Bat Optimized Link State Routing Protocol for Energy-Aware Mobile Ad-Hoc Networks

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Abstract: Mobile ad hoc network (MANET) can be described as a group of wireless mobile nodes that form a temporary dynamic and independent infrastructure network or a central administration facility. High energy consumption is one of the main problems associated with the MANET technology. The wireless mobile nodes used in this process rely on batteries because the network does not have a steady power supply. Thus, the rapid battery drain reduces the lifespan of the network. In this paper, a new Bat Optimized Link State Routing (BOLSR) protocol is proposed to improve the energy usage of the Optimized Link State Routing (OLSR) protocol in the MANET. The symmetry between OLSR of MANET and Bat Algorithm (BA) is that both of them use the same mechanism for finding the path via sending and receiving specific signals. This symmetry resulted in the BOLSR protocol that determines the optimized path from a source node to a destination node according to the energy dynamics of the nodes. The BOLSR protocol is implemented in a MANET simulation by using MATLAB toolbox. Different scenarios are tested to compare the BOLSR protocol with the Cellular Automata African Buffalo Optimization (CAABO), Energy-Based OLSR (EBOLSR), and the standard OLSR. The performance metric consists of routing overhead ratios, energy consumption, and end-to-end delay which is applied to evaluate the performance of the routing protocols. The results of the tests reveal that the BOLSR protocol reduces the energy consumption and increases the lifespan of the network, compared with the CAABO, EBOLSR, and OLSR.

Keywords: mobile ad-hoc network (MANET); optimized link state routing (OLSR); bat algorithm (BA) and genetic algorithm (GA)

1. Introduction

In the world of computers, networking is defined as the electronic communication that occurs between one or more wireless or wired devices connected to each other for data sharing, resource

sharing, and file exchanging [1]. This electronic communication occurs over long distances through the use of routers, switches, and Internet servers. Hardware and computer software devices, such as cables, radio, and satellites, are combined by the network.

An ad hoc network refers to a single session connection that does not use wireless base stations or routers [2] and is mainly developed for transitory network connections. In this kind of network, all nodes participate in the routing activities without the use of any infrastructure. Instead of classic routing, a flooding technique is employed by the network for data transition [3]. An ad hoc network is mainly used for emergency situations involving natural disasters and military operations [4]. The mobile ad hoc network (MANET) is a multi-hop, dynamic topology mobile network that performs autonomous operations offering routing services throughout the nodes [5]. The nodes have limited computing capability and can transmit the data packets from the sources to the required destinations [6]. This kind of network is appropriate for different applications involving outdoor activities, emergency situations, specific military operations, natural calamities, and communications in places without wireless facilities [7].

The MANET functions under conditions that hinder the recharging of nodes. Therefore, the energy utilization of the nodes must be equilibrated to increase the lifespan of the network [8,9]. In typical ad hoc network routing protocols, the routes that are under a minimal hop count metric are selected, and the energy usage of the nodes is not considered [10,11]. Under such conditions, the energy needed for transmitting and forwarding data packets can be easily exhausted by the routing process [12,13]. As mentioned above, MANET is a collection of nodes that are connected without infrastructure. An overview of a MANET is presented in Figure 1.
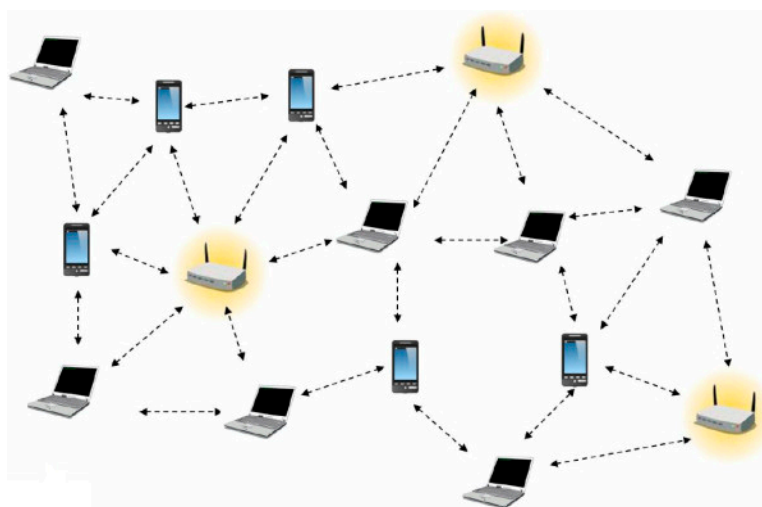

Figure 1. An example of a mobile ad-hoc network.

In MANETs, direct communication between the source and the destination nodes is required by routing protocols, such as the Optimized Link State Routing (OLSR) and the Ad-hoc On-Demand Distance Vector (AODV) routing protocol [14,15]. Thus, routing is crucial to determine the required optimal path for the transfer of data between the source and the destination nodes [16]. Various routing protocols classified as reactive, AODV [15], proactive, OLSR [17,18], hybrid, and zone routing board [19] are available in the MANET. One of the commonly used algorithms in solving routing problems is the bat algorithm proposed by Yang [20,21]. In addition to addressing routing problems, this algorithm can also solve numeric, engineering, and optimization problems [22–24]. This paper presents the integration of the Bat Algorithm (BA) with the OLSR protocol to improve the path selection mechanism by using different parameters.

The remaining of the paper is organized as follows: Section 2 explains the literature review. Section 3 presents the related methods and materials of this work which include the OLSR, BA, and

the quality of services parameters. Section 4 describes the main contribution of this work that is represented by the Bat Optimized Link State Routing (BOLSR) protocol. Sections 5 and 6 explain the simulation model and parameters, the evaluation metrics, and experimental results and discussion respectively. Finally, Section 7 concludes the work and suggested future work.

2. Literature Review

Mobile devices consume energy and rely on networks without infrastructures, such as the MANET, or networks with infrastructure. Different protocol problems are associated with MANETs, specifically, the procedure of discovering optimal paths between the source and the destination nodes, which involves high Energy Consumption (EC) from broad node communications [25]. When the source node sends data to the destination node, the appropriate path to their destination must first be identified by broadcasting routing requests. This activity consumes more power than data transmission, and the risk of connection failure is increased by the flexible processes of mobility-enhanced nodes. When the connection fails, routing requests must be re-initiated by the source nodes; this phenomenon increases the EC related to node operations [26]. The different routing protocols available in MANETs are classified as reactive, proactive, and hybrid [18]. The AODV is a typical example of a reactive protocol. In this protocol, routes are formed only when the source needs to transmit data to a destination [15]. An example of a proactive protocol is table-driven protocol, in which the updated information is maintained between the routes from every node to all other nodes present in the network [16]. Finally, the hybrid routing protocol attempts to integrate elements of the proactive and reactive routing protocols [18]. The central idea of hybrid routing is that proactive connections are available in areas with low mobility, whereas reactive connections are available in areas with high mobility [19]. Network routing problems have been recently solved through the implementation of different intelligent algorithms, such as African Buffalo Optimization (ABO) [6], ant colony optimization (ACO) [27], Genetic Algorithm (GA) [7,28], Artificial Bee Colony (ABC) [29], and Practical Swarm Optimization (PSO) algorithm [30].

