MANET's Energy Consumption using proposed Ant-Colony Optimization and Integer Linear Programming Algorithms

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Abstract. Mobile Ad-hoc Network (MANET) is a self-organizing wireless network that communicates without infrastructure and suffering from low power-battery. The challenges of under-optimization have received a great amount of attention from researchers, and Energy Consumption (EC) is the most important of those challenges for them in this field. Therefore, the main objective in finding a route from source to destination is to minimize node EC. Integer Linear Programming (ILP) and Ant Colony Optimization (ACO) are two algorithms that enhance EC and processing time, which are Quality of Service (QoS) requirements. In our paper, we proposed the two algorithms, which are evaluated regarding two criteria: EC and processing time using an experimental study. The optimal route of the proposed ILP is chosen from all possible routes using the minimum EC as an objective function and a set of constraints. The second algorithm is a proposed ACO version, based on ants' behaviour Looking for a path from their colony to their food source. The two proposed algorithms were implemented and compared according to different criteria (route selection, EC and processing time).

1. Introduction

Nowadays, due to the popularity of mobile phones, MANET has become one of networking and communication's most vigorous fields. Nodes are linked wirelessly to a self-configured network in this network without needing a fixed infrastructure such as base stations. The topology changes dynamically, as all nodes can move anywhere [1]. A node in MANET, with a limited power battery, provides complete access to transmit data very quickly from node to the other, and provides precise services. From the very beginning of the MANET research, saving EC was one of the major issues. When a node consumes its battery power, it isn't able to transmit or receive data and becomes a dead node.

QoS in MANET has become great interest area with the growth of Multimedia Technology. MANETs impose new constraints through design of routing algorithms for MANETs include decreasing EC, improved cost, high reliability and simple support. Each research of routing algorithms claims that his algorithm is better than others using simulation with different metrics [2]. The optimization strategy contains various approaches for minimizing EC and finding the optimal path. In [3], some protocols were intended to save more energy that provide greater QoS.

Integer Linear Programming (ILP) [4] is an optimized algorithms that used to solve the complicated issue of MANET topology, and cope with the latest EC algorithms technology. It involves maximizing or minimizing an objective function, in relation to different constraints where they used variables in integer values [5]. The selection of the route is based on a group of constraints minimizing the objective function. In the ILP technique [6], often considered unrealistic, it was suitable to include various algorithms to maximize network life.

Ant colony optimization (ACO) is a new general heuristic framework for solving the problems of combinatorial optimization. Ant colonies' behaviour is based on the ants seeking the optimal path from their nest to the source of food. From each node, the forward ants move until all nodes are visited. They decide to go to unvisited nodes when they arrive at a node with a certain probability that depends on two factors: the connection pheromone level and the distance between the two nodes. The ants deposit a certain pheromone amount on their path after they have finished their tour. The pheromones concentration that accumulates on the short paths gradually rises with the time of passage [7]. The back ants choose their route depending on the intensity of the pheromone during the foraging phase. The bio-inspired ACO method is used for vehicle communication [8] and mobile nodes. Reducing the amount of route discovery packets by adding an offset transition probability coefficient depending on the rate of EC which can extend the network's life [9]. The ACO prevents excessive EC of a certain local node resulting in more uniform EC for each node [10].

We suggest two algorithms to focus on optimization of QoS criteria (EC and execution processing time). First is the ILP technique, since it can be used not only as an effective modelling tool, but also as an efficient solving method for problems of realistic size. It selects the optimal path subject to a group of constraints to improve in QoS. This algorithm will be used as a reference model (benchmark). The other algorithm concentrates on route optimization using ACO to get the optimal path. The rest of the paper organized as following: Section two describes the EC calculations and the two proposed algorithms. A comparison study is conducted using simulation based on the same requests and network topology are describes on section three. The paper concludes in section four.

