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FIREFLY-BASED OPTIMIZED LINK STATE ROUTING PROTOCOL FOR ENERGY-EFFICIENT VEHICULAR AD HOC NETWORKS

Mustafa Tareq*¹, Saad Adnan Abed², Yasir Hadi Farhan³, Boumedyen Shannaq*⁴,
 Said AlMaqali⁵ and Oualid Ali⁶

¹College of Computer Science, University of Technology, Baghdad, Iraq

²Department of Computer Science, College of Computer Science and Information Technology, University of Anbar, Iraq

³Department of Artificial Intelligence, College of Information Technology, University of Fallujah, Iraq

⁴Management Information System Department, College of Business, University of Buraimi, Oman

⁵University of Buraimi, IT Department, Al Buraimi, Oman

⁶College of Arts & Science, Applied Science University, Manama, Kingdom of Bahrain

¹<https://orcid.org/0000-0002-3499-8257>, ²<https://orcid.org/0000-0002-8780-812X>, ³<https://orcid.org/0000-0002-2378-9177>,
⁴<https://orcid.org/0000-0001-5867-3986>, ⁵<https://orcid.org/0009-0002-2159-5288>, ⁶<https://orcid.org/0009-0001-1433-017X>

Email: *mustafa.t.abd@uotechnology.edu.iq

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ABSTRACT

Vehicular ad hoc networks (VANETs), a burgeoning technology within the wireless technology field, hold great promise. As it continues its progress, it stands ready to make increasingly significant contributions to advancing intelligent transportation systems in the foreseeable future. The scale of infrastructure, the number of vehicles, the complexity of scenarios, and the mobility of nodes can collectively contribute to heightened energy consumption during route selection between source and destination nodes, as well as during the transmission of application packets. VANET opts for routes containing a minimal count of intermediary nodes to reach the intended destination efficiently. With the expansion of the distance between nodes, there is a proportional increase in the requirement for broadcast power. The power capacity of the nodes directly influences the ease of establishing a route between two nodes. In this paper, we proposed a Firefly Optimized Link State Routing (F-OLSR) protocol, which utilizes swarm intelligence principles through the firefly algorithm (FFA). The goal is to enhance energy efficiency within an Optimized Link State Routing (OLSR) framework. The route is chosen depending on the amount of power the intermediary nodes between the source and destination nodes. The evaluation performance of the F-OLSR protocol was compared with that of popular protocols. The F-OLSR protocol was demonstrated to be an effective solution for choosing the optimal path with high power from source to destination and improving performance. Regarding energy consumption, the F-OLSR protocol achieved 2.30% and 2.31% concerning the packet size and node speed, which is better results in terms of packet size and node speed, which is a better result than the other protocols.



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I. INTRODUCTION

Wireless networks have gained significant attention in communication over the past few years. It finds applications across various technological domains, including industries, the military, and personal networks. One of the reasons why they are widely used is through wireless networks [1], [2]. In addition, the networks are not limited to fixed infrastructure, and this makes them unique compared to wired networks such as cellular networks, Wi-Fi, satellite communications, and others [3].

VANETs represent the specialized version of MANET, which is different in determining its architecture, a complex nature, and special applications [4]. Considering the prevalence of cars and vehicles in the modern era, there is an essential problem that regards the increasing number of fatalities and accidents on the roads and roads [5], [6]. VANETs are based on Dedicated Short Range Communication (DSRC) which allows cars and roadside buildings to be in contact with each other [7], [8]. This information system can be used to enable vehicles to share various types of information, including traffic, road conditions, and safety information, all of which are aimed at making traffic processes more efficient and ensuring road safety [9-11]. Figure 1 gives an example of a VANET.

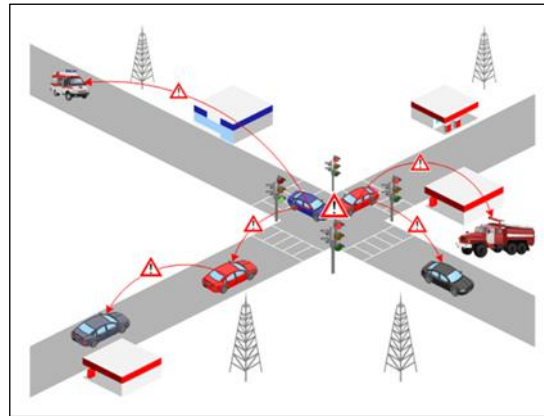


Figure 1: VANET communication.

Source: [12].

Differentiation of communications in VANETs which are Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications are typically classified as two categories. These are part of wireless interactions on a medium referred to as a Wireless Access in Vehicular Environments (WAVE) [13-16]. Application Unit (AU) and Onboard Unit (OBU) are the key units that support the communication of vehicles. With the usage of the OBU, every vehicle on the road has collected and analyzed information and sends data packets to all nearby Road Side Units (RSUs) or vehicles. The RSUs are WAVE devices that are either placed at the side or strategic points like intersections and parking area surrounding them [17-19].

Usually, the design of VANET routing protocols does not focus on power consumption [20]. Their major concern is to support the high velocity of node mobility and unpredictability of the wireless environment [21]. When a computer network is involved, or any other network in a network, the power levels of a specific node may in fact be a decisive factor in the ease of finding a path connecting two nodes [22]. Besides, Optimised Link State Routing (OLSR) is a well-established protocol in mobile ad hoc networks, although the standard edition is only slightly responsive to the special problems of VANETs, specifically regarding energy efficiency [23-25]. The large energy consumption of cars involved in constant data transmission can add to the Net-work instability and higher operation cost which are critical concerns in the large-scale development.

However, energy conservation is another important issue in the development of green, smart cities where the VANETs would play a key role. In an attempt to discuss this in a further detail, in VANET situation, the protocol chooses the route with minimum intermediary nodes to the target. As the distance between nodes is further, there is the increment in the need of transmission power. This paper presents us with Firefly Optimized Link State Routing (F-OLSR) protocol. The F-OLSR improves the traditional OLSR protocol by employing the attractiveness behaviour of the Firefly algorithm to identify the optimal routing path. The purpose of this bio-inspired approach is to enhance routing efficiency to mobile ad hoc network on VANET [26].