Hassan et al. [6] introduce a new routing scheme cellular automata African Buffalo Optimization (CAABO) based on Cellular Automata (CA) and African Buffalo Optimization (ABO) algorithms. The CAABO attempts to discover the paths that fulfil the delay requirements and limitations as well as improving the energy usage of the network. Brindha et al. [31] propose a new energy-efficient routing protocol by using different Quality of Service (QoS) parameters such as hops count, End-To-End (E2E) delay, and bandwidth. These parameters are managed via the GA algorithm to get an optimal solution. The new protocol is called Energy-Based OLSR (EBOLSR). Narayanan et al. proposed a new energy-aware method called the ACO–EEOLSR that contains the ACO-enhanced approach to obtain an energy-efficient OLSR for the MANET technology [32]. Alternatively, a clustering algorithm to be used in the OLSR protocol for a new energy-aware method is proposed by [33]. This new method is aimed to decrease the E2E delay while increasing the lifespan of the network. A study by Sundaram et al. [34] proposed an invasive weed PSO, a hybrid algorithm that is combined with the OLSR protocol to reduce the E2E delay while improving the throughput of the network. A new hybrid algorithm called PSO sigmoid increasing inertia weight is proposed for the selection of Multipoint Relay (MPR) to improve the performance of OLSR [35]. In addition, a new OLSR protocol mechanism that uses the willing concept to improve EC and increase the lifespan of the network is also suggested [36].

3. Research Methods and Materials

This paper proposes an energy-aware routing protocol for the MANET. The major elements of the research are OLSR, bat algorithm, and tested network evaluation metrics.

3.1. Optimized Link State Routing (OLSR)

The OLSR is proposed by Clausen et al. [37] as a proactive routing protocol for ad hoc networks and is built based on the link-state (LS) protocol with reduced signaling packets and control traffic

flooding [37]. Accordingly, the OLSR protocol broadcasts messages transmitted in the network by using MPRs, nodes that are specifically designed to broadcast only such messages [31,38]. The mechanisms of the OLSR protocol and MPR selection are shown in Figures 2 and 3, respectively.
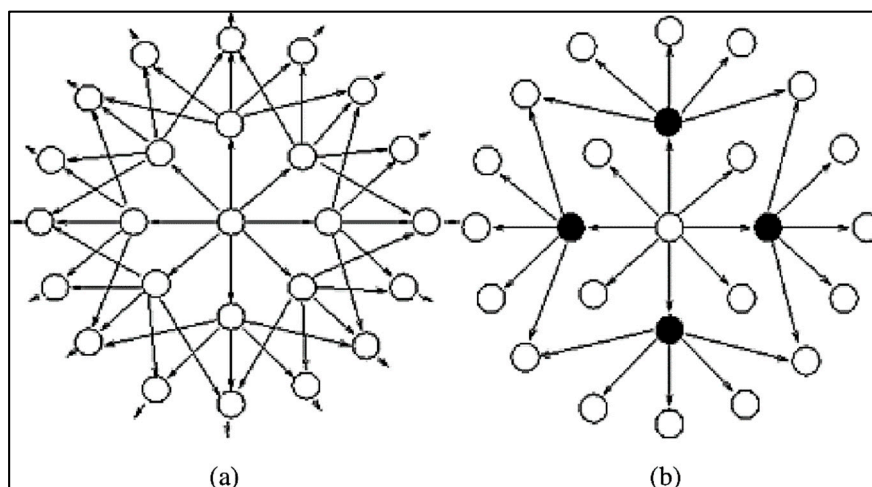

Figure 2. Flooding mechanism with/without Multipoint Relay (MPR) [39]. (**a**) Flooding a packet in a wireless multi-hop network; (**b**) flooding a packet in a wireless multi-hop network from using MPRs (marker in black).
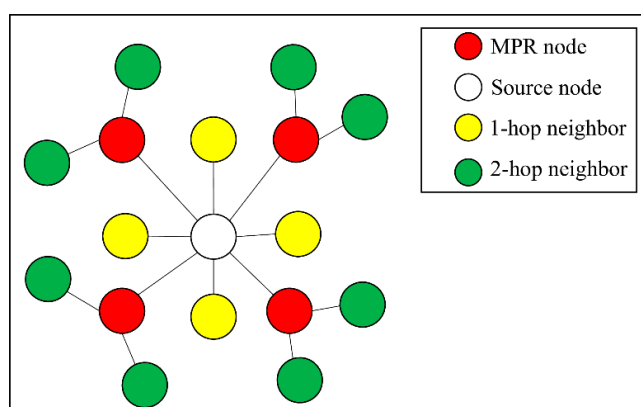

Figure 3. The mechanism of the Optimized Link State Routing (OLSR) routing process.

The OLSR protocol functions in a fully distributed manner and does not rely on any kind of central entity. When transmitting control messages, this protocol does not require reliable transmission because the messages are occasionally transmitted and are exemplified by the sequence number which rearranges them. The OLSR is also known to support node mobility. As mentioned earlier, MPRs aim to reduce the duplicity in the retransmission within the same area [39]. Every node existing within the network selects a certain group of nodes in their neighborhood and marks them as the MPRs, thereby retransmitting the broadcast packets [40]. Therefore, the neighbors of the nodes, which do not exist in the MPR set, can read and process the data packets obtained from the specified node but cannot retransmit them [41].

The MPR set is selected by one-hop neighbors that are characterized by bidirectional links [37]. For this process, the neighboring nodes with direct links must be identified by every node. All the links must be examined in both directions to validate these nodes. In this regard, a period broadcast of the hello message, which contains data about the neighbors and their link statuses, must be created in every node. Through these messages, every node can obtain information about their neighbors until two hops and to subsequently select the MPR set. A node starts constructing the MPR selector table, a 1-hop neighbor table, and the 2-hop neighbor table as soon as it obtains a hello message [37–39].

A different hello message will not further be transmitted to the entire network. This phenomenon indicates that various nodes that receive the messages do not transmit them [40]. A periodic broadcast of specified control messages known as Topology Control (TC) is performed by every node to build and maintain the data for a network topology that is needed for data packet routing. The TCs are forwarded by general broadcast data packets within the entire network [39]. Data obtained by the TC packets are then stored in an appropriate topology table. Every node maintains its routing table that helps the former to route the data packets to other destinations in a network. The TC messages received by the nodes are analyzed, and parts of these connected pairs are stored in a form (last hop and node), in which the node denotes the addresses that are detected in a TC message list [36]. The routing table is created from this database by following the linked pairs in descending order.

A group of connected pairs must be detected until the last hop node present in the source neighbor set is reached to discover an optimal route from the source to the destination [40]. The connected pairs, which are present on a minimal power usage route, are selected by the different forwarding nodes. If the bidirectional link is changed in the topology table or in the neighborhood, then the routing table must be recalculated [41].

