper one, the ants which take this path will reach the food place first. On their way back to the nest, the ants again have to select a path. After a short time the pheromone concentration on the shorter path will be higher than on the longer path, because the ants using the shorter path will increase the pheromone concentration faster. The shorter path will thus be identified and eventually all ants will only use this one.

Figure 1: Ants take the shortest path after initial search

This behavior of the ant can be used to find the out a path that satisfies multiple constraints in ad-hoc networks. Especially, the dynamic component of this method allow a high adaptation to changes in mobile ad-hoc network topology, since in these networks the existence of links are not guaranteed and link changes occur very often.

2.2. SIMPLE ANT COLONY OPTIMIZATION META-HEURISTIC ALGORITHM [11]

Let G = (V, E) be a connected graph with n=|V| nodes. The simple ant colony optimization meta-heuristic can be used to find the shortest path between a source and destination node on the graph G. the path length is given by the number of nodes on the path. Each edge of the graph has a variable \( \varphi_{i,j} \) (artificial pheromone), which is modified by the ants when they visit the node. The pheromone concentration is an indication of the usage of this edge. An ant located in node \( v_i \) uses pheromone of node \( v_j \in N_i \), to compute the probability of node \( v_j \) as next-hop.

\[
p_{i,j} = \begin{cases} \frac{\varphi_{i,j}}{\sum_{j \in N_i} \varphi_{i,j}} & \text{if } j \in N_i \\ 0 & \text{if } j \not\in N_i \end{cases} \quad (1)
\]
Where $N_i$ is set of one-step neighbors of node $v_i$. During the route finding process, ants deposit pheromone on the edges. In the simple ant colony optimization meta-heuristic algorithm, the ants deposit a constant amount of pheromone on the edge $e(v_i, v_j)$ when moving from node $v_i$ to node $v_j$ as follows:

$$\phi_{i,j} = \phi_{i,j} + \Delta \phi$$  \hspace{1cm} (2)

Like real pheromone the artificial pheromone concentration decreases with time to inhibit a fast convergence of pheromone on the edges. In the simple ant colony optimization meta-heuristic, this happens exponentially:

$$\phi_{i,j} = (1-q)\phi_{i,j}, \quad q \in (0,1]$$  \hspace{1cm} (3)

2.3. WHY ANT COLONY OPTIMIZATION META-HEURISTIC SUITS TO AD-HOC NETWORKS? \cite{11}

The simple ant colony optimization meta-heuristic shown in the previous section illustrates different reasons why this kind of algorithms could perform well in mobile multi-hop ad-hoc networks. We will discuss various reasons by considering important properties of mobile ad-hoc networks.

**Dynamic topology**: this property is responsible for the bad performance of several routing algorithms in mobile multi-hop ad-hoc networks. The ant colony optimization meta-heuristic is based on agent systems and works with individual ants. This allows a high adaptation to the current topology of the network.

**Local work**: in contrast to other routing approaches, the ant colony optimization meta-heuristic is based only on local information.

**Link quality**: it is possible to integrate the connection or link quality into the computation of the pheromone concentration, especially into the evaporation process. This will improve the decision process with respect to the link quality.

**Support for multi-path**: each node has a routing table with entries for all its neighbors, which contains also the pheromone concentration. The decision rule, to select the next node, is based on the pheromone concentration on the current node, which is provided for each possible link. Thus, the approach supports multi-path routing.

3. ANT COLONY BASED ROUTING ALGORITHMS

Initial studies have unveiled a great deal of matching properties between the routing requirements of ad-hoc networks and certain features of SI, such as the ability of ant colony to find a nearly optimal route between elements. Several algorithms which are based on ant colony optimization were introduced in recent years to solve the routing problem in ad-hoc networks. Recently, a new family of algorithms emerged inspired by swarm-intelligence, which provides a novel approach to distributed optimization problems. The expression “Swarm Intelligence” defines any attempts to design algorithms inspired by the collective behavior of social insect colonies and other animal societies. Several algorithms which are based on ant colony were introduced in recent years to solve the routing problem in ad-hoc networks. These algorithms show that the biologically inspired concepts can provide a significant performance gain over traditional approaches.

3.1 Di Caro, Ducatelle, and Gambardella (2004) \cite{12, 13, 14, 15, 16, 17, 18}: AntHocNet

AntHocNet combines the typical path sampling behavior of ACO algorithms with a pheromone bootstrapping mechanism. AntHocNet is a hybrid algorithm. 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 soon 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 for both topology and traffic. The algorithm tries to find paths characterized by minimal number of hops, low congestion, and good signal quality between adjacent nodes.

