Design of Self Organizing and Energy Efficient Routing Protocol for MANETs

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Abstract

MANETs are a collection of unstructured wireless mobile nodes that form a dynamic topology. The design and performance evaluation of AntHoc algorithms have been one of the prime areas of research in bio-inspired computing. In this paper, we propose a newer variation of the AntHoc protocol, which is a novel phenomenon that tackles major issues in MANETs like self-organization and adaptability. This can be achieved by evaluating the goodness value (pheromone traces) which is associated with the drain rate of the nodes, thus increasing overall network lifetime. All the packets are sent along the most energy-efficient path, which makes the network adaptive in nature. The algorithm is also self-organizing since an alternate path is chosen with low convergence time in case of a path failure. The performance evaluation of the proposed algorithm with respect to network lifetime and convergence time can be done using simulation tools such as NS2/QualNet.

Key words- MANETs, pheromone traces, network lifetime, self organization, energy efficiency

1. Introduction

In today’s fast evolving era, wireless communication is bringing fundamental changes to the field of data networking and telecommunication, and is making integrated networks a reality. One of the popular ad hoc networks is Mobile Ad-hoc Network (MANET). It is regarded as a system of wireless mobile nodes that can self organize into arbitrary and temporary network topologies freely and dynamically. Different protocols that are used in MANETs are evaluated based on different parameters such as average end-to-end delay, packet drop rate, average routing load etc. MANET offers an independent, scalable and flexible solution for mobile and dynamic topologies.

One of the greatest challenges in the design of MANETs is the limited availability of the energy resources. Energy-efficient communication is critical for increasing the life of power limited wireless ad hoc networks. Each of the mobile nodes is operated by a limited energy battery and usually it is impossible to recharge or replace the batteries during a mission. Since wireless communications consume significant amounts of battery power, therefore the limited battery lifetime imposes a severe constraint on the network performance. Power failure of a mobile node not just affects the node itself but also the node’s ability to forward packets on behalf of others and thus the overall network lifetime. A mobile node consumes its battery energy not only when it actively sends or receives packets, but also when it stays idle listening to the wireless medium for any possible communication requests from other nodes. Thus, energy-efficient routing protocols minimize both the active communication energy required to transmit and receive data packets and the energy during inactive periods.

Many desirable properties of networking systems can be seen in biological systems. Bio-inspired networking is a networking paradigm that is being looked into for solutions. In this paradigm, networking entities are compared to biological entities in order to adapt biological principles and determine an optimal solution. There are a few notable characteristics of bio-inspired networking such as: (i) adaptive: suitable to varying environmental conditions (ii) robust: resilient to failures (iii) self-organizing ability (iv) decentralized architecture: no central control[1]. Various routing protocols are being developed based on the principles of biological processes such as swarm or bee colony behavior, ant colony behavior, epidemic behavior, artificial immune system (AIS).

The need for judicial usage of energy and intelligent self organization in MANETs have motivated us to design a self organizing and energy efficient MANET protocol by integrating the principles of Ant hoc Net protocol and drain count, an energy efficiency metric, in order to achieve a MANET with increased overall network lifetime.

2. Literature survey and Related work

2.1. Traditional Routing Protocols for MANETs

MANETs mainly use three types of routing protocols. The reactive protocols such as Dynamic Source Routing (DSR),
Ad hoc On-demand Distance Vector (AODV) and Temporally Ordered Routing Algorithm (TORA) dynamically determine the routing path as and when there is a demand to transmit some data. The proactive protocols such as Destination Sequenced Distance Vector (DSDV), Optimized Link State Routing (OLSR) and Fisheye State Routing (FSR) dictates that routing tables be maintained at each node. Hybrid routing protocols such as Zone Routing Protocol (ZRP) are also used, which integrates the characteristics of proactive and reactive protocols, but also has demerits like it cannot be evaluated for unidirectional links and it can be applied only for very large networks[2].

AODV protocol favors the least congested route instead of the shortest route and it also supports both unicast and multicast packet transmissions even for nodes in constant movement. It also responds very quickly to the topological changes that affect the active routes. AODV does not put any additional overhead on data packets as it does not make use of source routing. Whereas, DSR protocol is not scalable to large networks and even requires significantly more processing resources[3][4]. Basically, in order to obtain the routing information, each node must spend lot of time to process any control packet it receives, even if it is not the intended recipient. Even DSDV introduces large amounts of overhead to the network due to the requirement of the periodic update messages[4]. FSR is more scalable to large networks than the protocols described so far in this section. However, scalability comes at the price of reduced accuracy. This is because as mobility increases the routes to remote destination become less accurate[4].