3.2. The Bat Algorithm

In 2010, a meta-heuristic search algorithm known as the Bat Algorithm (BA) was proposed by Yang et al. [20]. This bat-inspired algorithm relies on the echolocation behavior of the bats to determine the location of prey and to differentiate the insects existing in extreme darkness with varying degrees of emission pulse rates and loudness [21].

This research involves the emission of bat calls to the outer environment, followed by an analysis of the resulting echo sounds that bounce back. The objects' locations are detected, and the distance between the various targets is calculated through an assessment of the sound delay. The emitting sounds are loud pulses with different properties depending on the hunting tactics and species. These echolocation sound pulses are then characterized according to three different characteristics, namely, pulse frequencies, pulse emission rate, and loudness/intensity. The echolocation of the bats and the associated parameters are then examined through numerical optimizing algorithms [22]. The resultant bat algorithm is tested empirically, and the use of single or multi-objective standardized functions is employed to further compare this algorithm with other algorithms [23]. Algorithm 1 shows the basic BA according to [20]:

Algorithm 1: The basic BA

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1. begin
2. while ($t <$ Max number of iterations)
3. Generate new solutions by adjusting frequency;
4. update velocities and locations [(1) to (3)];
5. if (rand $> r_i$)
6. Select a location among the best locations
7. Generate a local location from the selected locations;
8. end-if
9. Generate a new location by flying randomly;
10. if (rand $< l_i$ & $f(x_i) < f(x)$)
11. Accept the new locations;
12. Increase r_i and reduce a_i;
13. end-if
14. Rank the bats and find the current best x;

Bats use echolocation to determine the distance and the differences between prey, food, and other obstacles. Assume that a random velocity of v_i is used by the bats to fly to a fixed position x_i with the

frequency of f_{min} with different wavelengths and loudness of l_0 in search of prey. The wavelengths or frequencies of the emitted pulses can be automatically adjusted, and the bats can calibrate their pulse emission rate r in the range (0, 1) depending on how close they are to their target. Regardless of the variance in their loudness, the loud volume varied between a huge positive value, l_0 and a minimal constant value of l_{min}. Figure 4 shows the mathematical bat algorithm.
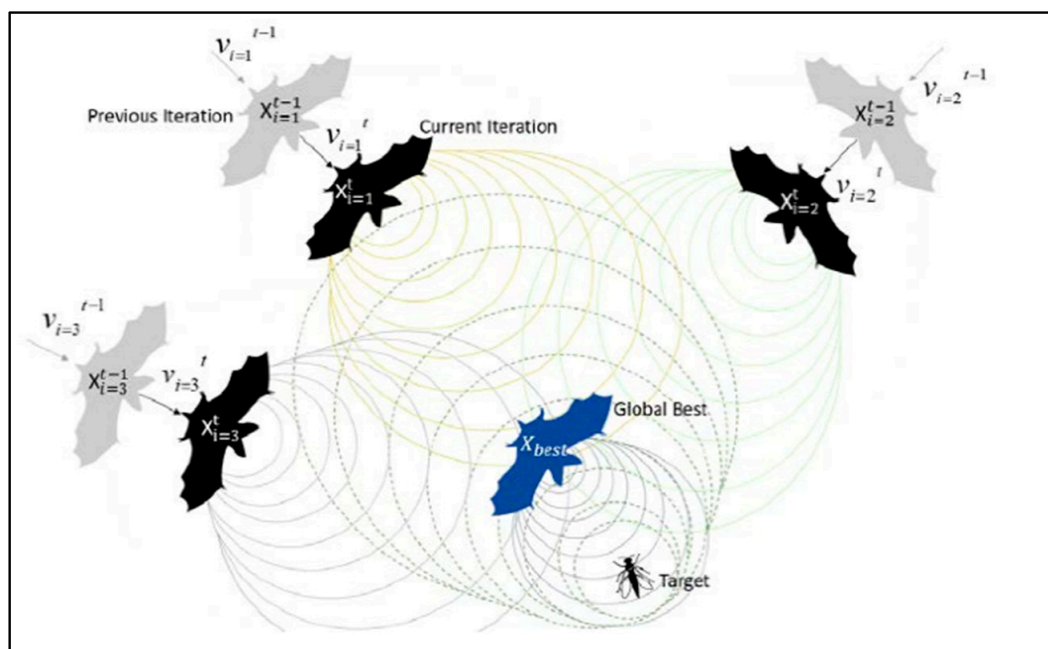

Figure 4. An overview of the bat algorithm.

In the initial stage, the bat population and their position, i.e., x_i, velocity v_i and frequency f_{min}, respectively, must be identified. The mobility of all these virtual bats can be discerned after updating their positions and velocities for the time step t, using Equations (1)–(3) in the following manner:

$$f_i = f_{min} + (f_{max} + f_{min})\beta, \tag{1}$$

where;

$$v_i^t = v_i^{t-1} + \left(x_i^{t-1} + \varkappa\right)f_i, \tag{2}$$

where;

$$x_i^t = x_i^{t-1} + v_i^t, \tag{3}$$

where $\beta \in (0, 1)$ represents the vector arbitrarily derived according to the uniform distribution. The variable $\varkappa$ denotes the current global best position (solution) that is located after the solutions obtained from m bats are compared. An arbitrary number is employed after the solutions from the current best bat solutions are selected. Nonetheless, the pulse emission rate r_i, is less than the number, and a different solution is accepted based on the present best solutions and is explained as follows:

$$x_{new} = x_{old} + el^t, \tag{4}$$

where $\varepsilon \in (-1, 1)$ represents a random number, and $l^t = <l_i^t>$ refers to the average loud volume of the bats present in the generation. Moreover, the loud volume l_i along with the pulse emission rate r_i would be updated. If the random number is less than the loud volume, l_i and f $(x_i)<$ f $(\varkappa)$, then a solution will be selected. The values of l_i and r_i are updated as follows:

$$l_i^{t+1} = al_i^t, \tag{5}$$

$$r_i^{t+1} = r_i^0[1 - exp(\gamma_t)], \tag{6}$$

where in Equations (5) and (6), α and γ have constant values. The bat algorithm can be repeated until a maximum cycle number is reached.

3.3. Quality of Services Parameters

General network quality is described or measured by the QoS and presents the amount of data sent from a source node and received by a destination node within a given period of time. Different parameters, such as throughput, packet delivery ratio, E2E delay, packet loss, jitter, and energy are used to quantitatively measure QoS and evaluate the network quality. The behavior of the MANET routing protocol is influenced by all these parameters [6]. Energy consumption, routing overhead, and delay are used in this study because of their comprehensive assessment to the performance of the MANET.

