Ant Based Routing Algorithms for Resource Constrained Networks

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***Abstract*—Routing in resource-constrained networks is a challenging task. Due to the complexity concerning resource constraints in terms of bandwidth utilization, energy consumption and latency, typical routing algorithms work poorly in such networks. Therefore, ant-based algorithms are used to address the problem. Among them, AntNet has shown promising performance results. This paper proposes and presents two algorithms which are inspired from AntNet. We compare our proposed algorithms with the basic AntNet, measure the performance and find that our proposed algorithms outperforms the basic AntNet in terms of success rate, energy consumptions and energy efficiency. The performance evaluations are conducted using NetLogo simulation environment.**

Keywords- Routing, Measurements, resource constrained networks, distributed algorithm, simulation.

I. INTRODUCTION

Researches in the area of routing in telecommunication networks have been of great interest in the past several years, especially in resource-constrained networks. Resource-constrained networks are distinguished by their constrained energy, processing, and memory [1], [2], [3]. The other features, which make such networks different from traditional networks, are: limited computation capabilities, bandwidth, and multi-hop routing. The limited resource nature poses a significant challenge in routing in those networks. In order to address the challenges of such networks, many routing protocols and algorithms [4], [5] have been designed and proposed. However, existing routing approaches are unable to cater the application demand resulting performance degradation. Therefore, it is required to have efficient routing algorithms for reliable and seamless communication

Among different routing approaches, ant-inspired algorithms show promising results in solving routing problems in sensor networks [5]- [6]. AntNet [7] is based on Ant Colony Optimization (ACO) [8] metaheuristics for routing in telecommunications networks. In AntNet, a set of artificial ants work concurrently towards finding optimal routing paths. Artificial ants iteratively traverse on finding a solution to the routing problem and communicate with other artificial ants by the way of informing them of possible routes to the destination by laying pheromones. AntNet has been compared to conventional routing algorithm and it outperforms those algorithms. AntNet has shown good performance in smaller random networks, however quickly degrades as the network size and link density increases [9], [10].

Researchers [6], [11]-[12] attempted to improve the performance of AntNet. In [11] Yun and Zincir-Heywood have presented the idea of adding popular destinations to the routing tables and update the destinations at the scheduled time based on visited nodes. Consequently, their approach showed the increased performance of AntNet. In [6] Zhang et al. introduced sensory abilities to forward ants, which are able to sense the geographic location of the destination. As a result, the algorithm showed increasing success rate and energy efficiency. However, to the best of our knowledge, none so far have presented an all inclusive algorithm that performs well in all performance aspects and at the same time scalable.

This paper proposes two algorithms: Improved AntNet routing and Pharaoh routing in order to make efficient use of meager resources in resource-constrained networks. Our research objective is to design and simulate algorithms that introduce performance improvements to AntNet so that we can make efficient use of scarce bandwidth, minimize energy consumption and maximize energy efficiency in resource-constrained networks. Another objective is to have a rapid convergence in route discovery. We conducted performance measurement through simulation and found that the proposed improved AntNet achieves an increased success rate and faster convergence time while the proposed Pharaoh routing achieves least latency, least energy consumption and most energy efficient.

The remainder of this paper is organized as follows: in section 2, we present the proposed approach. In section 3, we provide some experimental results and discussions; we conclude our work in section 4.

II. PROPOSED APPROACH

In this section, two AntNet based algorithms are proposed. The proposed algorithms are used in route discovery. These algorithms find the destination and discover paths to it. The algorithms are: Improved AntNet and Pharaoh Routing.

A. Improved AntNet

The proposed Improved AntNet is based mainly on AntNet. In this algorithm, Forward ants are given forward sensing capabilities. From any node in the network, these ants are able to sense whether connected nodes have already been previously traversed in their path towards the destination node or not. The behavior of backwards ants and the mechanism of the update of the link probability distributions are unchanged.

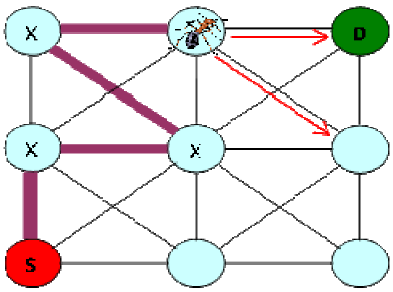

Figure 1. Forward sensing by a forward ant

Fig. 1 depicts an example of a forward ant in a grid network searching for the destination node. The bold (purple in color version) paths mark the paths, which has taken so far. The nodes visited in the path are marked with an X. The arrows in the figure point to the possible next nodes to be selected by the forward ant. The forward sensing capability prevents it from moving back towards the nodes that have been previously visited. The Improved AntNet algorithm is described as follows:

1. At some interval, forward ants are created at the source node and sent towards the destination. They move in parallel but independent of each other in finding the destination.