2.2. Energy Efficiency in MANETs

In this section, some of the energy efficient schemes developed by researchers in the field have been described. Energy is the most scarce resource and nodes spend energy during transmission and reception of data [5]. Four modes that must be considered for the total energy consumed are:

2.2.1. Transmission mode. Transmission energy is the energy spent to transmit a message, and is dependent on the size of the packet.

\[ T_X = \frac{(330+\text{Plength})}{2\times10^6} \]  

\[ P_T = \frac{T_X}{T_i} \]  

Where \( T_X \) is transmission Energy, \( P_T \) is Transmission Power, \( T_i \) is time taken to transmit data packet and \( \text{Plength} \) is length of data packet in Bits.

2.2.2. Reception mode. Energy spent to receive a packet is Reception energy.

\[ R_X = \frac{(230+\text{Plength})}{2\times10^6} \]  

\[ P_R = \frac{R_X}{T_X} \]  

Where \( R_X \) is a Reception Energy, \( P_R \) is a Reception Power, \( T_X \) is a time taken to receive data packet, and \( \text{Plength} \) is length of data packet in Bits.

2.2.3. Idle mode. In this mode, the node is neither transmitting nor receiving any packet. But energy is spent because the nodes have to listen to the network for any incoming packet. The node then has to move from idle mode to reception mode.

\[ P_I = P_R \]  

Where \( P_I \) is the power consumed in Idle Mode and \( P_R \) is power consumed in Reception Mode.

2.2.4. Overhearing mode. Energy spent by the node when it receives the packet that is destined to it. Unnecessary receiving of such packets consumes energy.

\[ P_{over} = P_R \]  

Where \( P_{over} \) is power consumed in Overhearing Mode and \( P_R \) is power consumed in Reception Mode.

The lifetime of ad hoc network is limited by the battery energy in wireless devices. Energy depletion of nodes can interrupt communication and, even worse, cause network partitioning. Energy related metrics used by power aware routing protocols are classified into four categories: transmission power, remaining energy capacity, estimated node lifetime, and combined energy metrics[6]. The Minimum Total Transmission Power Routing (MTPR) attempts to minimize the total transmission power consumption of nodes participating in an acquired route and transmission power is proportional to transmission distance[7]. Considering transmission power as the only cost metric increases the number of hops and end-to-end delay. Adding a power cost metric helps in reducing the hop count. In MBCR (Minimum Battery Cost Routing), the sum of residual energy of all the nodes is calculated and the path with the least cost and maximum energy is chosen, allowing the nodes with less energy to participate in transmission. The improved approach to this is Min-Max Battery Cost Routing (MMBCR) which always chooses the path with maximum residual energy and hence increases the network lifetime[8]. The lifetime of the network is decided based on the energy metric, drain rate, which is defined as the rate at which energy is consumed by the node. Network lifetime can be maximized if the path with least drain rate is chosen and hence it is denoted by,

\[ DR_i(t) = \alpha \times DR_i(t - \tau) + (1 - \alpha) \times DR_i^{\text{sample}} \]  

Where, \( DR_i(t) \) and \( DR_i^{\text{sample}} \) represents the previous and the newly monitored drain rates, \( \tau \) represents time interval.

2.3. Bio-Inspired Computing

The common rationale behind this effort is to capture the governing dynamics and understand the fundamentals of biological systems in order to devise new methodologies and
2.3.1. Ant Colony based routing. There are various approaches to Bio inspired networking and Ant Colony optimization (ACO) is one among them [9][10]. Ant hoc network is a metaheuristic way of performing a local search to reach the destination (food) and imitates the behavior of an ant colony. In Ant hoc, packets (ants) travel in random direction to reach the destination (food) in a non-deterministic way. Paths to all destinations are not maintained at all times. Hence it uses proactive routing to determine when the session has to be initiated. The ants leave behind scent traces known as pheromone traces along the path that they take. When an ant finds a food source, it returns to the nest in the same path. Ants have the ability to converge at the shortest path from their nest to the food source. On its return journey, the ant continues to leave the pheromone trail behind in the path, thereby increasing the concentration of pheromone deposition along the successful path, while the others will slowly fade away. This causes other ants to be more likely to follow the shortest path, and creates a positive feedback loop. Further, all the other ants follow the same shortest path, in this way ants communicate with each other with respect to environmental changes (pheromone traces) through stigmergic communication [11] techniques.