The given protocol is a combination of the FFA and OLSR protocol. The suggested FFA is specifically used to improve the path selection processes through the consideration of different parameters. It tries to ensure a good route by choosing intermediate nodes with a high energy value. The FFA algorithm works on the assumption that communication elements of a device have different power consumption levels when transmitting data and receiving data. When this algorithm is implemented, it can be seen that the path with the fewest amount of communication nodes between two communication nodes can not always be the most energy-efficient. In multi-hop networks such as the VANETs, this requires the combination of energy information in all the nodes in the multi-hop path in order to assess energy consumed in the communication path. Thus, the main ideas of this paper include:

Creation of F-OLSR which is the proactive routing protocol in vehicle communications that is based on ABC selects the routes which consume minimal power. Assessing the performance of the newly implemented F-OLSR protocol by comparing it to the BOLSR, BeeIP and OLSR routing protocol. The remainder of this paper is organized as follows: Section 2 reviews related studies, whereas section 3 describes the research materials and methods. Section 4 presents the proposed approach and Section 5 is dedicated for the simulation model and parameters. Section 6 entails a complete description of the performance metrics. Section 7 clarifies the experimental findings and Section 8 concludes the suggested algorithm.

II. LITERATURE REVIEW

To begin with, VANET has drawn the attention of many scholars. Among the most important questions in the framework of VANETs is the question of the best path that would allow the transmission power to the maximum between the source and the destination. The literature has suggested a wide range of methods of using VANETs with swarm intelligence algorithms, such as bat algorithm, bee colony, and ant colony. Several research studies were devoted to the challenging aspect of maintaining and detecting the correct route that secure communication between a source and a target nodes with respect to dynamic changes in network topology and changes in mobility patterns.

In a similar publication [10], [27] a new routing protocol was suggested to be used in VANETs called F-Ant with the basis of which is the fuzzy logic. The protocol uses bandwidth, connection and vehicle congestion as some of the factors, to determine the validity of the links. Considering the difficulties of bandwidth constraints and vehicle congestion in VANETs, F-Ant is interested in providing the quality of road safety services and pursuing specific Quality of Service (QoS) goals, such as the attainment of the high delivery rate with minimum E2E delays. The efficacy of F-Ant is proved by simulation results, which are specifically effective in the city. It has a high benchmark performance when compared to ABC and AODV protocols both in terms of E2E and PDR performance. The proposed protocol, however, is a very energy-intensive method of transferring the packet through the network.

The author came up with a bio-inspired clustering algorithm in VANETs known as BICsf, which involves the use of a hybrid algorithm between the glowworm swarm optimization (GSO) and krill herd (KH) algorithm [28]. The proposed scheme will include energy conscious cluster formation and cluster head election through GSO algorithm. Moreover, an effective cluster managing algorithm is created based on the behavioral principles of KH. Genetic operators, which include mutation and crossover, are also used to find the best location of UAVs. In route choice, a weighted-residual-energy-based path-detection function, number of neighbors, and inter-UAV-distance are used, in order to provide the most efficient communication. BICSF performance is measured against cluster-building time, energy consumption, cluster lifetime and delivery success probability and compared to clustering algorithms using the grey wolf optimization algorithm and ant colony optimization algorithm.

In [29], GreeDi-based reactive routing protocol was presented to maximize the energy-efficient routing of source and destination nodes in VANETs. The protocol's route selection hinges on evaluating intermediary nodes' energy consumption between the source and destination. The algorithm's efficacy was assessed within VANET scenarios modeled on city maps. Notably, GreeDi demonstrated superior performance compared to the original AODV protocol, particularly concerning power consumption. However, the GreeDi protocol has less throughput, a maximum average throughput reaching 54%. The Bee-inspired protocol, known as BeeIP, was introduced by [30], with the authors investigating the protocol's foundation in swarm intelligence (SI). This protocol is developed to make multi-path routing for mobile nodes. The BeeIP utilizes hunters to accumulate route evidence and assigns a selection metric value to each path during their return journey. These metrics' significance and impact on protocol behavior cannot be overstated.

An experimentally evaluated metric within BeeIP focuses on speed, which involves the addition of transmission delay along each intermediate connection in the route, beginning from the target and progressing to the source. This methodology guarantees the selection of the swiftest path among the available choices. BeeIP is intended to estimate the routing on the path basis and to identify the failure of links in case no forager packets are received back to the source node within a designated time. In such instances, the source node assigns a foraging capacity of zero to the path and classifies it as unrecognized. This dual approach prevents the assignment of the broken path's ID to future foragers while also allowing the path to potentially become available again if a forager ultimately returns to become available again if a forager ultimately returns potentially. Simulation results highlight BeeIP's commendable adaptability and efficiency in choosing the most suitable path.

The outcomes demonstrate that BeeIP consistently outperforms other protocols regarding overall performance. Similarly, the artificial bee colony was introduced for mobile ad-hoc networks for minimizing energy consumption [8]. In [29], a new protocol was proposed, which was named Bat-Optimized Link State Routing (BOLSR) to make OLSR protocol more energy-efficient. It is important to note that both OLSR and the Bat Algorithm (BA) use mechanisms of path discovery that are similar in that both use the exchange of particular signals. By taking advantage of this shared attribute, BOLSR calculates an optimal path between a source node and a destination node by taking into account the power relationship between network nodes. To determine the performance of BOLSR, it was compared to CAABO and the conventional OLSR protocol through performance metrics like routing overhead, energy consumption, and end-to-end (E2E) delay. The findings indicate that BOLSR decreases energy usage and increases the total network life cycle.

Nonetheless, the suggested protocol can still be enhanced in regards to energy efficiency and throughput. A different refined protocol, which was also known as ECBLTR was suggested in [12] aimed to maximize the lifetime of the network. This protocol tackles the reduction of efficiency of a network in VANETs due to the high mobility rate of vehicles. To select cluster head (CH), a Sugeno fuzzy inference model is used and a number of input parameters have been utilized, which are residual energy, local distance, node degree, node concentration and distance to the base station. The findings indicate that with the combination of a suitable channel model and a good routing protocol, link throughput in VANETs may be greatly enhanced, especially when the size of the network is constant. Nevertheless, ECBLTR protocol has a relatively high power consumption. The proposed methodology of the study is introduced in section 3.