- Routing overhead parameter: this value is the total number of routing packets divided by the total number of delivered data packets. The additional bandwidth, which has been consumed by the overhead for delivering data network, can be measured using this parameter. The robustness of the network is influenced by the routing overhead in terms of the battery power consumption of the nodes and the utilization of the bandwidth [6].
- EC parameter: route discovery is implemented to calculate every probable path from the source to the destination node. The optimum path is then selected by the protocol based on its criteria, such as the minimum number of hops and the shortest path. The selected path is used until it gets destroyed. Thus, the node energy in this route decreases. In a situation when a node loses its energy, the messages cannot be sent and consequently leads to the exclusion of the node from the network. This occurrence negatively affects the lifespan of the ad hoc network. Part of the initial energy is taken as an energy constraint [9].
- Delay parameter: it is considered as one of the most important parameters in the telecommunication system. Delay refers to the total time that is spent to send the packets from source to destination nodes via the network. Different aspects of the network are responsible for increasing/decreasing the delay: (1) processing, (2) queuing, (3) transmission, and (4) propagation.

4. BOLSR Protocol

The OSLR is described as a mechanism used in the discovery of the LS and for the dissemination of information in the entire ad hoc network. The disseminated information can be utilized by individual nodes to detect neighbor nodes and compute the next hop logic. Despite the advantages of the OSLR, it has limitations associated with the route remaining fixed onto a set of nodes. The fitness or quality of the nodes that are selected for the route cannot be determined using this protocol. This phenomenon results in the excess drain of resources, such as bandwidth and charge, along with the route. The rest of the nodes are left untouched.

The BA, which is based on the echolocation or bio-sonar characteristics of micro-bats [20], is an optimization algorithm that can obtain variables required for the improvement of route node selection. The following section provides details of the integration between the bat algorithm and the OLSR protocol. This integration aims to improve the performance of the OLSR.

4.1. Criteria Function

A Criteria Function (*CF*) is used to improve the effectiveness of the OSLR protocol through the provision of the node quality logic to the algorithm. With this function, a summation of a set of characteristics for each possible route is effectively provided. Weights are given to the functions in terms of the priority and the sustainability of the route. This sum is considered as a measurement of

fitness for a given route and is used to measure the appropriateness of using a node for a specific route. Below is the *CF* used in the analysis:

$$CF(x) = \begin{cases} 0, & \text{one hop to the destination} \\ r, & \text{otherwise} \end{cases},$$

where $r = w(1)$ chargeMean + $w(2)$ chargeVar/$w(3)$ chargeMean + $w(4)$/chargeVar and w denotes the weight ratio and it has the range of $1, 2, \ldots, n$.

The *CF* aims to explain the proportional and inversely proportional correlation between the variables and the nodes' fitness factors. If the correlation between the route length variable and the fitness factor is inversely proportional, then the weight $w1$ is set to zero but not $w4$. This function can also be implemented in a system of nodes to optimize the energy variance and overhead values.

4.2. General Optimization Scheme

A feedback mechanism, in which the route given by the fitness variable is processed by the OLSR protocol, is employed to optimize the values of the weighting ratios. The Objective Function (*OF*) computes the objective value, ∂, from the overhead, energy variance, and Packet Delivery Ratio (PDR) values using the following formula:

$$\partial = \frac{Overhead * EnergyVariance}{PDR}. \tag{7}$$

The actual effectiveness of the selected route is provided by the objective function. This value can be employed in the optimization scheme by comparing it with the values for routes that are selected before the current selection. This process would provide insights into the suitability of the weight values. The most appropriate values of weight ratios are provided by continuous feedback as described earlier. Figure 5 shows the overall optimization scheme for the BOLSR protocol.
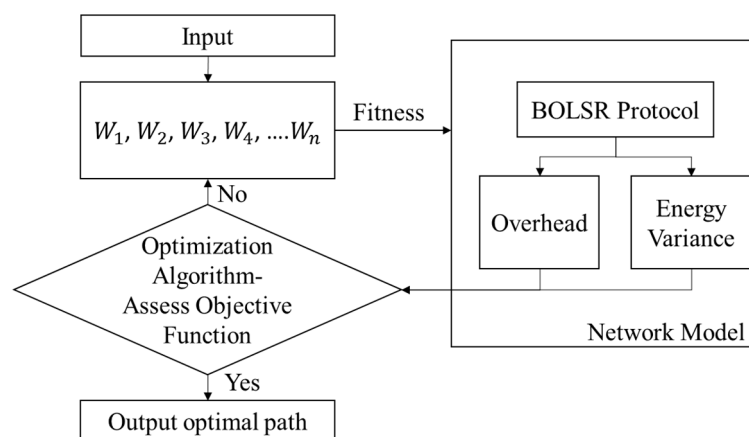

Figure 5. The optimization scheme of the protocol.

The weight values are presented in Table 1. These values are used to further optimize the weight ratio selection and consequently the objective function. Optimization mainly aims to reduce the values of the overhead and energy variance.

Table 1. The bat algorithm parameters.

Parameter	Value	Description
n	20	Number of solutions for each generation
d	6	The dimension of the bat algorithm
hB	10	Upper boundary
LB	−10	Lower boundary
fmin	0	Lower frequency
fmax	10	Higher frequency
Alpha	0.9	Constants
Gama	0.04	Constants

4.3. Bat Algorithm Design

The BA uses the echolocation of bats to produce a metaheuristic algorithm used in optimization schemes. The effectiveness of the weight ratios $w_1, w_2, \ldots, w_n$ can be effectively identified through the optimization algorithm in terms of alteration in the values of the objective function. As previously described, OSLR uses the nodes that are selected based on the fitness variable. Energy variance, the E2E delay, the PDR, and the overhead values are then measured. The OF is calculated and then used in the BA to optimize the weight values that are utilized in calculating the fitness variable. A new set of nodes defined by the new fitness value is then processed continuously until the desired degree of optimization for the OF is achieved. The three major equations used in the BA are Equations (1)–(3). The parameters utilized in the optimization are presented in Table 1.

The bat, which is a vector of four elements, represents each solution. The weighting factors of the terms that are used in the *CF* represent the element of this vector in which the Bat, w, and weight ratio are equals and have the range of (1–4) values. The ∂ that is given by Equation (7), provides an estimated value for the overall performance of a selected route. The equation assumes that minimizing the value of the *OF* will lead to a balanced node loading which will reflect positively on the node charge variance, overhead, and E2E delay across the entire system of nodes. This ∂ thus provides an easy optimization metric, as simply minimizing this quantity would optimize the performance of the whole system. The value of this ∂ is a key variable used in the proposed BOLSR.

5. Simulation and Result

This section presents the experimental work for evaluating BOLSR and comparing its performance with those of three approaches, the state-of-the-art approach CAABO, EBOLSR, and OLSR. The simulation was implemented using the MATLAB toolbox. Figure 6 shows the implementation of the routing protocols in the MATLAB simulation.