2. System Models and Formulation Problem

2.1 Energy Consumption calculations

MANET is regarded to be an undirected graph network $G = (S.L)$, where S denotes the nodes and L denotes to directional link between nodes. In our algorithms, the nodes are distributed uniformly in given area, where it generates the requests sequence by using Poisson distribution. The complete bandwidth for each node that transmits\receives signals does not exceed B. In the two proposed algorithms, they are calculating the total consumed energy E by a given node as follows:

$$E = E_0 + E_{tx} + E_{rc} + E_{cp} \tag{1}$$

Where; E_0 , is the EC by a node to be survive

E_{tx}, is the EC for transmitting a node packet
E_{rc}, is the EC for receiving a node packet
E_{cp}, is the EC for the node compute process

The cost of the energy path among the nodes of $(s.d)$ is calculated from two separate cost functions, namely, transmission energy cost and reception energy cost. Transmission energy costs are the total EC between the nodes during travel. The reception energy cost is the amount of EC in relation to the distance from Euclid.

$$E_{tx} = Kbd^{\alpha} \qquad ; K = 100 \times 10^{-12} \text{ j/bit. m}^{\propto} \tag{2}$$

$$E_{rc} = Lb \qquad ; L = 50 \times 10^{-9} \text{ j/bit} \tag{3}$$

Where; b, the packet size in bits

d, the distance in meters for packet transmission
α, the packet loss constant

Substituting in Equation (1), and considering that E_0 and E_{cp} are used in the two algorithms as constant values, so for comparative reasons they can be disregarded. The EC in a node when a packet size b transmitted and received for distance d, is then approximately given by Eq. (4).

$$E = Lb + Kbd^\alpha \tag{4}$$

2.2 Proposed Integer Linear Programming

With the proposed ILP algorithm, its aim to get the optimal route among $(s.d)$. Despite the reality that the shortest route isn't the primary objective, it is one of the vital issues since the shortest path is not always the minimum EC. As the iteration is the most challenge in our algorithm, we used matrix multiplication. The hop count is considered an important issue that depends on node intensity (number of nodes per area). The proposed algorithm's objective is to discover a route that meets particular demands, such as saving energy and minimize delay. The traffic amounts between $(s.d)$ are transmitted through single path (non-split traffic amount). Since λ_{sd} for node-pair (s, d) is routed on single path, The path hop-count cannot exceed the maximum permitted hop count H_{sd}. The formulation of problems and constraints shown as below.

Output variables:
$$y_{ij}^{sd} = \begin{cases} 1 & \text{if the route from s to d goes through the link (i.j)} \\ 0 & \text{otherwise} \end{cases}$$

Objective function:
In our optimization we seek to minimize EC of network nodes. The initial battery capacity is considered. This means that the number of broadcast cycles supported by each node is counted and the smallest value is selected.

$$\text{Min} \sum_{(i.j)} E_{ij} \, y_{ij}^{sd} \tag{5}$$

Constraints:

a) <u>Delay constraint:</u> This constraint guarantees that the delay given by the mean of every node pair (s, d) doesn't surpass the pre-determined maximum allowed hop-count H_{sd}.

$$\sum_{(i.j)} y_{ij}^{sd} \leq H_{sd} \qquad \forall(s.d) \tag{6}$$

b) <u>Bandwidth constraint:</u> This constraint insures that bandwidth is available along the path.

$$\sum_{sd} \sum_i y_{ij}^{sd} \lambda_{sd} + \sum_{sd} \sum_j y_{ij}^{sd} \lambda_{sd} \leq B \; \forall i \in V \tag{7}$$

c) <u>Transmitting power constraint:</u> It depends on the distance between i and j nodes, $\propto$ is a typically parameter that takes value 2.

$$d_{ij}^\alpha X_{ij} \leq P_{max} . \forall i \qquad i.j \in V \tag{8}$$

d) <u>Route constraints:</u> It ensures the route of validity between pairs of nodes.