III. METHODOLOGY

This paper presents a routing protocol specifically designed for energy-efficient operation in VANETs. The key elements of this paper include the incorporation of the OLSR methodology, the utilization of the Firefly algorithm (FFA), and the assessment metrics applied for network testing.

III.1 OPTIMIZED LINK STATE ROUTING (OLSR)

It is an active routing strategy that works in a network setting, as presented by Clausen et al. It is made upon the link-state (LS) framework, which has been improved to reduce the number of packets and control traffic flooding [31]. The OLSR's functionality revolves around broadcasting messages within the network using Multi-Point Relays (MPRs), which are nodes specifically designated for transmitting these messages [30], [32]. The OLSR protocol is completely decentralized and it does not require any central body. It does not necessitate a high degree of reliability in controlling message transmission because they are periodically transmitted and are denoted by sequence numbers, which allow correct ordering. The other important characteristic of OLSR is that it is suitable to mobile nodes. Multi-Point Relays (MPRs) use reduce redundancy in the retransmission across the same neighborhood. In the network, a special group of neighboring nodes called MPRs is chosen by each node in the network, and it is the MPRs that pass broadcast packets [30], [33].

Therefore, the non-member nodes which are not included in the MPR set of a node are capable of receiving and processing the data packets but not forwarding or re-transmitting them [34]. The MPR set is selected from the pool of one-hop neighbors connected by bidirectional links [35]. In this procedure, each node must identify its neighboring nodes with direct links. All links need to be assessed in both directions to confirm these nodes. In this context, each node generates periodic broadcasts of hello messages containing details about its neighbors and the status of their links. These messages enable each node to gather information about its neighbors within a two-hop range, subsequently facilitating the selection of the MPR set.

Node initiates the construction of the MPR selector table, a table for one-hop neighbors, and another for two-hop neighbors [31], [33]. No additional distribution of a unique hello message occurs throughout the entire network. The fact that this happens implies that the nodes who receive such messages do not forward them any further [35], [36]. To establish and maintain the network's essential topology information for routing data packets, each node periodically sends out specific control messages known as "Topology Control" (TC). These TC messages are disseminated as overall transmission packets across the network. The data extracted from TC packets is subsequently kept in a suitable topology table. Each node preserves a routing table that aids in directing data packets to their intended destinations within the network.

Upon receiving TC messages, nodes analyze them and store connected pairs as a combination of the last hop and the current node. Here, the node represents addresses identified in the TC message list [27]. This stored data as the foundation for constructing the routing table sequentially, resulting in the connected pairs being in descending order. To control the most effective path from the source to the target, a sequence of interconnected pairs must be identified, continuing till the final hop node within the source's neighboring set is reached [35], [37]. These connected pairs, forming the route with minimal power consumption, are chosen by various forwarding nodes. In cases where there's a change in the bidirectional link within the neighboring configuration, recalculating the routing table becomes necessary [38].

III.2 FIREFLY ALGORITHM (FFA)

FFA is a swarm-based intelligence algorithm inspired by the flashing behavior and attraction patterns of fireflies. In nature, Fireflies use their bioluminescent flashes as signals to communicate with potential mates and ward off predators. Fireflies are translated to candidate solutions In the Firefly Algorithm (FFA), where each solution moves through the search space based on their brightness and attractiveness to other fireflies. FFA is based on the notion of attraction to brighter individuals, where the movement toward more luminous fireflies enable the swarm to converge on optimal solutions. In FFA, the brightness of each firefly is the solution's quality, the better the solution, the brighter it shines. Fireflies with higher brightness attract those with lower brightness, which enables the FFA to explore the solution space effectively. This movement continues till no firefly is visible within range, then random movement is triggered to promote exploration of unexplored regions.

The algorithm works based on a population of fireflies with each of the fireflies positioning in the search space being the potential routing path. The attraction between the fireflies reduces with distance, hence, balancing exploration and exploitation in the process of optimization. The FFA starts with a swarm of size SN fireflies deployed randomly, each of them represents a routing path. Let $X_i = \{x(i, 1), x(i, 2), \dots, x(i, D)\}$ represent the i th firefly's position in the swarm, with D indicating the dimensionality of the problem. Each firefly is associated with a brightness $I(X)$, and attractiveness β , where the objective function $f(X)$ is proportional to the brightness. The attractiveness is a relative value with respect to the distance to other fireflies. Also, light intensity diminishes as the distance from its source increases. Moreover, the light of a firefly is impacted by the medium absorption, which eventually decreases its attractiveness. Hence, the distance between two fireflies, and the absorption coefficient are considered in calculating a firefly's attractiveness as shown in Equation 1.

$$\beta(r) = \beta_0 e^{-\gamma r^2} \quad (1)$$

Where r is the distance between two fireflies, γ is the absorption coefficient, and β_0 is the attractiveness at $r=0$. We set the light absorption coefficient to $\gamma = 1$ and the baseline attractiveness to $\beta_0 = 1$. This provides a natural, dimensionless decay of attractiveness per hop in graph-based routing. This ensures that fireflies interact primarily with near neighbors, which aligns with the localized decision-making of link-state routing protocols such as OLSR. The exponential term in Equation 1 ensures that attractiveness diminishes as the distance between fireflies increases, preventing premature convergence and encouraging balanced exploration. The distance r_{ij} between any two fireflies x_i and x_j in FFA is computed using the Euclidean distance formula, as presented in Equation 2.

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{m=1}^D (x_{im} - x_{jm})^2} \quad (2)$$

A firefly x_i moves toward a brighter (more attractive) firefly x_j based on the following movement equation 3.

$$x_i(t+1) = x_i(t) + \beta \times r(x_j(t) - x_i(t)) + \alpha \times \epsilon_i \quad (3)$$

Where α is a randomization controller parameter, and ϵ is a uniformly generated random vector. In this work, we set the value of α to 0.2 which is typically used in previous FFA studies to avoid slow convergence, or stagnating in low-quality local optima.

When all fireflies have similar brightness levels or when a firefly cannot find a brighter neighbor. Thus, the second term in Equation 3 performs a random walk to explore new regions of the search space [39].