2. Forward ants select the least cost path joining the source and destination. The next node is selected according to a link probability distribution. Initially, each link share equal probability.

3. Forward ants maintain a taboo list of nodes already visited. Before moving forward towards a node, the forward ant checks if that node exists in the taboo list. If it exists, the forward ant selects the next link to an unvisited node with the least probability distribution.

4. If a forward ant reaches a node from which all neighboring nodes exist in the taboo list, it dies.

5. Once the destination is reached, a backward ant is created and sent back along the same path to the source node updating the link probability distribution at every hop exactly as in AntNet. Once it reaches the source node, it dies.

This forward sensing capability allows more forward ants to pass through as many nodes as possible in search of the destination node. Through this capability every node in the grid network is visited for possible destinations. Although this may cause an increase in power consumption, it may yield a higher success rate than AntNet. Forward sensing also eliminates the possibility of loops. Because of this feature, ants will never revisit nodes, which they already have visited. This helps in reducing convergence time of the algorithm. The functional flow chart of the forward ant of the Improved AntNet Routing algorithm is shown in Fig. 2.

B. *Pharaoh Routing*

In ant colonies, pheromones are used to attract foragers to trails that lead to food. Recently, researchers at the University of Sheffield have discovered that not only do Pharaoh ants

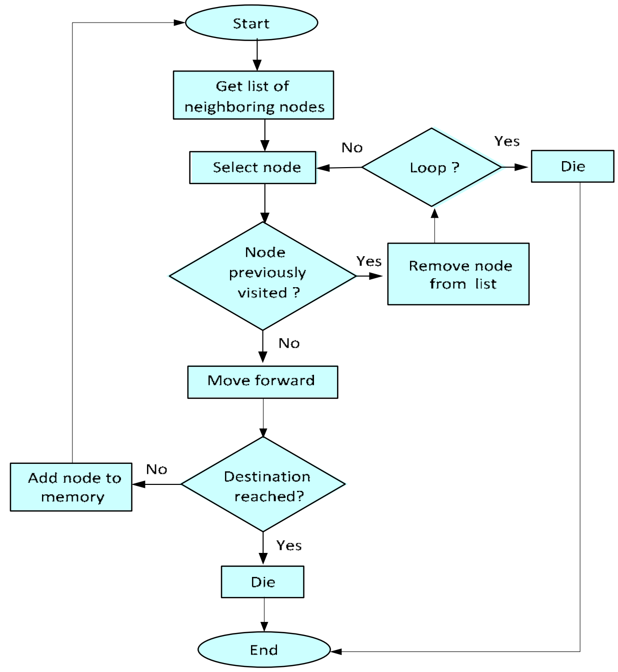

Figure 2. Improved AntNet forward ant flow chart

(Monomorium pharaonis) colonies lay pheromones that lead to food but also lay negative pheromones on entry points to paths that may lead away from the food to repel other foragers from those paths [13],[14]. These findings have been further reinforced in [15], which shows that this phenomenon increases the effectiveness of foraging. Similarly, using such element in the area of network routing can increase the efficiency of route discovery methods and decrease convergence times.

Motivated by those findings of Pharaoh Ants [13]- [15], we propose the Pharaoh Routing algorithm where negative pheromone is considered to increase the effectiveness of foraging.

In Pharaoh Routing algorithm, whenever a loop is discovered by a forward ant, a negative pheromone is placed at the entry point of that loop such that other forward ants do not waste time in traversing those routes.

Fig. 3 illustrates the way Pharaoh ants work in marking loops or paths. The paths marked in bold lines are the loops ants are to avoid. One is an actual loop and the other is a dead end node to avoid, both previously traversed by a forward Pharaoh ant. The Pharaoh Routing algorithm is described as follows:

1. Similar to AntNet and Improved AntNet, forward ants are created at the source node and sent towards the destination node at some interval.

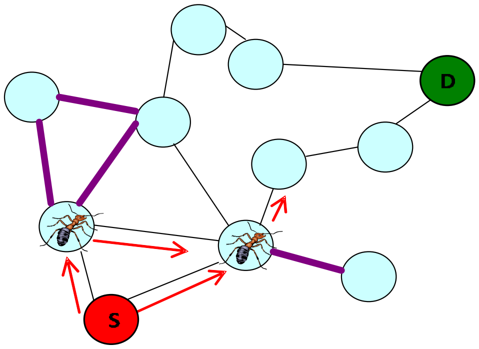

Figure 3. Forward Pharaoh ant example

2. Forward ants select the least cost path joining the source and destination. The next node to visit is selected according to a link probability distribution. Initially, each link share equal probability.