$$\sum_i y_{ij}^{sd} - \sum_j y_{ji}^{sd} = \begin{cases} 1 & \text{if s=i} \\ -1 & \text{if s=i} \qquad \forall i \in V \\ 0 & \text{Otherwise} \end{cases} \tag{9}$$

e) <u>Balance energy consumption constraint:</u>
In our algorithm, we added a balance EC constraint to make sure that all nodes consumed the energy from the intended battery. The constraint concept is to force the system to use the minimum nodes previously used. Therefore, the system can only use nodes that consumed less than the average EC. The challenge of this constraint is the EC in the beginning node and requesting that equal to zero. To tackle this challenge, a threshold value has indeed been added to guarantee that all nodes are above the average EC, in order to relax this constraint and activate it after three requests. In other hand all nodes will die together.

```
Inputs:  N. H_{sd} . λ_{sd} . B . P_{max}
Initialize the network topology
1.  Generate transmission requests randomly using Poisson distribution.
2.  For r=1 to k;
3.      find all nodes, exclude s, d out of the nodes
4.  For the rest of the nodes, assume number of hops:
5.      If hop=1;
6.          Select the shortest route between (s, d);
7.      Else If hop=2;
8.          Find all combinations of one node;
9.      Else If hop=3;
10.         Find all combinations of two nodes;
11.     Else
12.         Stop at hops=3;
13.     End if
14. End for
15. If y_{ij}^{sd} = 1 ; route is valid
16.     Calculate d_{ij} ; (use the Euclidean distance).
17. Else y_{ij}^{sd} = 0 ; choose another route.
18. End if
19. Choose the shortest distance route.
20. Calculate E_{tx}, E_{rc} from Eq. (2,3)
21. Calculate the processing time.
Output: route, total EC (E) and processing time (T)
```

Figure 1: Proposed ILP Algorithm

In figure 1, our proposed ILP algorithm, we choose the optimal route to achieve objective function with the mentioned constraints. First, we initialize value of nodes number N and requests K; the locations are haphazardly over the terrain area. With assuming the range of transmission for each node as a similar range for all nodes. Find the node-to-neighbourhood transmission range distance. Then transmit random requests as Poisson distribution. After that calculate each distance, using Euclidean distance. Then find all possible permutations that exclude both $(s.d)$ nodes. And after that, check the validity of route by calculating the required energy to transmit and receive the packet (internal node in the route), sending for source, and lastly, the residual energy should be smaller in the destination node. Finally, calculate the total EC and processing time.

2.3 Proposed Ant-colony Algorithm

The proposed ACO is a successful algorithm expressing the feasible solutions of optimization problems with ant paths. It's using the ant group's general routes resulting in the best solution. Ants tend to release more pheromones on reliably short paths [11]. With time passing, the pheromones concentration accumulating on the short paths gradually rises and the other ants choose these paths. Occasionally, all the ants will gather under positive feedback on the optimal path, which precisely matches the ideal issue solution for optimization.

Firstly, delay adjacency matrix is estimated depending on distance matrix. The node distance is only available in the node edges within the neighbourhood of the transmission range. In case of no neighbourhood relationship among the two nodes, the pheromone substance on that link will be zero. There is an initial pheromone amount τ_0 between nodes (i, j), once neighbourhood relationship is established. For each path, the pheromone amount is updated when the ant crosses from node i to j, as follows: $\tau_{ij} = (1 - \rho)\tau_0 + \Delta\tau_{ij}$;where $\Delta\tau_{ij}$ is the pheromone's increasing value (10)

The probability of path preference is calculated for both intermediate nodes as source nodes upon receipt of a path response ant. Assuming that the current node i receives a path reply ant for destination d from node j, then the path probability is determined as pursued.

$$P_{ij} = \frac{[\tau_{ij}]^{\propto}[B_{ij}]^{\delta}[D_{ij}]^{\beta}[\eta_{ij}]^{\gamma}}{\sum_{l \in N_i}[\tau_{ij}]^{\propto}[B_{ij}]^{\delta}[D_{ij}]^{\beta}[\eta_{ij}]^{\gamma}} \qquad (11)$$

Where α, β, γ and δ (>=0) are tuneable parameters that control the relative pheromone weight trail $[\tau_{ij}]$, bandwidth $[B_{ij}]$, delay $[D_{ij}]$ and hop count $[\eta_{ij}]$ respectively. Also, $[N_i]$ is the neighbours of i and I is neighbour node of i through which a path is available to destination. Relative metrics are calculated with the following equations as when next hop on the path from i to d is j.