IV. THE PROPOSED F-OLSR

The existing work mainly focuses on combining the FFA with the proactive routing protocol known as OLSR to implement the F-OLSR routing protocol and improve energy consumption. In order to succeed in the VANET systems, the cooperation of the nodes is essential, as they should exchange the information concerning the link quality and partial route. The issue of power consumption is a major issue with VANETs because the node can crash when the battery power runs out, negatively affecting the network life. It is thus necessary to enhance routing protocols to choose routes of nodes of high energy levels. We suggested F-OLSR which applies Firefly Algorithm (FFA) in determining the shortest paths with the nodes of high power and thus saving energy in all nodes and greatly increasing network lifetime. Path discovery in this method is done through OLSR and the optimization of energy efficient routes is done through F-OLSR algorithm (as shown in Algorithm 1).

Algorithm 1: F-OLSR Algorithm.

```

Generate nodes ( $i=1, \dots, N$ )
Initialize node positions.
Initialize the speed of nodes randomly.
Specify the Src and Dis nodes
Initialize the population of solution  $X_i, i=1, \dots, SN$ 
Send a HELLO message from each node to its neighbors
If the node is in the busy or free state then
  For all fireflies in  $X$  do
    While the entire network remains unprotected do
      Determine the path of  $X_i$ 
      Identify the neighbors of the route
      Compute the distance between adjacent nodes
      Calculate fitness (light intensity) of each firefly
    End while
  End for
  Memorize the brightest firefly (best route)  $OP = [ ]$ 
While (stopping criteria are not met) do
  For each firefly  $i = 1$  to  $SN$  do
    For each firefly  $j = 1$  to  $SN$  do
      If ( $Intensity_j > Intensity_i$ ) then
        Calculate the distance based on Equation 2
        Compute attractiveness with respect to new distance
         $X_i \leftarrow$  update firefly position based on Equation 3
        Calculate  $f(X_i)$  and update light intensity
      End if
    End for
  End for
  Calculate fitness value for all solutions Rank fireflies and find the current best solution Update the optimal path  $OP = [ ]$  with the brightest firefly
   $c = c + 1$ 
  If the current best route surpasses the route stored in  $OP$  then
    Update  $OP$  with the new best position
  End if
End while
Return  $OP$ 

```

Source: Authors, (2026).

The first step of the suggested algorithm is producing as many nodes (fireflies) as indicated as ($i=1$) of a population of SN . The second step is to initialize the positions of the nodes where each node is given a randomly generated velocity and the source and destination node is given. After this the population X_i of solutions is established each solution X_i ($i = 1, 2, \dots, SN$) being expressed in a vector form, SN being the number of solutions. In the initial setup, every node transmits a HELLO packet to all his neighbors to establish whether a node is free or occupied.

Fireflies modify their positions (solutions) relative to the brightness of other fireflies in the swarm and also relative to the level of energy by the measure of the fitness score of the new solution. Upon this search, fireflies mutually communicate and share energy information, calculate the position of nodes, and calculate distances. The equation (4) used in the calculation of energy-related information is the fitness function that is used in calculating the brightness of each firefly. It is also necessary to determine power-draining or energy-conscious nodes.

$$f(x) = \sum_{i=1}^D \text{Energy}(x_i) \quad (4)$$

Where $\text{Energy}(x_i)$ is the remainder energy in the selected i th node. The FFA constantly calculates energy probability every time the node visits the network. It is significant to identify the count of nodes demonstrating complete power awareness or susceptible to leakage of power efficiency. The method entails a starting step, and a main search procedure that is repeated till a satisfactory fitness answer is discovered on the most OLSR-conscious node. The algorithm will verify that there is a source route and calculate the amount of nodes around a brighter firefly as a firefly relocates towards it. In case there is no source route, this algorithm will spawn a packet broadcast and reconsider firefly energy. In addition, it separates outgoing and incoming broadcast packets with respect to energy transmission.

Therefore, a node that is located distant consumes significant energy causing an increase in energy loss. The approach that we propose implies the use of the route requests through intermediary nodes. The FFA attempts to determine the nodes that have high power availability by ignoring the nodes which have small power resources. At the destination, the FFA helps determine an optimum path between the source and the target taking into account the power of the intermediate node and attempting to reduce the number of hops made. The number of solutions in F-OLSR is shown in figure 2. Upon identification of the best route, transmission packets are launched using the source node. This is the best choice of path illustrated in Figure 3.

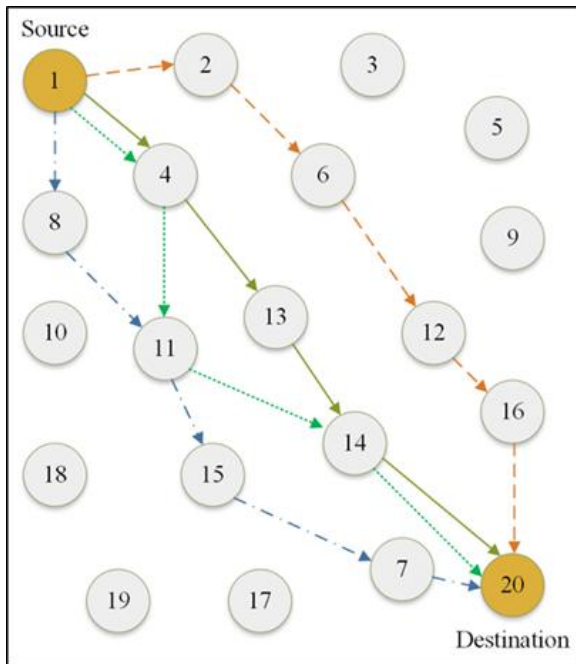


Figure 2: An excerpt of number of solutions in F-OLSR.
Source: Authors, (2026).