3.2 Guenes et al. (2002) \cite{19}: Ant-Colony-Based Routing Algorithm (ARA)

ARA imports some basic aspects of AntNet into AODV. It is a purely reactive algorithm in which both forward and backward ants set up the paths to the nodes from which they arrive from. Also data packets update the pheromone tables reducing the number of ants needed to sample existing paths. According to simulation experiments, ARA’s performance turns out to be slightly better compared to AODV but worse than DSR in highly dynamic environments.

3.3 Marwaha et al. (2002) \cite{20}: Ant-AODV

In Ant-AODV, AODV is extended by a mechanism of proactive updating of the routing tables based on uniform ants. This increases the chance that a node or one of its neighbors will have a route to a destination when needed. The ants
randomly traverse the network and keep track of the last n visited nodes. The results of simulation experiments indicate that Ant-AODV performs better than AODV and of a simple ant-based algorithm.

3.4 Baras and Mehta (2003) [21]: Probabilistic Emergent Routing Algorithm (PERA)

These authors have introduced two routing algorithms for MANETs. The first algorithm is a proactive one very similar to AntNet. Nodes maintain pheromone entries for all destinations by periodically launching forward ants, which take random decisions for unbiased exploration, and data packets are deterministically routed over the paths with the highest quality. The large routing overhead and the inefficient route discovery of this algorithm led to PERA, which is purely reactive algorithm not very different from AODV. The forward ants are now flooded through the network towards their destinations. This strategy leads to the dynamic discovery of multiple paths. However, data packets are routed over the single best path available. The presence of multiple paths is helpful in the quick recovery from link failures. The performance of the algorithm is comparable to that of AODV according to a limited set of simulation experiments.

3.5 Heissenbüttel and Braun (2003) [22]: Mobile Ant-Based Routing (MABR)

The algorithm proposed by these authors makes use of geographical partitioning of the node area and of pheromone exploiting geographical addressing. The algorithm is intended for large-scale MANETs and is purely proactive. Forward/backward ants are used to periodically check if the path to a randomly chosen destination is functional and reflects the current state of the network. Accordingly, paths followed by the ants are positively or negatively reinforced. In addition, pheromone evaporation favors further exploration and removal of out-of-date paths.

4. PROBLEMS WITH UNIPATH ROUTING PROTOCOLS

In single path routing, only a single route is used between a source and destination node. Single path routing protocols cause increases the call blocking probability and decreases overall network utilization. Additionally, single path protocol can increase end-to-end delay and packet loss rate. However, multipath routing protocols which aim to establish multiple paths between sources to destinations can solve these problems. Multipath routing protocols have more benefits than single path protocols such as (a) decrease the call blocking probability and increase overall network utilization, (b) increase the reliability of data transmission (i.e., fault tolerance), (c) decrease end-to-end delay, (d) enhance reliability and avoid broken, (e) higher aggregate bandwidth and (f) beneficial for balancing network load.

5. PROPOSED ANT COLONY OPTIMIZATION SPLIT MULTIPATH ROUTING (ACO-SMR) ALGORITHM

In this section we discussed the properties of SMR protocol, implementation rules of ant colony optimization based split multipath routing protocol (ACO-SMR) and describe the phases of ACO-SMR protocol

5.1. Properties of SMR protocol

- Source routing, packets contain complete routes.
- Complete route information known at source (included in BA).
- Provides two paths (can be modified to more paths).
- Provided paths are maximally disjoint.
- Routes selected at destination.
- One of the paths is the shortest-delay path.
- FAs contain the source ID and unique sequence number.
- Intermediate nodes forward all duplicate FAs that traversed through a different incoming link.
- Destination first replies the fastest path (shortest-delay path) and then the maximally disjoint path after a while is replied.

5.2. Implementation rule of ACO-SMR

Let $P_{ij}(d,t)$ be a probability in the time $t$ of the route being selected from node $i$ to the destination $d$ which next hop is $j$. $\tau_{ij}(d,t)$ is the pheromone in the time $t$ of the route from node $i$ to the destination $d$ which next hop is $j$. $\Delta \tau_{ij}(d,t)$ is the increment of the pheromone in the time $t$ which is generated by the ant packet. In order to realize the ACO-SMR algorithm, we will use the follow rules:

**Rule** No intermediate nodes are not allowed to send BAs as in DSR and AODV [1,2,3], even when they have route information to the destination, because If nodes reply from their cache, it is very difficult to determine maximally disjoint multiple routes since the destination does not receive enough FAs and will not know the information of routes formed from intermediate nodes cache.
Rule 2 Initial pheromone of the nodes: Pheromone table is spatial in the network initialization. The pheromone of the new path is calculated as follows:

\[ \tau_{i,j}(d,t) = \alpha \times N_i + \beta \times Q + \gamma \times H_i \quad \text{and} \quad \alpha, \beta, \gamma \geq 0, \alpha + \beta + \gamma = 1 \]  

(4)

Rule 3 Final pheromone of the nodes: Node i will delete route entry \( P_{i,j}(d,t) \) when its \( \tau_{i,j}(d,t) \) is 0. This Rule enables ACO-SMR to have a good adaptation to the dynamic node change.