There are different reasons that motivated us to use MATLAB instead of other tools such as NS2 or NS3. The state-of-the-art related work such as the work of [42] used MATLAB in MANET research. MATLAB is defined as a computer programming tool that offers to the user a suitable environment for implementing numerous types of calculations in simple, swift, and efficient ways [43]. It is employed to implement differential mathematical equations and algorithms such as the bat algorithm. Unlike other tools, MATLAB facilitates the process of implementing algorithms that require iterations and specific functions in order to investigate optimal solutions. Moreover, it includes libraries that provide a symbolic solution, data analysis, and graphic plots of the results. The simulation model and parameters are presented in Section 5.1. Next, the evaluation metrics are provided in Section 5.2. After that, experimental results and discussion are presented in Section 5.3.
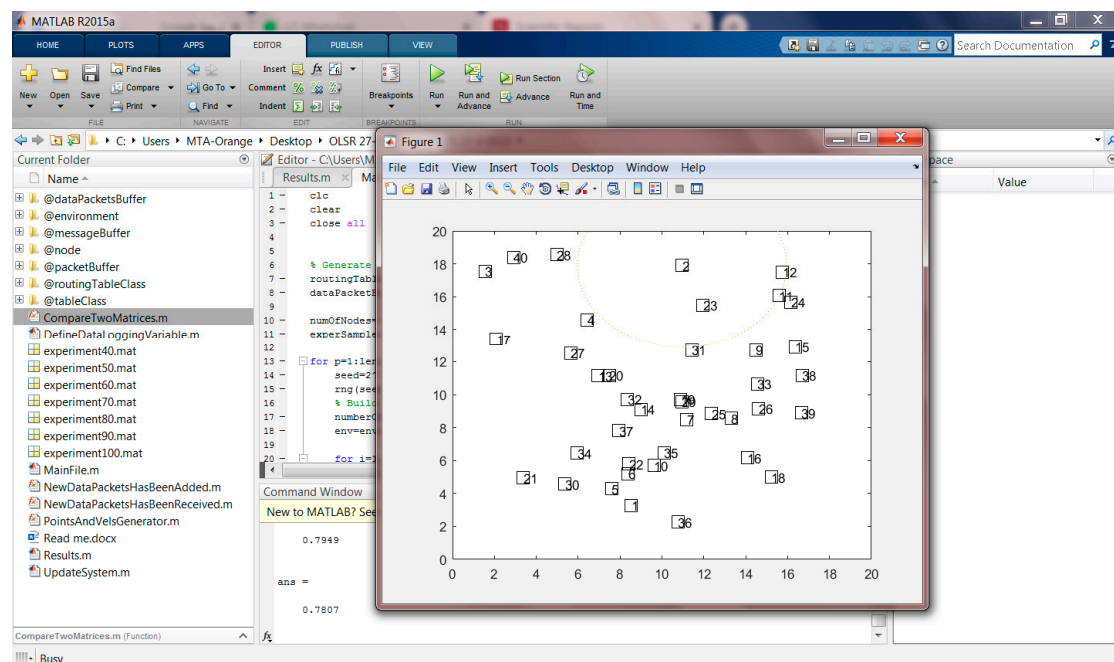
Figure 6. Snapshot of the simulation.

5.1. Simulation Model and Parameters

The simulation of the proposed BOLSR protocol is discussed in this section. The aim of the experimental tests of the simulation is to improve the MANET performance and prolong its lifespan [42]. The objective is to use the BOLSR to find the path with the highest levels of energy and a minimum delay. Afterwards, three routing protocols along with the BOLSR are tested and their results are compared. Figure 7 represents the main steps that were used to implement the simulation of the BOLSR and other protocols. The simulation model consists of four main modules. Firstly, the MANET environment Module A was employed to create simulation environments. This module was achieved by integrating the main characteristics of MANET, such as network size, a number of nodes, bandwidth and so on. The next step was implementing the routing protocols as Module B in which several optimization algorithms were used to address the progress of the solution. Three different scenarios (node speed, number of nodes, and simulation time) with various parameters were implemented in Module C to assess the performance quality of the protocols. The scenarios were altered in each set of runs of a particular protocol. In Module D, the performance metrics of PDR, E2E, Routing overhead ratio (ROR), and EC were implemented to evaluate the protocols. Finally, a results visualization graphical user interface module is included to view the results and related analysis.
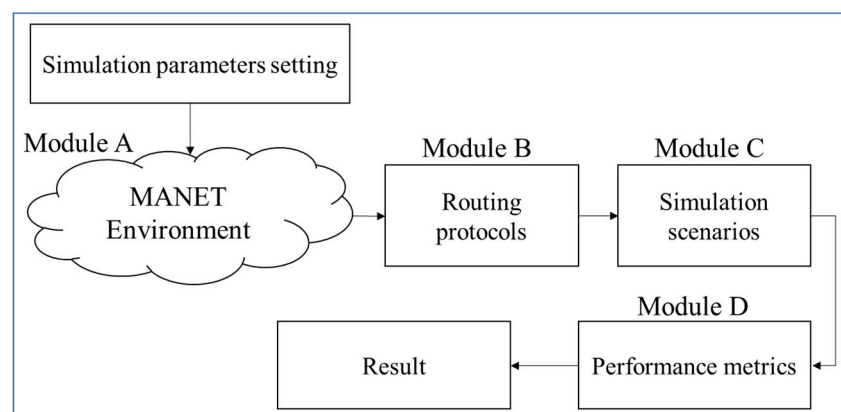

Figure 7. The mobile ad hoc network (MANET) simulation model.

The setting of the simulation's parameters was adopted from [4,6–9,25,44]. Table 2 describes all the parameters used for the setting of the simulation.

Table 2. The simulation parameters.

Parameter	Value	Unit
No. of run	5	-
Queue size	50	Packet
Mobility Model	Random Way Point	-
Packet Size	512	Byte
Transmission Range	250	Meter
Protocol	OLSR, BOLSR, EBOLSR, CAABO	-
Area	1250	m^2
Nodes	(40–100)	nodes
Simulation time	(10–70)	ms
Node speed	(1–11)	m/s
Traffic type	CBR/UDP	-
Packet size	512	byte
Transmit power	1.4	Joule
Reception power	1.0	Joule
Idle power	0.05	Joule

5.2. The Evaluation Metrics

Varying metrics are used to evaluate network performance in general [43–46]. The major challenges for MANET routing include the overhead, E2E delay, energy efficiency, and PDR [9,23,46]. Different solutions have been provided for various routing problems, such as security, EC, bandwidth, and QoS [5–7]. The metrics discussed in the following subsections were used to measure the performance of the BOLSR.

5.2.1. Routing Overhead Ratio (ROR)

ROR is the total routing packet (RP) divided by the total number of RP and delivered data packets (DDP), where the RP indicates the packet that is spent to discover all the nodes in the network. On the other hand, the DDP refers to the actual data that is transmitted from source to destination nodes. The ROR is calculated as follows:

$$ROR = \left(\sum \frac{RP}{RP + DDP}\right) * 100. \tag{8}$$

5.2.2. Energy Consumption

EC is the energy used by the nodes within the network during specific simulation time. EC can be calculated using the energy level of each node after simulation, and the basic energy level of each node considered during the calculation. EC is calculated as follows:

$$EC = \sum_{i=1}^{n} ini(i) - ene(i). \tag{9}$$

In Equation (9), the node number is referred to as *n*, and the counter is represented by *i*, *ini* denotes the initial energy level for each node while *ene* denotes the node energy levels after the simulation.