Routing table for each possible destination node is d, this shows amount of pheromone deposited on the edge, link(k,n). The probability of a node choosing the next node is $P'_nd$. $|N_k|$ is the number of neighbor node of k, $q_n$ is the length of the queue associated with the link connectivity k to n and a is weight of the importance of the heuristic function with respect to pheromone deposition.

$$P'_nd = \frac{\eta_{nk}^{l_n-a+\alpha \times l_n}}{\sum_{l'=1}^{q'_n} \eta_{nk}^{l_n-a+\alpha \times l_n}}$$ (8)

where $l_n = 1 - q_n/\sum_{l'=1}^{q'_n} q'_n$ (9)

As proposed in [12],

$$P_{k,l}(t) = \frac{[F_{k,l}(t)]^\alpha [\eta_{k,l}]^\beta}{\sum_{l'=1}^{q_j} [F_{k,l'}(t)]^\alpha [\eta_{k,l'}]^\beta}$$ (10)

$$\eta_{k,l} = 1 - \frac{q_j}{\sum_{l'=1}^{q_j} q_{k,l'}}$$ (11)

Probability function $P_{k,l}$ for an ant to choose link (k,l) using a combination of both pheromone concentration $F_{k,l}$ and heuristic function $\eta_{k,l}$. $N_k$ are the available interconnecting nodes where $\alpha$ and $\beta$ specify the respective adjustable weights of $F_{k,l}$ and $\eta_{k,l}$.

2.3.2. Ant hoc Net. The Ant hoc Net protocol is a hybrid routing protocol that causes other ants to follow the shortest successful path. It uses reactive protocol to send the data and control packet to destination [9]. In [7], the algorithm runs in two passes: forward and backward. In the forward pass, the route is constructed by a group of forward ants (FANTs), each of which starts from a unique source node. In the first iteration, an ant searches a route to the destination randomly. Later, an ant searches the nearest point of the previously discovered route. This could take many iterations before the ant can find a correct path with a reasonable length. A solution is to flood the sink node ID from the sink to all the nodes in the network before any ant starts. The points where multiple ants join are aggregation nodes. In the backward pass, the first FANT that reaches the sink gets converted to backward ant (BANT) and travels back to the corresponding source node by following the path discovered in the forward pass. The other FANTs get destroyed. Pheromone is deposited hop by hop during the traversal. Nodes in the discovered path are given weights depending on the node potential which indicates heuristics for reaching the destination. Pheromone trails are the heuristics to communicate with other ants of the route discovered. The trail followed by ants most often gets more and more pheromone and eventually converges to the optimal route. Pheromone in the non-optimal routes gets evaporated with time. The indicator in each data aggregation point gives estimate of the number of paths aggregating in the point.

2.3.3. Artificial Immune System (AIS). AIS is used for misbehavior detection in MANETs and it was first described in [13]. The scheme used is specifically designed to discover nodes that do not correctly implement the dynamic source routing (DSR) protocol. They use negative selection on packet traces to find nodes that produce abnormal sequences of protocol interactions [1]. Their preliminary simulations showed mixed results, they found that their algorithm required a significant delay before the false positive rate fell to a reasonable level.

2.3.4. Epidemic Routing. Just as humans can only transmit infection to others within a small range of their physical location, MANETs also can often communicate with other wireless devices within a small range. The nodes in a MANET may never be fully connected at any particular instant in time, but it is still quite possible to send a packet from a source to destination without actually having a predefined path. Epidemic routing, a routing protocol based on epidemic algorithms was developed as a solution to this problem [1]. Epidemic routing attempts to propagate a message to a single destination node. Taking advantage of node mobility, nodes forward messages to “susceptible” nodes that happen to be in close proximity. Those nodes are then “infected” and can carry the message towards the intended destination. The nodes then enter the “recovery” state. There are a few variations of epidemic routing such as Priority Epidemic routing (PREP) that are being worked upon to prioritize the messages for transmission and deletion using a priority function [14].
2.3.5. Energy efficiency in Ant hoc Net. In [15], along with the foraging behavior of ants, an Energy Aware Ad hoc routing protocol (EAAR) is used which incorporates the effect of power consumption in routing a packet and also exploits the multi-path transmission properties of ant swarms and hence it increases the battery life of a node. The efficiency of the protocol with respect to some of the existing ones has been established through simulations. It has been observed that the energy consumed in the network, the energy per packet in the case of EAAR are 60% less compared to MMBCR and the packets lost is only around 12% of what we have in AODV, in mobility scenarios[16].