3. Forward ants maintain a taboo list of nodes which, they already visited. If a node is visited that exists in the taboo list, a loop is discovered. If the loop is longer than half of the path taken by the ant, the ant dies. Otherwise, the loop is removed from the forward ants' memory and the path is marked with a negative pheromone such that other forward ants avoid taking that route.

4. Once the destination is reached, a backward ant is created and sent back along the same path to the source node while updating the link probability distribution at every hop exactly as in AntNet. Once it reaches the source node, it dies.

As forward ants act similarly to Pharaoh ants, it increases the effectiveness of the foraging behavior in grid networks. Unrewarding routes are marked in such way so that other forward ants do not waste time in going through them towards the destination.

More forward ants find the destination in less time. As a result it is expected that the noticeable improvements of this algorithm is in terms of increased success rate and reduced energy consumption. The functional flow chart of the forward ant of the Pharaoh Routing algorithm is shown in Fig. 4.

III. RESULTS AND DISCUSSIONS

In order to evaluate and compare the proposed two routing algorithms for resource-constrained networks, we used NetLogo simulator environment. The environment used to test the performance of the algorithms was modeled using NetLogo's graphic design tool to simulate a network. Through NetLogo, network parameters were varied in order to study their effect on the overall performance of each algorithm. The simulator facilitates to deploy the number of resource-constrained nodes and their connectivity. The simulation was run on an n-dimensional node grid with a number of nodes equal to n x n and r number of node connectivity. In the simulation test bed as depicted in Fig. 5, we considered the total number of nodes as 49 (n x n=7 x 7 node grid) with a node connectivity of 3 (r=3). In this evaluation, we used success rates, latency, energy consumption and energy efficiency as performance metric.

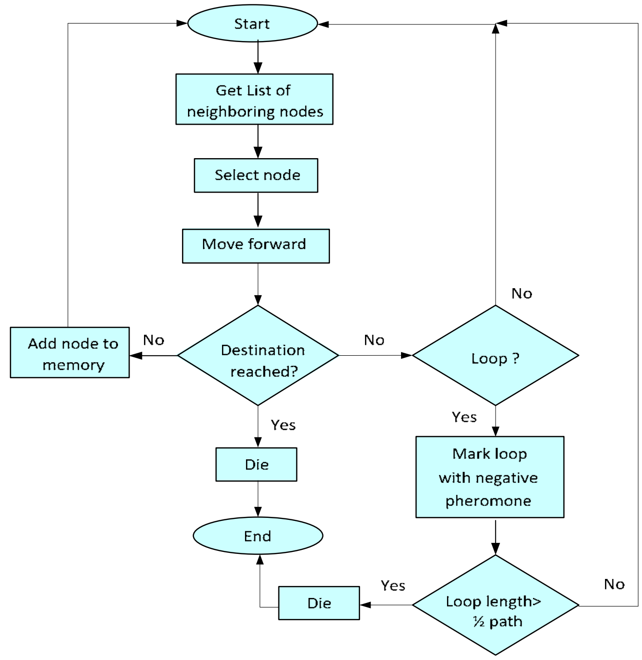

Figure 4. Pharaoh Routing forward ant flow chart

For the comparisons, we implemented the proposed two algorithms and the AntNet algorithm in the simulator. We ran the test for 100 time units, which were considered as ticks. For every performance metric 10 samples were taken and the means were calculated. In order to better compare the proposed algorithms, we showed the performance of each metric in standard deviation. The performance metrics and their comparisons for each algorithm are described below:

A. Latency

The latency is defined as the time it takes for an ant to go from the source node to the destination node. In this simulation, the latency is expressed as the number of hops in each route as opposed to the actual time it takes to traverse the route. The final latency of the three algorithms is shown in Fig. 6 and Table I.

TABLE I. FINAL LATENCY FOR n = 7 / r = 3

AntNet	7.4
Improved AntNet	8.2
Pharaoh	6.1

Standard deviations of the final latency for each algorithm are 3.17, 2.4, and 0.88 respectively. Pharaoh Routing's low deviation shows that the readings are clustered closely around the mean which gives indication of a higher reliability of the algorithms' performance for this metric. As for the AntNet and Improved AntNet, the relatively higher standard deviation value indicates that forward ants require more time for searching the destination node.