5.2.3. E2E Delay

E2E delay refers to the accumulative time that is spent to send all data packets across the network. The average E2E delay is calculated as follows:

$$E2E \; delay = \frac{\sum_{i=1}^{n} (Ri - Si)}{n},$$

(10)

where *n* refers to the successful packets that are received by destination nodes, *i* refers to the unique packet identifier, *Ri* refers to the receiving time of the packet with the indexing number *i*, and *Ri* denotes the sending time of the packet with the indexing number *i*.

5.3. Experimental Results and Discussion

This section provides a brief discussion of the results of the proposed BOLSR protocol compared with three other protocols. The performance metric that was used to assess the performance of the proposed protocol includes the parameters of PDR, E2E delay, EC, and ROR. The three key network scenarios of the tests were related to the parameters of a number of nodes, node speed, and simulation time. These parameters were altered to observe their effects on the PDR, E2E delay, EC, and ROR of the BOLSR, CAABO, EBOLSR, and OLSR protocols. It is worth mentioning, that the figures below depict the effects of EC, ROR, and E2E delay parameters in different scenarios as the BOLSR protocol is focused on reducing energy consumption, overhead, and delay.

The results obtained from implementing the three scenarios are presented in Tables 3–5. Each scenario was implemented five times to obtain the required results. The mean was used to evaluate the performance of the network routing protocols and the Standard Deviation (SD) was used to evaluate the variation in the behavior of the routing protocols within the five runs.

The results obtained during the implementation of the first scenario are shown in Figure 8. Figure 8a shows the average effect of the number of nodes in the ROR of the BOLSR, CAABO, EBOLSR, and OLSR protocols. Figure 8b shows the ROR SD of the routing protocols. The results show that the overhead ratio of the four routing protocols is increased with the increase of the number of nodes (40–100). In MANET, the nodes of the network are dynamically collecting information about each other. Furthermore, during the nodes' movement, there might be link failures between these nodes which results in recalculating the routing tables. These issues lead to an increase in the overhead ratio and the energy consumption of the network. The results further show that the BOLSR maintains the lowest overhead ratio among the rest which implies finding the optimal path in terms of overhead ratio and energy consumption.

Table 3. Scenario 1: The number of nodes.

Model			Number of Nodes						
Criterion	**Protocol**		**40**	**50**	**60**	**70**	**80**	**90**	**100**
PDR	OLSR	Mean	55.3	57	60	62.8	65.1	69.3	71.2
		SD	4.24	2.24	5.18	2.50	4.78	1.74	3.11
	EBOLSR	Mean	63.2	66.4	69.5	70.1	72.7	74.4	80.3
		SD	4.69	3.00	3.21	2.76	4.53	3.97	4.07
	CAABO	Mean	68.51	71.03	74.61	74.88	79.29	84.05	84.90
		SD	3.84	2.94	4.44	3.08	2.24	4.22	4.97
	BOLSR	Mean	73.33	74.6	77.5	79.1	84.6	87.9	90.4
		SD	2.85	2.36	3.85	3.00	3.73	2.95	4.01
E2E	OLSR	Mean	29.5	29.2	28.6	28.1	26.5	25.7	22.3
		SD	5.49	7.71	2.38	8.00	3.27	6.92	4.41
	EBOLSR	Mean	27.2	26.8	24.7	23.1	22.4	21.9	20.2
		SD	3.13	8.04	3.45	4.87	3.29	8.53	4.57
	CAABO	Mean	25.92	23.93	22.07	21	19.99	18.24	16.93
		SD	4.62	6.08	4.33	6.55	3.92	7.53	6.55
	BOLSR	Mean	23.7	22.5	20.1	19	18.5	16.7	15.5
		SD	4.20	5.43	2.46	5.71	3.13	7.19	4.57
ROR	OLSR	Mean	20.45	21.59	24.5	26.36	28.47	29.65	31.52
		SD	7.99	5.63	9.35	6.46	5.10	6.73	3.63
	EBOLSR	Mean	16.35	16.96	20.14	20.23	21.02	22.44	25.18
		SD	5.64	7.77	4.91	7.98	3.71	7.49	5.53
	CAABO	Mean	13.65	14.96	16.09	18.33	19.23	19.11	22.11
		SD	6.73	4.71	8.08	5.60	7.62	3.90	6.72
	BOLSR	Mean	12.16	13.43	14.82	15.01	16.19	16.88	17.54
		SD	4.20	6.24	3.92	6.88	3.68	6.28	4.73
EC	OLSR	Mean	49.76	67.23	75.84	87.74	95.81	100.34	115.21
		SD	9.50	25.98	10.51	15.12	9.20	14.29	22.41
	EBOLSR	Mean	45.07	50.49	55.15	67.06	75.7	86.53	100.52
		SD	11.15	22.71	7.96	19.39	22.67	16.26	21.77
	CAABO	Mean	43.15	46.52	49.09	61.81	66.01	77.48	96.94
		SD	10.34	20.41	13.38	9.96	15.14	18.97	17.46
	BOLSR	Mean	38.56	39.99	44.59	51.38	60.43	69.93	95.84
		SD	12.81	19.89	11.19	18.04	10.11	20.07	11.01

Table 4. Scenario 2: The speed of nodes.

	Model				Node Speed			
Criterion	**Protocol**		**1**	**3**	**5**	**7**	**9**	**11**
PDR	OLSR	Mean	96.79	90.46	82.7	72.41	67.35	65.4
		SD	6.28	15.48	3.03	11.90	5.04	10.00
	EBOLSR	Mean	97.7	93.02	83.44	79.25	74.7	71.1
		SD	4.21	9.04	6.77	13.37	11.55	12.05
	CAABO	Mean	98.16	95.31	84.89	79.98	75.23	73.35
		SD	5.33	7.07	1.76	11.10	1.54	9.75
	BOLSR	Mean	98.55	96.3	86.1	81.5	77.8	75.3
		SD	7.49	11.34	8.34	11.53	6.91	12.22
E2E	OLSR	Mean	16.32	24.67	28.21	33.41	39.21	47.11
		SD	7.97	2.71	11.01	0.90	3.23	4.14
	EBOLSR	Mean	14.63	22.41	27.41	31.92	37.31	45.25
		SD	3.45	7.81	3.27	1.27	8.27	5.27
	CAABO	Mean	13.54	21.92	25.5	29.67	36.88	42.53
		SD	5.05	5.60	1.54	8.07	2.49	6.33
	BOLSR	Mean	12.81	20.21	23.04	28.42	34.67	38.21
		SD	4.25	1.54	6.69	3.64	7.64	3.64
ROR	OLSR	Mean	21.79	38.46	58.18	67.29	69.92	72.32
		SD	9.57	3.02	6.34	2.13	11.88	5.67
	EBOLSR	Mean	19.2	32.2	44.61	54.76	63.64	67.49
		SD	1.76	9.67	3.90	10.15	7.58	8.61
	CAABO	Mean	18.45	30.73	41.41	51.32	59.92	64.02
		SD	4.90	8.83	3.39	11.63	5.42	12.76
	BOLSR	Mean	18.12	29.85	39.44	48.6	55.6	59.4
		SD	2.32	5.79	2.83	6.82	4.01	7.63
EC	OLSR	Mean	72	83	94	123	157	168
		SD	9.82	6.84	5.34	9.41	4.64	4.06
	EBOLSR	Mean	65	74	89	111	135	145
		SD	8.28	3.55	8.60	6.51	9.55	4.30
	CAABO	Mean	62	71	85	104	129	137
		SD	6.60	5.10	8.06	2.93	8.66	4.53
	BOLSR	Mean	61	69	82	98	119	129
		SD	5.95	4.33	7.02	4.52	7.18	6.67

Table 5. Scenario 3: The simulation time.