$$[D_{ij}] = \frac{1}{delay(path(i.d))} \tag{12}$$

$$[\eta_{ij}] = \frac{1}{hopcount(path(i.d))} \tag{13}$$

$$[B_{ij}] = Bandwidth(path(i.d)) \tag{14}$$

As the source, the intermediate nodes have multiple paths to their destination after finding the preferential probability paths through different neighbours. For data transmission, the higher probability path will be chosen. The proposed ACO is based on energy control, which relies on node residual battery power calculation for route selection, taking into consideration the average and minimum energy level required for the route. It differs from the conventional ACO as following:

a) Forward ants only are used to update the value of pheromone without using the backward ant to reduce overhead time.

b) The preference path probability P_{ij} selects the next node dependent upon four QoS metrics (the pheromone amount value, delay, bandwidth and hop-count).

c) Using a pre-processing phase, the parameters of algorithm (initial τ, α, γ, β, ρ, and Q) are selected by running it for a reasonable range of each parameter and fixing the others to find the parameters set of that best fit, while matching with the reference model. It has to be repeated for each different topology.

```
Inputs: N. M. λₛd. B. K. δ
Initialize the network topology
Inputs (pre-processing phase): ∝. β . γ . ρ. τ . Q
1.  For i=1 to N do
2.      Calculate the pheromone matrix table
3.      For j=1 to M do
4.          Update pheromones τij  using eq. (10).
5.          Calculate Pij  eq. (11).
6.          Confirm the selected route with the probability distribution.
7.      End for
8.  End for
9.  Calculate Etx. Erc from Eq. (2,3)
10. Calculate the processing time.
Output: route, total EC (E) and processing time (T)
```

Figure 2: Proposed ACO Algorithm

First, we initialize value of number of nodes N and requests K; the locations are haphazardly over the terrain area. With assuming the range of transmission for each node as a similar range for all nodes. Define input parameters: Source node s, Destination node d, iterations number k, number of ants M, pheromone parameters α, cost factor β, bandwidth parameter δ, delay parameter γ, initial pheromone matrix τ, evaporation coefficient of pheromone ρ and the increase factor of pheromone intensity Q. Then, the process of route discovery, Ants are sent from s to d and follower ants are sent from destination on receipt of first ants. The followers follow the same path as the first ants travelling to s, thereby updating pheromone values at nodes along the path on the basis of minimum EC at nodes, average energy of the path and the path hop-count. When Follower ants reach the source, route is established. Finally, calculate the total EC and processing time.

3. Experimental Results and Analysis

3.1 Simulation Setup and parameters setting

In this section, the proposed algorithms are used to characterize MANET's effective routing route with minimize EC and processing time. Our simulation takes place in a two - dimensional free - space region. The node coordinates are randomly and uniformly distributed. N nodes are supposed to be distributed uniformly. All nodes have the same energy as indicated in table1. Using the Poisson distribution function generates the request set. The traffic amount λ_{sd} for both nodes (s, d) is assigned by a normal distribution random function with a variance equal to half the mean value. The number of nodes N=15 nodes and the amount of requests k=50 requests are considered in this research. All inputs are shown in Tables 2, and 3 below.

Table 1. General parameter setting

Parameter definition	Value
Topology size	180X180 m^2
Node distribution	Uniform distribution
Number of requests distribution	Poisson distribution with the mean value = 1
Transmission range	80 m
Initial Energy	0.5 Joule
Bandwidth	500 b/s

Table 2. Parameters setting for proposed ILP algorithm

Parameter definition	Parameter	Value
Traffic amount for each request from s to d	λ_{sd}	Poisson distribution
The maximum allowable hop-count	H_{sd}	3

Table 3. Parameters setting for proposed ACO algorithm

Parameter definition	Parameter	Value
Characterizes the importance of pheromone values	α	1
Characterizes the heuristic delay factor	γ	0.01
Characterizes the heuristic cost factor	β	1
Pheromone evaporation coefficient	ρ	0.68
Initial pheromone value	τ_0	0.13
Pheromone increasing value	$\Delta\tau_{ij}$	0.05
Pheromone intensity increase factor	Q	1