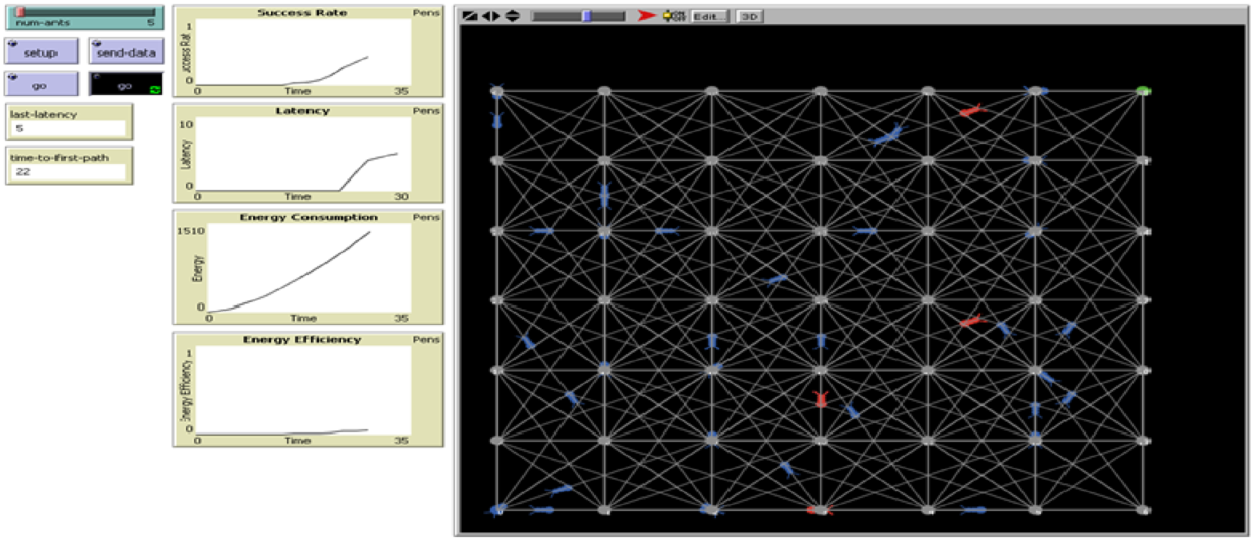

Figure 5. Simulation snapshot in a grid network for n = 7 / r =3

B. Success Rate

The success rate of individual algorithms is expressed in terms of the ratio of the total number of ants that arrive at the destination node versus the total number of ants dispatched from the source node.

Fig. 7 shows that the Improved AntNet has a higher success rate while maintaining comparable latency value as that of the AntNet and Pharaoh Routing. Due to the forward sensing capabilities to forward ants, the Improved AntNet shows positive increase in the success rate. Pharaoh Routing achieves also higher success rate than AntNet. Because forward ants mark the paths that end up in loops with a negative pheromone while preventing other forward ants from venturing into paths that lead away from the destination node and into unwanted loops.

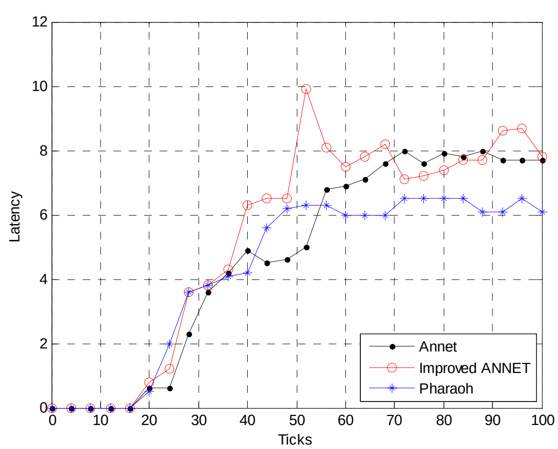

Figure 6. Latency for n = 7 / r = 3

C. Energy Consumption

The energy consumption is defined as the total amount of energy consumed in the network. Therefore, the total amount of energy consumed is equivalent to the total number of ants sent through the grid network. Even though the Improved AntNet has a higher success rate, it consumes far greater energy than the others which may not be acceptable in networks where energy resources may be scarce. As shown in