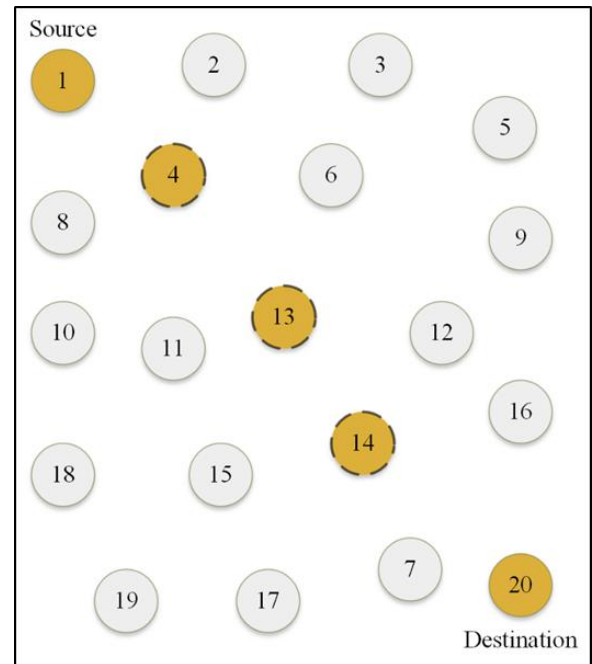


Figure 3: The optimal selection path in F-OLSR.
Source: Authors, (2026).

This paper provides configuration of the network through an OTcl script that defines the routing protocol, the network traffic, the number of nodes and the propagation model that should be used. Then, a trace file and Network Animator (NAM) will be produced from the simulation process to be used for data analysis and visualization, respectively.

V. SIMULATION MODEL AND PARAMETERS

The simulation is discussed based on the proposed F-OLSR protocol. The ageing objective of this simulation was to improve the functionality of VANET and increase its longevity. It was intended to utilize the F-OLSR protocol to find routes that had a high energy cost, a high throughput and reduced delays. The key actions performed on the way to the implementation of the simulation of the proposed F-OLSR protocol are demonstrated in Figure 4. The study was chosen in two real life scenarios, one in an urban setting and the other in a highway setting. Precisely, the urban scenario selected was Auckland CBD, and the highway scenario was the Auckland motorway. There are four basic modules of the simulation model. The former module is the creation of the VANET environment that sets up the setting of the simulation.

These involve the incorporation of the important VANET features like the size of the network, the number of nodes, bandwidth and other pertinent parameters. The next process involved routing protocols whereby a number of optimization algorithms were being applied to address the progression of solutions. Finally, but not the least, the performance assessment of the F-OLSR protocol was performed through the use of two scenarios. To begin with, the highest speed allowed to nodes is 5, 10, 15, 20 m/s. Secondly, the size of packets was varied by this simulation e.g. 128, 256, 512, and 1024 bytes. Evaluation was done using a random-based mobility model which is a standard mobility model in VANET. Finally, the protocol was evaluated in terms of major measures e.g. the ratio of delivered packets, average energy rate, average delay, and throughput.

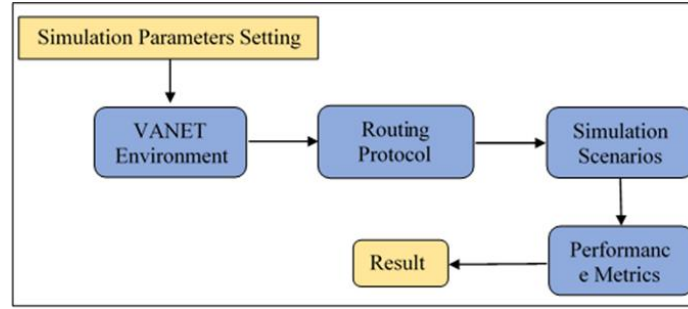


Figure 4: The VANET Simulation Model.

Source: Authors, (2026).

The type of traffic utilized in the experiments is the Constant Bit Rate (CBR) that is normally used with the UDP transport on a multi-hop network and is applicable in the real-time applications. Each node was configured to have a transmission range of 250m. The simulation area was 1200 x 800 m in length and width under all conditions where node energy is set at 100J and the duration of the simulation was 40s. The distribution of the nodes was random and placed in 20 positions with two nodes at a large distance as the source and destination. Table 1 summarizes all the simulation parameters.

Table 1: Simulation Parameters.

Parameter	Value	Unit
Number of nodes	20	Nodes
Queue size	100	Packet
Scenario Dimension (m x m)	1200 x 800	M2
Protocols	F-OLSR, OLSR, BEEIP	Protocols
Packet size	128, 256, 512, 1024	Bytes
Transmission range	250	m
Application layer	CBR	—
Initial energy	100	Joules
Power consumption during transmission	1.35	mW
Sleep power	0.001	mW
Idle power consumption	0.05	mW
Power consumption during reception	1.7	mW
Simulation duration	40	Second
Transport layer	UDP	—

Source: Authors, (2026).

VI. PERFORMANCE METRICS

Performance measurements are very essential to the quantitative estimation of routing protocols in VANET. The evaluation of the performance of the networks or even the comparison of the analysis of various routing protocols requires quantitative measurement so that the measurement can be made. In this current work, the performance criteria in the aforementioned evaluation are a lot, and they include as further discussed below:

1. Average Delay

The time taken to accurately transmit a data packet from source and to target over a network [30], [31]. The following equation is what is used to compute this measure:

$$Average\ Delay = \frac{\sum_{i=1}^n (R_i - S_i)}{n} \quad (5)$$

Here, R is the amount of packets received. S represents the total packets transmitted, and N is the total data packets.

2. Average Throughput

This is used to indicate the average number of data packets that have been successfully received during the simulation. It is a statistic that determines how effective the routing protocol is in enabling destinations to get data packets [24], [33]. Mean throughput will be calculated by use of the following formula:

$$Average\ Throughput = \frac{\sum Received\ Packets}{time\ duration\ from\ start\ to\ stop} * \frac{8}{1000} \quad (6)$$

3. Average Energy

Mean energy usage is estimated by the total number of energy used by each node divided by the energy used initially:

$$Average\ energy\ consumption = \frac{\sum energy\ consumed}{\sum initial\ energy} * 100 \quad (7)$$

4. Packet Delivery Ratio

This statistic is calculated by taking the total amount of data packets sent by the source nodes and dividing it by the total amount of data packets received by the destination nodes. It measures the effectiveness of a protocol to deliver the packets to its source to the intended recipient [34], [37]. The recipe to achieve the ratio of packets delivery is calculated as shown in the formula below:

$$PDR = \frac{\sum \text{packets received by destinations}}{\sum \text{packets sent by sources}} * 100 \quad (8)$$