3.2 Results and analysis

In order to evaluate the two algorithms, we designed network topology for two dimensional free space area of 180×180 m^2 and 15 nodes whose locations are uniformly distributed by their centre (x, y) as shown in figure 3. All nodes are assumed to have same 80-meter transmission range and are displayed as circle range arcs. For both proposed algorithms, this topology is fixed for both algorithms. In the table 4, the routes are obtained for 10 requests out of 50 requests in both algorithms given with EC values of nodes and the processing time and the same values of traffic amount for each request between $(s.d)$. The validation of selected route is checked using the Radio Frequency (RF) range of each node in the topology plus calculating the energy consumption using exact physical equations. The routes are depending on optimal path in the proposed ILP algorithm and depending on QoS metrics (the pheromone amount value, delay, bandwidth and hop count) in ACO algorithm.
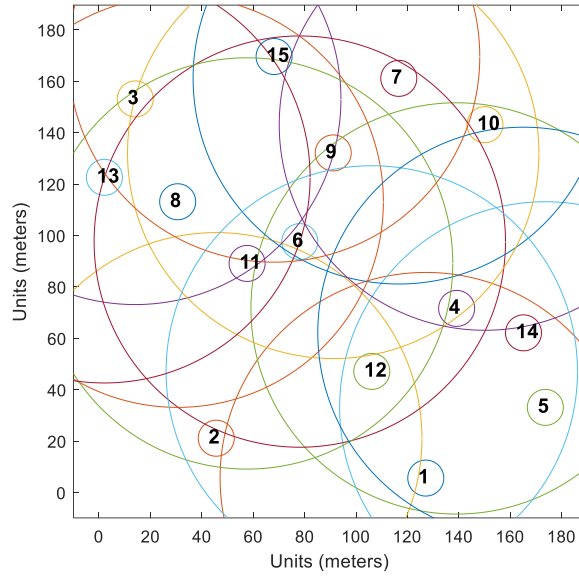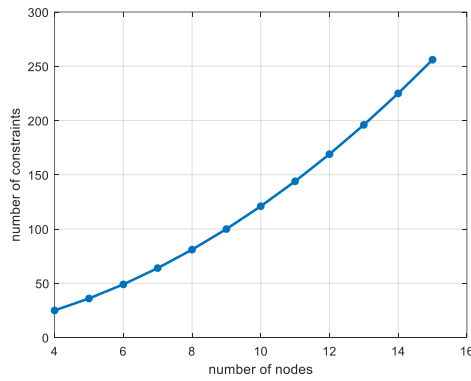
Figure 3: Nodes locations over area

Figure 4: Number of nodes Vs number of constraints in ILP
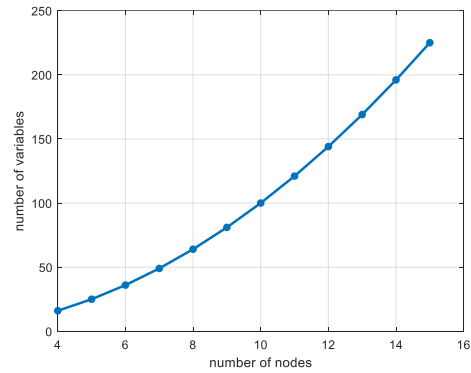

Figure 5: Number of nodes Vs number of variables in ILP

In the proposed ILP, solving the problem of routing selection to get the optimistic path which satisfies the best QoS is high complicated issue. The reasons behind this are the problem nature (ILP) in addition to large number of variables and huge number of constraints as shown in figures 4-5. In our simulation, we use 15 nodes as its variables equal to 225 and 256 constraints.

Table 4. Exact values of consumed energy and processing time for proposed algorithms