Model			Simulation Time						
Criterion	Protocol		10	20	30	40	50	60	70
PDR	OLSR	Mean	70.23	72.89	74.05	77.37	80.22	82.53	85.39
		SD	3.61	6.85	2.84	5.02	4.06	6.02	3.44
	EBOLSR	Mean	73.8	75.1	77.31	80.19	83.3	84.13	88.31
		SD	4.85	6.55	3.83	5.28	2.49	5.79	6.56
	CAABO	Mean	76.61	78.91	79.73	83.51	87.87	89.99	91.01
		SD	2.55	6.93	5.26	7.05	5.97	6.69	5.59
	BOLSR	Mean	78.36	80.63	83.71	86.3	90.91	93.2	95.25
		SD	3.05	5.56	3.77	5.95	4.39	6.13	4.86
E2E	OLSR	Mean	11.61	17.55	20.22	26.56	30.68	32.12	33.11
		SD	3.24	5.44	3.39	4.67	3.67	3.85	3.49
	EBOLSR	Mean	10.12	16.54	18.85	22.68	27.11	29.71	30.25
		SD	4.06	5.70	3.74	5.55	4.21	5.83	5.52
	CAABO	Mean	9.67	13.1	16.34	20.21	25.07	27.87	28.23
		SD	3.50	4.87	3.13	3.39	4.51	3.74	3.27
	BOLSR	Mean	8.07	11.78	14.37	18.41	21.61	24.21	26.31
		SD	3.67	4.35	3.32	4.88	3.30	4.59	3.76
ROR	OLSR	Mean	39.74	41.78	43.62	47.16	48.27	49.92	50.12
		SD	0.84	4.16	2.07	1.34	3.08	1.30	3.21
	EBOLSR	Mean	34.19	36.29	39.83	43.02	44.54	46.28	47.34
		SD	2.88	2.55	3.29	2.95	1.73	3.11	4.02
	CAABO	Mean	33.11	35.04	39.44	42.34	42.67	44.85	46.91
		SD	1.13	3.21	2.21	3.58	1.81	3.85	2.83
	BOLSR	Mean	31.97	33.07	38.29	40.66	41.53	43.33	45.26
		SD	1.64	2.95	1.43	3.44	1.98	4.16	2.23
EC	OLSR	Mean	33	54	67	79	98	103	111
		SD	15.69	25.21	14.40	22.07	16.17	30.19	18.64
	EBOLSR	Mean	25	46	53	65	87	92	103
		SD	16.95	23.53	10.55	18.74	9.56	24.27	10.22
	CAABO	Mean	23	39	48	62	84	89	99
		SD	14.40	20.53	11.72	16.55	17.38	10.59	21.31
	BOLSR	Mean	20	32	45	60	79	86	97
		SD	18.99	20.65	13.46	19.23	13.57	17.82	12.78

Consequently, the effect of the number of nodes on EC for the BOLSR, CAABO, EBOLSR, and OLSR under the different number of runs is shown in Figure 9. The EC of the nodes are steadily increased when the number of nodes is increased, and the highest EC is recorded in the OLSR. On the other hand, the BOLSR consumes less energy than other protocols as the calculations of its optimal paths are constrained by the dynamics of nodes energy measures.
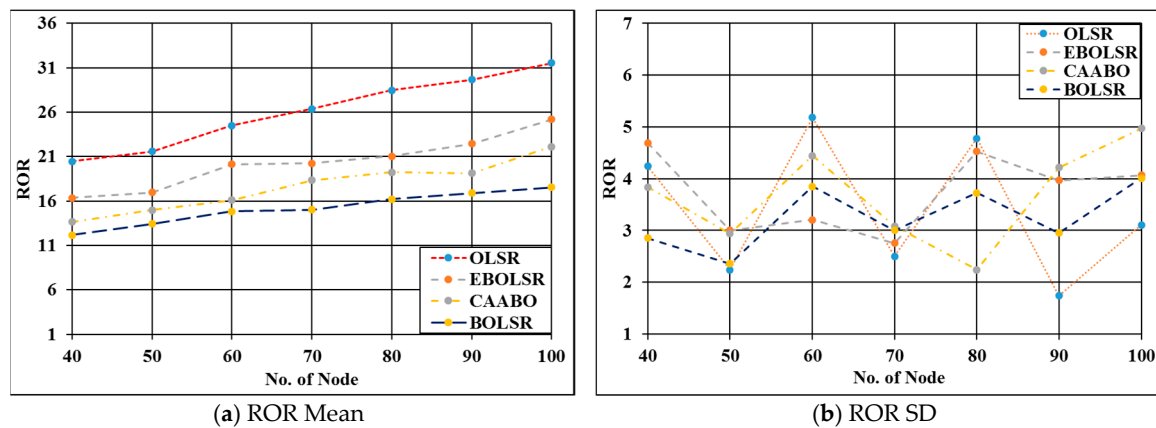
(**a**) ROR Mean　　　　　　　　　　　　　　　　　　(**b**) ROR SD

Figure 8. Routing overhead ratio (ROR) vs. No. of nodes.

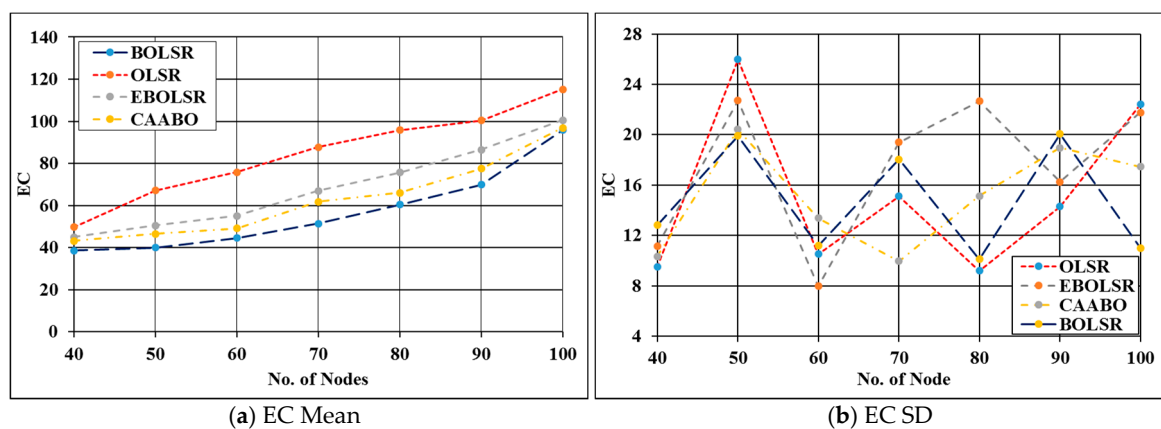(**a**) EC Mean　　　　　　　　　　　　　　　　　　(**b**) EC SD

Figure 9. Energy Consumption (EC) vs. No. of nodes.