VII. EXPERIMENTAL RESULTS

Figure 5(a) provides a comparison between the F-OLSR, BeeIP and OLSR protocols. The obtained results depend on the parameters, which are mentioned in Table 1 and different speeds of nodes. The outcome of the average throughput is contrasted at varying node speeds. The routing protocols have varying throughputs on average, with an increase in the speed of the nodes in the network. With increased speed of 5 m/s to 20 m/s, F-OLSR recorded a throughput of 58.61-49.16 kbps, BeeIP recorded throughput of 44.19-43.81 kbps and OLSR recorded a throughput of 46.29- 40.92 kbps. These results emphasize the high performance of F-OLSR with regard to the mean throughput compared to the other routing standards. This is attributed to the increased loss ratio of packets due to node speeds which are fluctuating; making both the OLSR and BeeIP to share this advantage. The channel capacity is also efficiently utilized when the packets reach their destinations promptly and without any losses hence raising the throughput.

VII.1 IMPACT OF NODE SPEED

The comparisons of the F-OLSR, BICSF, BeeIP and OLSR protocols on average energy are presented in figure 5(b). Mean energy is compared between various node speed. These routing protocols have emerged to have different patterns of energy uses when there is an increment in the speed of the nodes across the network. When the speed increased from 5 to 20 m/s, F-OLSR consistently showed consumption levels ranging from 0.023 to 0.024. It is worth noting that F-OLSR exhibited lower energy consumption compared to the BeeIP, BICSF, and OLSR protocols. This mismatch can be traced to using an FFA in the F-OLSR protocol. This protocol successfully chooses the most efficient and effective path between sources and destinations. Consequently, as the algorithm retains the route information in its memory, the previously required power consumption for route identification on each node is diminished.

The variations in the average E2E delay for the F-OLSR, BeeIP, BICSF, and OLSR protocols are shown in Figure 5(c). These routing protocols exhibit diverse average delays as node speeds increase. The speed escalated from 5 to 20 m/s, F-OLSR's delay rose from 7.92 to 21.80 ms, the BeeIP protocol increased from 37.10 to 37.98 ms, BICSF showed a rise from 15 to 15.5 ms, and OLSR saw an increase from 26.03 to 32.20 ms. These results confirm the average latency advantage of F-OLSR over alternative routing protocols. The benefit of the F-OLSR protocol is that it keeps track of the shortest way between sources and destinations, removing the need to spend time setting up the path at each intermediate node for each transmission.

Figure 5(d) shows the experimental findings for the F-OLSR, BeeIP, BICSF, and OLSR protocols regarding the PDR. The suggested protocol outperforms the BeeIP and OLSR protocols in terms of PDR. When node's speed is 5 m/s, the F-OLSR achieves 99.88%, whereas BeeIP reaches 99.74%, BICSF achieves 86.10%, and OLSR is 99.67%. This phenomenon is attributed to F-OLSR's retaining and acknowledging its established path. As a result, data transmission strictly follows the path determined by the protocol. As a result, effective packet delivery is the norm, and the packet delivery ratio maintains high consistency. Additionally, the protocol's minimal retransmission and drop rates contribute to the enhancement of high throughput. A comparison of the proposed protocol's node speed performance versus several cutting-edge protocols is shown in Table 2.

Table 2: Results of the proposed protocol in comparison to the state-of-the-art protocols' performances.

Node Speed (m/s)	BOLSR	OLSR	BeeIP	F-OLSR	BICSF
Average throughput (kbps)					
5		46.29	44.19	58.61	
10		43.96	44.18	55.46	
15		40.95	43.88	55.19	
20		40.92	43.81	49.16	
t.test		0.00086	0.00086	-	
Average energy consumption (%)					
5		2.37	2.35	2.31	2.34
10		2.40	2.39	2.34	2.38
15		2.43	2.42	2.38	2.40
20		2.47	2.44	2.41	2.42
t.test		0.060	0.099	-	0.218
Average end-to-end delay (ms)					
5	19	26.03	37.10	7.92	
10	18.5	32.19	37.11	10.90	
15	16.7	30.44	36.81	11.85	
20	15.5	32.20	37.98	13.8	
t.test	0.0025	2.81E-05	3.90E-07	-	
Packet delivery Ratio (%)					
5	86.1	99.67	99.74	99.88	
10	81.5	99.67	99.71	99.78	
15	77.8	99.63	99.70	99.79	
20	75.3	99.63	99.69	99.78	
t.test	7.98E-05	0.00055	0.0057	-	

Source: Authors, (2026).

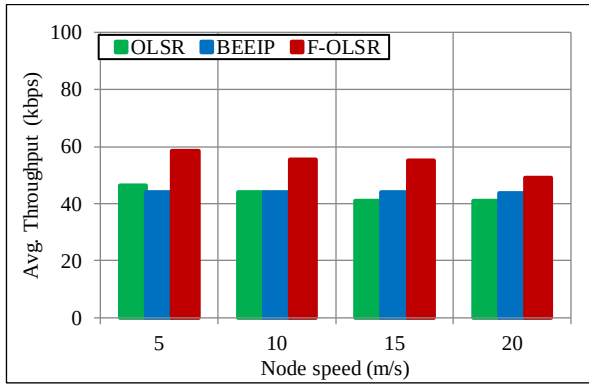


Figure 5(a): Average Throughput vs. Node Speed.
Source: Authors, (2026).

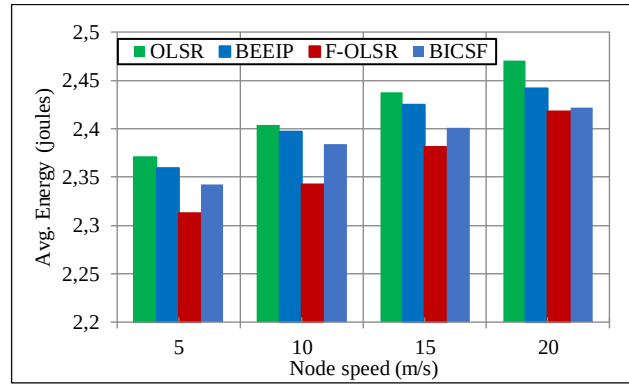


Figure 5(b): Average Energy vs. Node Speed.
Source: Authors, (2026).