| No	S	D	λ_{sd}	Proposed ILP			Proposed ACO		
				Route	EC (mJ)	Time (Sec)	Route	EC (mJ)	Time (Sec)
1	2	13	148.8881	2→11→8→13	1.0095	0.1563	2→11→13	1.9941	0.1719
2	3	4	151.0536	3→8→6→4	1.2405	0.1719	3→9→4	2.6669	0.1406
3	10	8	155.6393	10→7→9→8	1.0532	0.1563	10→9→8	1.7246	0.1094
4	7	2	143.4684	7→9→11→2	1.2316	0.1563	7→6→12→2	2.937	0.0938
5	7	13	140.1907	7→15→3→13	0.9182	0.0938	7→6→15→8→13	3.6599	0.0781
6	14	2	145.5589	14→4→12→2	0.9656	0.125	14→12→2	1.8084	0.1094
7	3	12	147.4157	3→11→6→12	1.3344	0.0938	3→11→12	2.2209	0.0781
8	10	3	159.214	10→7→15→3	1.0902	0.0938	10→9→3	2.1944	0.0625
9	1	9	152.4462	1→4→6→9	1.4338	0.0938	1→4→9	2.2929	0.0625
10	2	15	146.7721	2→11→8→15	1.4291	0.0625	2→11→3→9→15	4.2123	0.0781
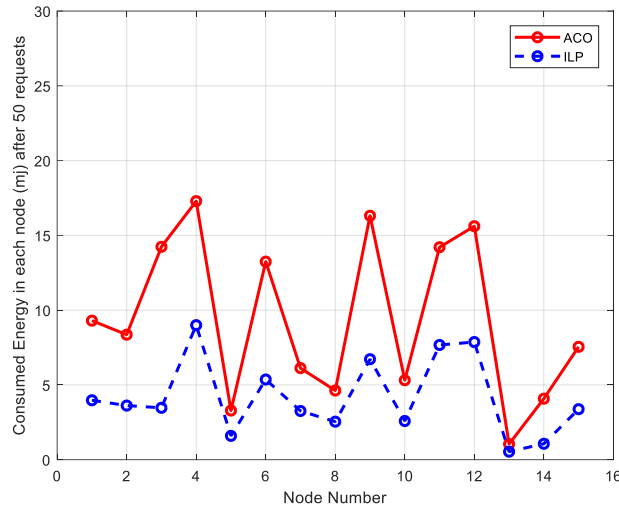
Figure 6: Relationship between node number and consumed energy for two algorithms.

The relationship between consumed energy in each node after 50 requests and the node number for both models are shown in figure 6. In this figure, the total EC per node in proposed ACO is greater than proposed ILP. According to node position, because of route selection in proposed ACO model. The centralized nodes (4,6,9,11,12) consume more energy than edges nodes (1,2,3,5,7,8,10,13,14,15).
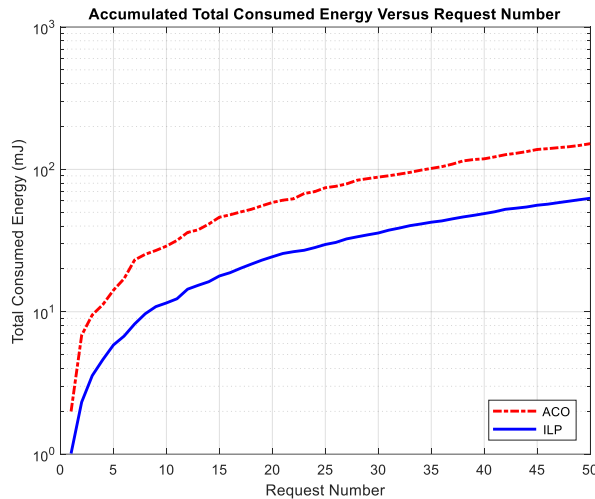

Figure 7: Relationship between total consumed energy for two algorithms.
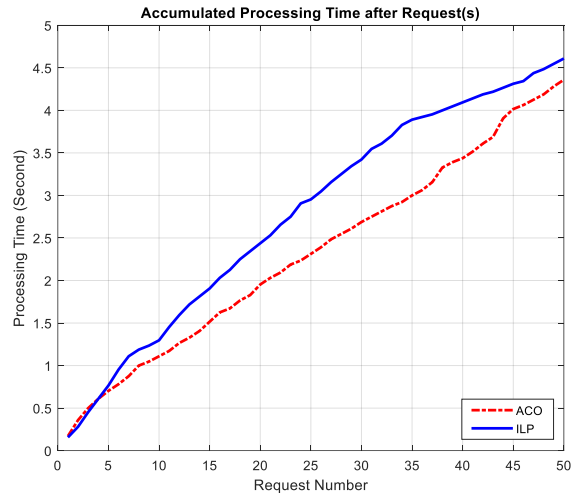

Figure 8: Relationship for processing time for two algorithms.