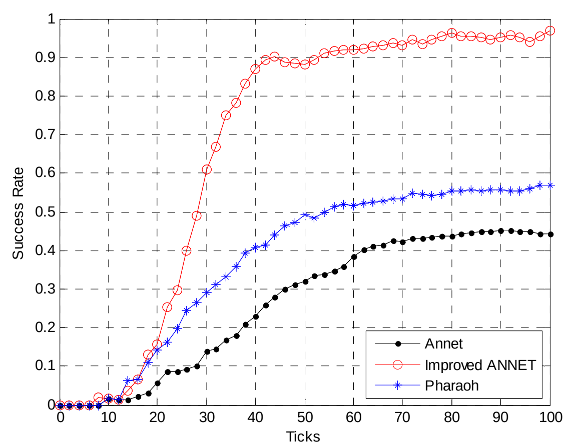

Figure 7. Success Rate for n = 7 / r = 3

Fig. 8, Pharaoh Routing consumes the least amount of energy among all the three algorithms. Because a very few ants spend time in going through the paths that lead away from the destination node and into unwanted loops. As a result, less energy is being consumed.

D. *Energy Efficiency*

The energy efficiency is the ratio of the total number of ants that arrive at the destination versus the total amount of energy consumed in the grid network. As shown in Fig. 9, Pharaoh Routing algorithm demonstrates as the most energy efficient one among the three algorithms.

E. *Path Discovery Time*

The path discovery time is a metric which is referred to as convergence time. It is important to know how much time is required for each algorithm before the source node is aware of a route to the destination node and is able to begin transmitting data. As more paths are discovered, the source node can always adjust the route of its data path if a shorter route is discovered.

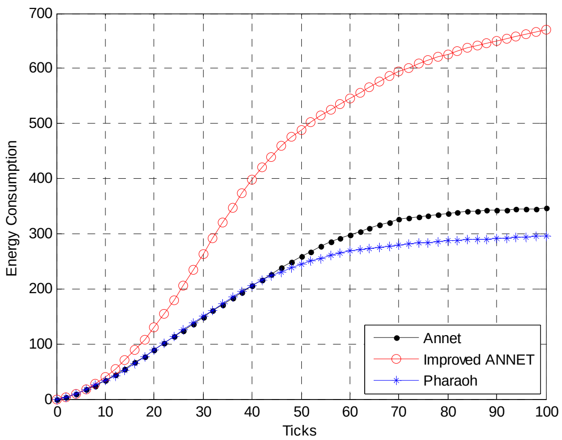

Figure 8. Energy Consumption for n = 7 / r = 3

The path discovery time is expressed in ticks or number of cycle units. This unit is a NetLogo counter that represents execution time. Table II illustrates the time to path discovery values observed in the evaluation. The unit of the result is shown as a number of ticks:

TABLE II. TIME TO PATH DISCOVERY FOR n = 7 / r = 3

AntNet	37.9
Improved AntNet	29.1
Pharaoh	31

The standard deviations observed for the time to path discovery values for the three algorithms are 18.25, 6.37 and 9.97 respectively. These values indicate to what degree each data value is dispersed around the mean. They can also be an indication of accuracy.

The AntNet and Pharaoh Routing have slightly more disperse time values than Improved AntNet. This is an indication of how accurate the Improved AntNet could be in this regard.

Looking at the measurements results, we can draw the following conclusions regarding the improvements introduced in Improved AntNet and Pharaoh Routing algorithms: Improved AntNet has the highest success rate and convergence time while the Pharaoh Routing has the least latency, least energy consumptions and finally the most energy efficient.

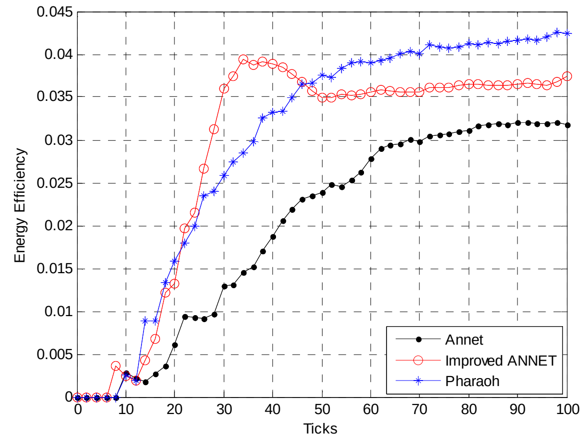

Figure 9. Energy Efficiency for n = 7 / r = 3

IV. CONCLUSION

The application of ant-based routing for resource constrained networks is becoming an increasingly popular approach. In this direction, two algorithms: the Improved AntNet and Pharaoh routing are designed and proposed. The conducted experiments show the effectiveness of the proposed algorithms in terms of energy efficiency, low latency, and higher success rate. As for the future work, we might consider experiment with varying network parameters. Other possible future directions, we would consider the use of the two metaheuristic: AntNet and Genetic algorithm in order to have better performances.

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