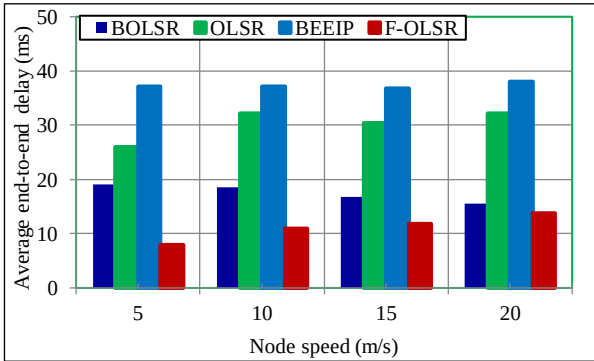


Figure 5(c): Average End-to-End Delay vs. Node Speed.
Source: Authors, (2026).

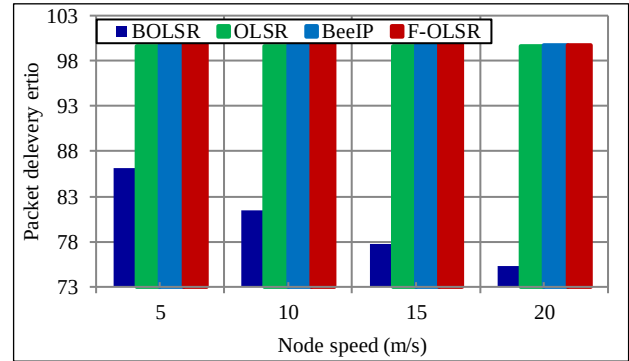


Figure 5(d): Packet Delivery Ratio vs. Node Speed.
Source: Authors, (2026).

VII.2 IMPACT OF PACKET SIZE

In this section, the performance of the proposed F-OLSR protocol is compared to the performances of BeeIP and OLSR protocols. Results of the experiment of average throughput were obtained at different packet sizes under given simulation parameters. As Figure 6(a) indicates, the average throughput also increases with the increase in the packet size between 128 and 1024 bytes. Compared to BeeIP and OLSR, F-OLSR has a better average throughput. Particularly, F-OLSR achieves average throughputs of 87.64 kbps and 150.34 kbps at the packet sizes of 128 bytes and 1024 bytes, respectively, in comparison with BeeIP with average throughputs of 26.08 kbps and 121.88 kbps, respectively, and OLSR with average throughputs of 40.51 kbps and 1 This is due to the reactive routing scheme that is used by F-OLSR. In case of a Route Request (RREQ), several Route Reply (RREP), messages are created/sent, which enables F-OLSR to keep the routes between the source and its destination current.

As a result, alternative paths may be taken in case of failure of the primary route causing the loss of packets and a huge enhancement in the average throughput. Figure 6 (b) shows how average energy consumption is varied among the protocols F-OLSR and BICSF, BeeIP and OLSR depending on the packet size. There is the proportional increase in average energy use with an increase in the size of the packet indicated in all protocols. The corresponding path quality measured by the F-OLSR was done by investigating four varying packet sizes. The minimum packet leninth sizes of 128 to 1024 bytes increased the energy consumption of F-OLSR by 0.30 per cent to 2.41 per cent, BICSF by 2.43 per cent to 3.01 per cent, BeeIP by 2.38 per cent to 2.68 per cent and OLSR by 2.41 per cent to 2.72 per cent. It is interesting to note that the available results clearly show that the proposed F-OLSR is better in terms of mean energy consumption compared to BICSF, BeeIP, and OLSR protocols.

This better test results are linked to the fact that as the protocol finds a route, then it repeatedly uses the same route to transmit all the packets. This is the shortest of the routes and involves the least number of hops. Therefore, intermediate nodes do not involve them in needless route search that would incur extra energy expenditure and battery drainage. In order to provide an overall picture, Table 3 shows a performance comparison of different protocols. The visual information in Figure 6(c) presents the mean of the individual time of the e2e delay in the circumstances of a packet size in case of F-OLSR, BeeIP, and OLSR protocols. These routing protocols exhibit some delay changes with e2e delays with increment in the size of the packet in the network. As the three protocols underwent packet size augmentation as 128 bytes to 1024 bytes, there were insignificant changes with the values ranging between 20.7 and 54.15 m/s, 31.94 and 70.85 m/s, and 33.66 and 77.72 m/s across F-OLSR, BeeIP, and OLSR respectively.

In addition, F-OLSR always has low end-to-end delays as opposed to the BeeIP and OLSR protocols. This is a positive attribute that is greatly credited to the fact that F-OLSR can control the majority of packets to follow a path that is most appropriate hence minimizing end-to-end delay. F-OLSR can keep real-time routing data and can quickly create alternative paths in case of a breakdown of the connection, e.g. in case of dynamic node repositioning through acceleration. Consequently, the mean e2e delay is reduced practically to minimal. Figure 6(d) shows the comparison of F-OLSR, BeeIP, and OLSR protocols in terms of the average PDR. The size of packets also affects the mean ratio of packet delivery as derived in the form of Eq. (5). In comparison to the BeeIP and the OLSR protocols, our protocol always yields a better average PDR.

An example is that, using 128 and 1024 bytes packet sizes, F-OLSR protocol achieves the average values of 99.69 and 99.70 in the delivery ratio of packets. This is because the higher the results of F-OLSR in terms of packet delivery ratio are relative to that of BeeIP and OLSR protocols as well. The usefulness of F-OLSR is due to the fact it deployed the FFA algorithm to constantly survey and modify its path as soon as the optimal and shortest path is noticed. As a result, the future data packets continue tracing the same path as the source to a destination without any extra overhead. This design reduces the occurrence of dropped packets, which results into higher ratio of packet delivery. Conversely, in OLSR and BeeIP, a source node will verify his or her route cache before trying to send a packet to a destination to make sure that there is an existing route there.

Table 3: The performances of the proposed protocol when compared with the performance of a few state of the art protocols in terms of the sizes of the packets used.