In figure 7, it illustrates the total EC in the proposed ACO model is greater than proposed ILP model. As the delay (consumed time) is one of the important ratios in QoS, figure 8 shows the relationship between accumulated consumed processing time and the requests number for proposed ILP and proposed ACO models. From this figure it shows that the proposed ACO model consumed less time after request 4, which processing time is equal to 0.6094 second. From this analysis, the proposed ACO model is consumed more energy with less processing time than proposed ILP model.

4. Conclusion

The paper proposes ILP and ACO algorithms. The first algorithm is established using an exact formula of mathematics. As a first step, it's based on finding all possible routes for a given request from source to destination nodes. In the same step, the hop count is considered to be a significant problem because multiple hops involve node-to-node data transmission in MANET. As a second step, using the Euclidean formula, a simple mathematical method is used to evaluate path length, to discover the

optimal path from all possible paths acquired in the first step. This algorithm's output outcome is used as a reference to evaluate other algorithms ' accuracy with regard to the shortest path.

After some improvements, the second algorithm ACO is proposed. Forward ant only updates the pheromone to reduce overhead time without using backward ants. The probability of each route P_{ij} selects the next node depend on QoS metrics (pheromone amount value, delay, bandwidth and hop count). Using a pre-processing phase, all parameters of algorithm (initial τ, α, γ, β, ρ, and Q) are selected by running it for a reasonable range of each parameter and fixing the others to find the parameters set of that best fit, while matching with the reference model. The proposed algorithm is dynamic selection of the parameters which fit the topology and the nodes distribution (the preprocessing phase). Experiments in simulation demonstrate that the ACO model presents a great solution for low time consumption and proposed ILP present a great solution for energy consumption.

References

[1] S Vijayalakshmi, M Sweatha, A survey on history and types of Manet, *International Journal of Emerging Trends in Science and Technology,* vol. 3, no. 07, pp. 4310-4315, 2016.

[2] Jiang Ailian, Zheng Lihong, An effective hybrid routing algorithm in WSN: Ant colony optimization in combination with hop count minimization, *Sensors,* vol. 18, p. 1020, 2018.

[3] Korhan Cengiz, Tamer Dag, Energy aware multi-hop routing protocol for WSNs, *IEEE Access,* vol. 6, pp. 2622-2633, 2017.

[4] Hany Ramadan, Benbella S. Tawfik, Alaa El Din M. Riad, Energy aware routing algorithm in MANET using linear programming, *International Journal of Computer Systems Science & Engineering,* vol. 33, pp. 421-428, 2018.

[5] Schrijver, Alexander, Theory of linear and integer programming, Amsterdam: John Wiley & Sons, 1999.

[6] Montemanni, Roberto, Integer programming formulations for maximum lifetime broadcasting problems in wireless sensor networks, *Journal of Wireless Sensor Network,* vol. 2, pp. 924-935, 2010.

[7] Guan Boxin, Zhao Yuhai, Self-adjusting ant colony optimization based on information entropy for detecting epistatic interactions, *Genes,* vol. 10, p. 114, 2019.

[8] Santanu Majumdar, Shivashankar, Patury Rajendra Prasad, S Adarkatti Santosh Kumar, Koppala Narayana Sunil Kumar, An efficient routing algorithm based on ant colony optimisation for VANETs, in *IEEE International Conference On Recent Trends In Electronics Information Communication Technology*, India, 2016.

[9] Yang Dong, Xia Hongxing, Xu Erfei, Jing Dongliang, Zhang Hailin, Energy balanced routing algorithm based on ant colony optimization for mobile ad hoc networks, *Sensors,* vol. 18, p. 3657, 2018.

[10] Li Peng, Nie Huqing, Qiu Lingfeng, Wang Ruchuan, Energy optimization of ant colony algorithm in wireless sensor network, *International Journal of Distributed Sensor Networks,* vol. 13, no. 4, pp. 223-232, 2017.

[11] Dorigo Marco, Maniezzo Vittorio, Colorni Alberto, Ant system: optimization by a colony of cooperating agents, *IEEE ,* vol. 26, p. 29–41, 1996.