In[17], an improved Ant-based On-demand Energy Route (AOER) protocol for IEEE 802.15.4 mesh networks is proposed which uses the information of network status by Forward Ant and stored in an inversed pheromone table which simplifies the data structures of route packets. This simplified structure can avoid wasting of storage memories and processing capabilities which are very important for low-power wireless network devices. Combination of the average path energy, average network energy and minimum remaining node energy of the path are used to evaluate paths and update the inversed pheromone table. Forwards the Backward Ant from the destination to the source is based on the pseudo-random- proportional-selection strategy. Nodes with higher pheromone trail values are selected as the next hop with higher probabilities, therefore the network loads are distributed and nodes energy consumptions are balanced. A proactive route maintenance mechanism is also used in AOER to trigger route maintenance and avoid over-use of node energy.

2.3.6. Applications of ACO-Inspired Protocol. This energy efficient and self organizing Ad hoc Net protocol finds various applications. A few of them have been listed here.

- Vehicle Routing Problem (VRP): a set of vehicles stationed at a depot has to serve a set of customers before returning to the depot, minimizing the number of vehicles used and the total distance traveled by the vehicles. More than one route might be required to serve all orders. This can also be implemented for any type of traffic maintenance, say for finding the least congested path for ambulance, fire brigades and other emergency services[18].
- Military combat operations - Bugs released for investigation purposes
- Wireless Sensor Networks
- Disaster Recovery - for recovery of communication channels in times of natural disasters such as earthquakes.

3. Proposed work

The protocol that is proposed in this paper amalgamates the concept of drain count into Ant hoc Net in order to make it energy efficient. If the energy of a node is lesser than the set threshold energy, then the drain count value of the path is incremented by a factor of 1. Ants use a probabilistic way to find multiple paths with different goodness values (drain count). The path that has the least drain count i.e. the path which has least number of nodes having energy below the threshold energy, is chosen from among the paths that are traversed by the first few forward ants that arrive at the destination node. This ensures that a path with a reasonably short distance is chosen.

3.1. Reactive Route setup:

At the beginning of the session, if the path is already established between the source and the sink, a unicast packet is sent. Otherwise, packets are broadcasted to all the neighboring nodes. As these ants travel through the network towards the sink, they store the nodes that they visit in a list inside the packet. They deposit pheromone traces \( P_i \) which is directly proportional to the drain rate of node i.

\[
P_i = p_{ij}^{k} \times Dr_i
\]

where, \( Dr_i = TP_i + Rp_i + Oh_i + I_i \)

\[
p_{ij}^{k} = \begin{cases} 
\left(1 - \frac{1}{\sqrt{n_i}}\right)^{\alpha} \times \frac{p_i^{j}}{\sum_{j}p_i^{j}\left(1 - \frac{1}{\sqrt{n_j}}\right)^{\beta}} & \text{if } j \in j_i^k \\
0 & \text{otherwise}
\end{cases}
\]

| \( P_i \) | the pheromone deposited at node i. |
| \( p_{ij}^{k} \) | the probability of choosing the next hop for a promising path [9]. |
| \( j_i^k \) | is the tabu list of not yet visited nodes |
| \( \eta_{ij} \) | is the visibility of j when standing at i |
| \( \tau_{ij} \) | is the pheromone level of edge(i,j) |
| \( \alpha \), \( \beta \) | adjustable parameters that control the relative weight of trail intensity |
| \( Dr_i \) | Drain rate of node i. |
| \( TP_i \) | Transmission power at node i. |
| \( Rp_i \) | Receiving power at node i. |
| \( Oh_i \) | Energy wasted due to Overhearing activities of other nodes. |
| \( I_i \) | Energy wasted in idle mode of node i |

We introduce the term drain count. Routing decisions are based on this energy metric, where the drain count is incremented by one if the residual energy of the node is lesser than the set threshold.
than certain threshold energy level. The threshold energy level changes dynamically with respect to the energy levels of the entire network.

The path with the least drain count is chosen, as it increases the network lifetime since it utilizes the path that has maximum energy available in the nodes. The drain count values of 25% of the FANTs that are sent from the source are compared at the sink as and when they arrive. At the destination node, the FANT with the least drain count value is converted into a reactive BANT, and is sent along the chosen path. The BANT retraces the same set of nodes, collecting quality information (pheromone deposition) and updating the routing tables based on this information. The information that is brought in by the first few FANTs is stored at the destination node with the aim of reducing convergence time in case of link failure, which facilitates self organization of the network.

3.2. Proactive route maintenance process

Paths to all destinations are not maintained all the time, hence it uses proactive routing to determine when the session has to be initiated. Nodes periodically broadcast messages containing the best pheromone information available with them. Using this information, neighbors update with the best pheromone value with them and broadcast it to other nodes.

3.3. Data packet forwarding

Criteria for choosing the best optimal path to conserve energy are:
1. Choose the path with least drain count
2. If the least drain count value is same for 2 or more paths, choose the path with shortest hop count
3. If the least hop count value is same for 2 or more paths, choose the path with the least transmission energy.