Packet Size (byte)	OLSR	BeeIP	F-OLSR	BICSF
Average throughput (kbps)				
128	40.51	26.08	87.64	
256	51.02	44.21	105.26	
512	84.02	93.65	132.18	
1024	105.95	121.88	150.34	
t.test	0.027	0.059	-	
Average energy consumption (%)				
128	2.41	2.38	2.30	2.43
256	2.41	2.43	2.33	2.41
512	2.51	2.43	2.36	2.62
1024	2.72	2.68	2.41	3.01
t.test	0.037	0.055	-	0.053
Average end-to-end delay (ms)				
128	33.66	31.94	20.7	
256	39.25	37.34	23.50	
512	55.88	49.78	34.17	
1024	77.72	70.85	54.15	
t.test	0.094	0.129	-	
Packet delivery Ratio (%)				
128	99.45	99.50	99.69	
256	99.49	99.51	99.70	
512	99.51	99.53	99.71	
1024	99.46	99.55	99.7	
t.test	1.003E-06	3.556E-06	-	

Source: Authors, (2026).

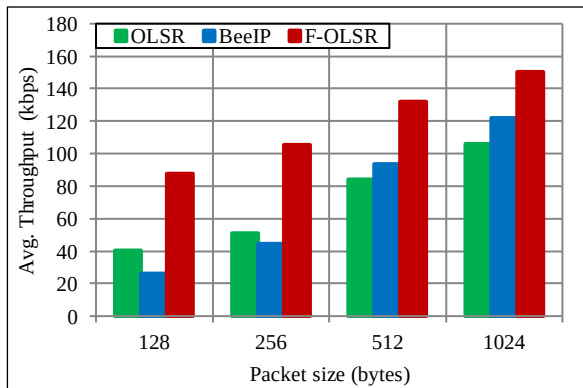


Figure 6(a): Average Throughput vs. Node Speed.

Source: Authors, (2026).

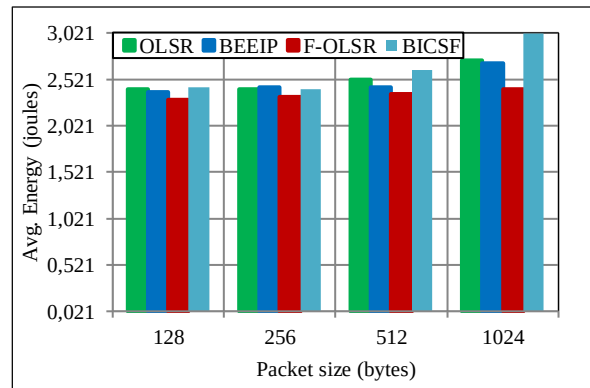


Figure 6(b): Average Energy vs. Node Speed.

Source: Authors, (2026).

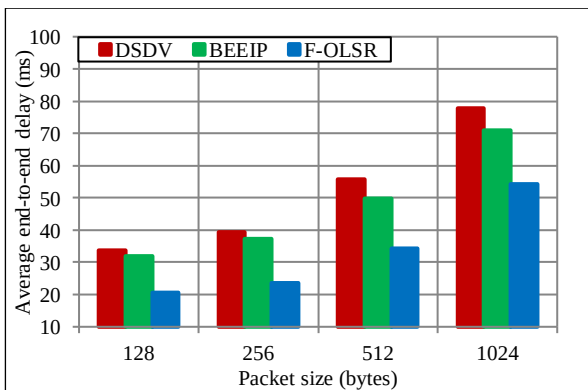


Figure 6(c): Average End-to-End Delay vs. Node Speed.

Source: Authors, (2026).

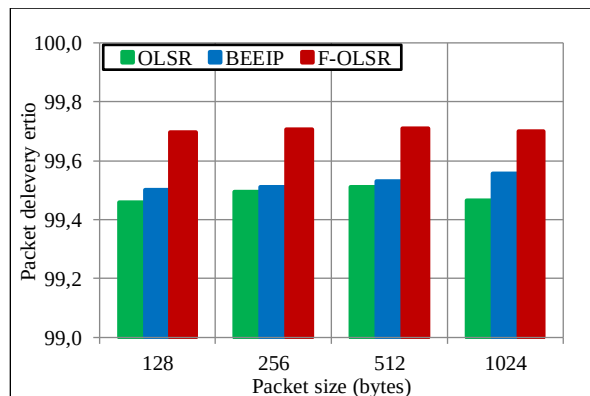


Figure 6(d): Packet Delivery Ratio vs. Node Speed.

Source: Authors, (2026).

VIII. CONCLUSIONS

The present research was dedicated to the optimization of the current OLSR routing protocol of VANETs. The offered F-OLSR is inspired by the behavior of a swarm of fireflies, constituting the attempt to address the problem of energy consumption under the impact of overloaded packets between the nodes of the sources and the destination. F-OLSR puts much emphasis on determining an optimal route. The performance of the protocol was measured using four different measures. The results of simulation assure the superiority of the proposed protocol to all the counterparts: BeeIP, BOLSR, and the standard OLSR protocols. This superiority is always exhibited in all parameters that have been studied such as speed of the node and the size of a packet.

The implicit strong point of the proposed F-OLSR protocol is that a solid path with nodes having the largest amount of energy is chosen. It was shown that the F-OLSR protocol is a good solution in selecting the best possible path with power that is high between source and destination and enhancing performance. On energy consumption, the F-OLSR protocol got 2.30 and 2.31 in relation to the packet size and speed of the node respectively that is superior to the other protocols. In further practice, as an attempt to solve security issues that are part of routing schemes, such as possible attacks such as black holes.

IX. AUTHOR'S CONTRIBUTION

Conceptualization: Mustafa Tareq, Saad Adnan Abed.

Methodology: Mustafa Tareq, Yasir Hadi Farhan.

Investigation: Mustafa Tareq, Saad Adnan Abed, Yasir Hadi Farhan.

Discussion of results: Mustafa Tareq, Yasir Hadi Farhan.

Writing – Original Draft: Mustafa Tareq.

Writing – Review and Editing: Boumedyen Shannaq, Said AlMaqbali.

Resources: Oualid Ali.

Supervision: Boumedyen Shannaq, Said AlMaqbali.

Approval of the final text: Mustafa Tareq, Yasir Hadi Farhan, Oualid Ali.

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