Rule 4 The intermediate nodes bidirectionally update the pheromone table hop by hop, which can accelerate the convergence rate of the algorithm and improve the speed of response to node mobility. It can fully use the information that the ant packets carried to create more backup paths, decreasing the average end-to-end delay and improving the efficiency of pheromone table establishment.

Rule 5 During the route finding process and route maintenance, ants deposit pheromone on the edges. An ant changes the amount of pheromone of the route entry when moving from node i to node j as follows:

\[ \tau_{i,j} = \tau_{i,j} + \Delta \tau_{i,j} \]  

(5)

Rule 6 Like real pheromone the artificial pheromone concentration decreases with time to inhibit a fast convergence of pheromone on the route entry. This happens exponentially (every \( \Delta t \) time):

\[ \tau_{i,j}(d,t + \Delta t) = (1 - \rho)\tau_{i,j}(d,t)\rho \in (0,1] \]  

(6)

Rule 7 The renewal rule of \( P_{i,j}(d,t) \) in the route finding process and route maintenance:

\[ p_{i,j}(d,t) = \frac{\tau_{i,j}(d,t)}{\sum_{k \in V(i,d)} \tau_{i,k}(d,t)} \]

\[ j \in V(i,d), \sum_{j \in V(i,d)} p_{i,j}(d) = 1 \]

V\((i,d)\) is the set of next hop which has the route entry from node i to the destination d.

5.3. Route Discovery and Route Maintenance Phase

In ACO-SMR establishes and utilizes multiple routes of maximally disjoint paths. Providing multiple routes helps minimizing route discovery process and control message overhead. A FA packet is generated when the source node needs to transmit data packets and doesn’t have the route. A node receiving a FA packet for the first time creates record in its routing table. It computes the pheromone value according the RULE (1-7), and then creates the reverse path to the source node. Then the node relays the FA packet to its neighbors. Duplicate FA packets are identified through the unique sequence number and destroyed by the nodes. We proposed that it is useless for destinations to wait for too many FAs and yields longer delays. An approach is proposed in this paper to solve this problem.

When the first FA packet reaches the destination node, it is processed in a special way. The destination node extracts the information of the FA packet and destroys it. Subsequently, it creates a BA packet and sends it to the source node. The BA packet has the same task as the FA packet. When the sender receives the BA packet from the destination node, creates a record in its routing table, computes the pheromone value according the RULE (1-7), then creates the forward path to the source node. Then they send another BA when the number of FA they received reaches four. This approach not only gets enough FA to send BA which is maximally disjoint to the route that is already replied, but also brings down end-to-end delay through limiting the number of BA received by destinations. The link-disjoint path is established and data packets can be sent.

The flow sheet of ACO-SMR is shown as follow:

Figure 2: The flow sheet of FA received by intermediate nodes
6. CONCLUSION AND FUTURE WORK

Routing in MANETs is ‘a hard work' and actually it is an interesting research area that has been growing in recent years. Its difficulty is mainly generated because of the constant changes in the network. There exist some traditional solutions such as proactive protocols and reactive protocols, each one with their advantages and disadvantages. In spite of this, these solutions have to improve to offer better performance. In fact, there is a new generation of hybrid routing protocols that have 'the potential' to provide higher scalability than pure reactive or proactive protocols, and moreover to maintain routing information much longer because of the collaboration between nodes. All these protocols are uni-path protocols with some disadvantages that in single routing, only a single route is used between a source and destination node. Single path routing protocols cause increases the call blocking probability and decreases overall network utilization. Additionally, single path protocol can increase end-to-end delay and packet loss rate.

In this paper, we have proposed a new routing algorithm for MANETs, which combines the idea of ant colony optimization (ACO) with split multipath routing (SMR) protocol. The algorithm is efficient for end to end delay and packets delivery ratio.

We will simulate our proposed algorithm with one of network simulators and we compare the scheme performance with other routing algorithms.

References