3.4. Handling link failure

Link failures can be detected in Anthoc Net via failed transmission of data or control packet or hello messages. Hello messages are short messages that are periodically sent out by all the nodes in the network to check for the existence of neighbor nodes. When FANTs fail, Repair forward ants which are similar to reactive forward ants are activated. They follow available pheromone information where possible, and are broadcasted otherwise. But they have a limited maximum number of broadcasts, so that they cannot travel far from the old failed route. When there is a loss in the data packet, the node unicasts a warning to the node it received the data from in order to inform that it can no longer forward data to this destination. In case of BANT failure, the information stored at the destination node is used to select an alternative path. Extended fields are added to the packet as shown in Table 2. Destination node requires the total sum of drain count for every path and hence this counter is added to the packet so that updations can be done for every session initiation.

Remaining energy of the node is used for comparison with the threshold energy level. Probability factor is used to decide the next hop. Records are used to store all the possible paths to the destination node which is used as alternate paths in case of link failure and provides self-organization. We assume that every node maintains a pheromone table (2D matrix) and neighbor table (single dimension vector).

<table>
<thead>
<tr>
<th>Table 2. Extended packet header</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>RREQ ID</td>
</tr>
<tr>
<td>Destination IP Address</td>
</tr>
<tr>
<td>Destination Sequence Number</td>
</tr>
<tr>
<td>Originator IP Address</td>
</tr>
<tr>
<td>Lifetime</td>
</tr>
<tr>
<td>Timestamp</td>
</tr>
<tr>
<td>Remaining Energy</td>
</tr>
<tr>
<td>Drain Count</td>
</tr>
<tr>
<td>Probability Factor</td>
</tr>
<tr>
<td>Record</td>
</tr>
</tbody>
</table>

3.5. Assumptions:

1. Initial energy of the nodes is equal to the initial traces of pheromone.
2. Forward reactive ants are considered as control packets (RREQ) to find the path to the destination.
3. Pheromone acid is deposited along the path and this is considered as goodness value which is directly proportional to the drain rate of each node.
4. Backward reactive ant is considered as RREP packet sent to the source node.
5. A node is said to be a drained node if its energy lies below a threshold energy level which varies with respect to the transmission requirements.

<table>
<thead>
<tr>
<th>Table 3. Explanation of the notations used in Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>$E_i$</td>
</tr>
<tr>
<td>$E_\text{th}$</td>
</tr>
<tr>
<td>$D_c[k]$</td>
</tr>
<tr>
<td>$\text{Hop}[k]$</td>
</tr>
<tr>
<td>$\text{Tr}[k]$</td>
</tr>
</tbody>
</table>
3.6. Algorithm

while (true)
{
    Begin1: Initiate session, assume initial traces of pheromone
    At the source node,
    If (path S → D)
        then send unicast packet
        send RREQ packets(FAnt) via the established path to the destination D.
    else
        send broadcast packet
        send RREQ packets(FAnt) to all the neighboring nodes.
    // Ants deposit pheromone acid along the path and this goodness value is directly proportional to the drain rate of each node.
    if (link failure)
        Start local route repair
        create Repair FAnt
        goto Begin1
    for all nodes i along the path k,
    if (Ei < Enth)
        DrainCount ← DrainCount+1;
    At the destination node D,
    wait till 25% of FAnt reaches D,
    Begin2: for all path k,
        dcmin = min { DC[k] }
        if (two or more path have same dcmin)
            hopmin = min { HOP[k] }
        if (two or more path have same hopmin)
            trmin = min { TR[k] }
        send BANT(RREP messages) to the path chosen updating the routing table at each node.
        if (link failure)
            Start local route repair
            create Repair BANT
            goto Begin2
    End
} // end while

4. Conclusion and future work

In this work, we have proposed that energy in Ant Hoc protocol can be efficiently utilized by choosing a path with better network lifetime. It has been analytically observed that, the amount of pheromone deposited helps us to probabilistically determine an efficient path. Further to our proposed work, the algorithm can be implemented and it can be evaluated using performance metrics. The results can be statistically analyzed using network simulation tools such as NS2 or a commercial tool such as QualNet by varying the node density from 10 to 100 in steps of 10, and pause time varied from 1 to 180s in steps of 20s each. Hence, it could be observed that energy of each node could be monitored to choose the best possible path and maximize the network lifetime to avoid frequent link failures due to drained nodes.

5. References

Biologically Inspired Cooperative Routing for Wireless Mobile Sensor Networks