The effect of the number of nodes on the E2E delay for the BOLSR, CAABO, EBOLSR, and OLSR is depicted in Figure 10. The E2E delay of the nodes is steadily decreased when the number of nodes is increased, and the highest E2E delay is recorded in the OLSR as Figure 10a,b shows. In all the four protocols, the increase of the number of nodes makes the connection between the nodes easier and requires less time. The BOLSR achieves the lowest E2E delay because the increase of the number of nodes gives it the flexibility to identify nodes with high energy capacity which stabilizes the paths.

(**a**) E2E Mean　　　　　　　　　　　　　　　　　　(**b**) E2E SD

Figure 10. End-To-End (E2E) delay vs. No. of nodes.

In the second scenario, the variation of the speed of nodes is evaluated against PDR, E2E delay, EC, and ROR. The results of the node speed scenario are shown in Table 4.

Based on Table 4, the effect of the node speed on the routing overhead of the four protocols is shown in Figure 11. In general, when the node speed increases from 1 to 11 m/s, the routing overhead ratio increases too. As the previous results, the performance of the BOLSR is better than the CAABO, EBOLSR, and OLSR protocols with regards to the ROR. The BOLSR set's up robust and steadier routes as is shown in the ROR and EC measures in which there are less likelihoods of route failure, and hence, reducing the need for the route discovery process.

(**a**) ROR Mean   (**b**) ROR SD

Figure 11. ROR vs. node speed.

The effect of the node speed on the EC for the BOLSR, CAABO, EBOLSR, and OLSR are shown in Figure 12. The results show that the EC of the nodes is dramatically increased when the node speed is increased as high node speed increases the probability of the link failure between nodes. Again, the EC of the BOLSR routing protocol is lesser than the CAABO, EBOLSR, and OLSR for the same mentioned reasons.
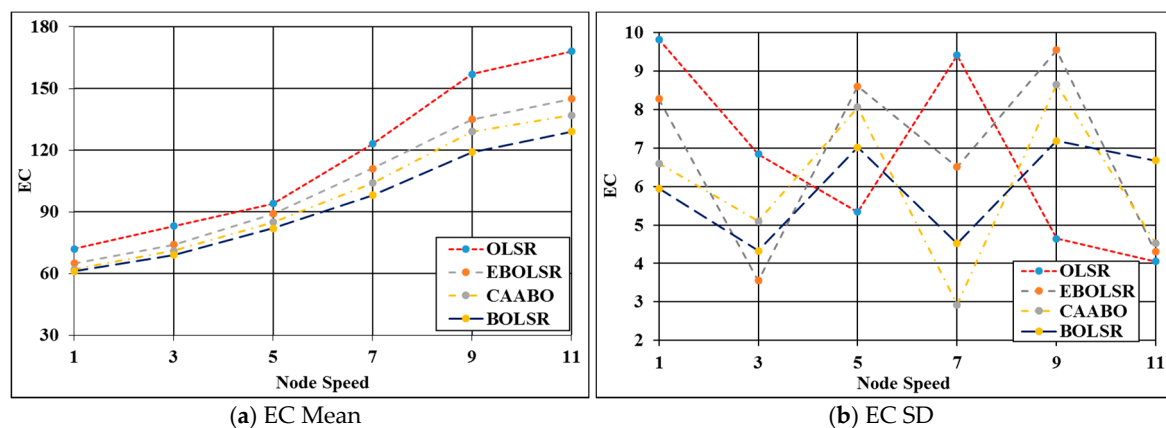

(**a**) EC Mean   (**b**) EC SD

Figure 12. EC vs. node speed.

The effect of the node speed on the E2E delay for the BOLSR, CAABO, EBOLSR, and OLSR are shown in Figure 13. The node speed causes a higher probability of link failure which dramatically increases the E2E delay of the nodes. The SD results of Figure 12b clearly show that the BOLSR outperforms the other protocols as it optimizes routes based on various parameters.

In the third scenario, the protocols were evaluated against the simulation time. Generally, the increase in the simulation time exhausts the energy of the nodes which increases the ROR and E2E of the network. The results of this scenario are shown in Table 5.
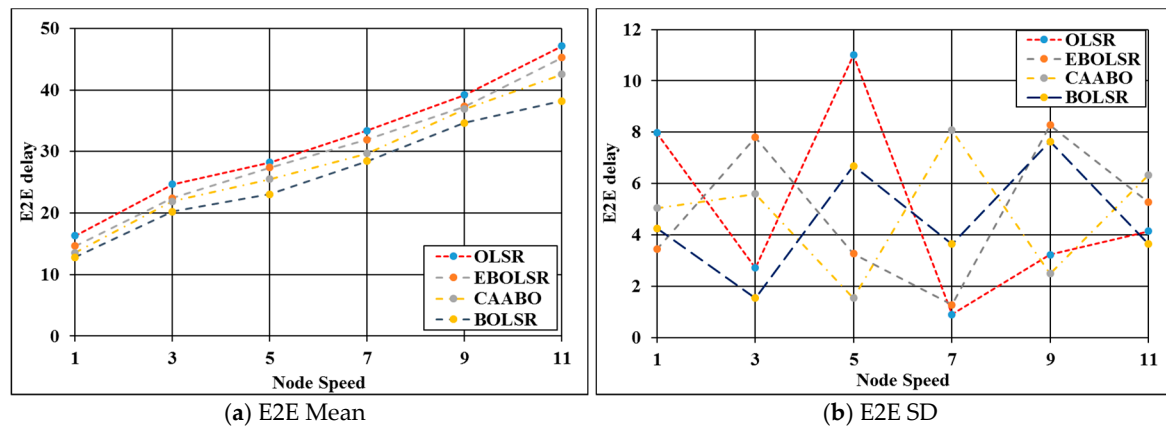
(**a**) E2E Mean

(**b**) E2E SD

Figure 13. E2E delay vs. node speed.

Based on Table 5, the effect of the simulation time on the routing overhead of the four protocols is shown in Figure 14. In general, when the simulation time is increased (10–70 s), the ROR is tremendously increased. The lowest ROR is recorded in the BOLSR and the highest ROR is recorded in the OLSR protocol while the EBOLSR and CAABO maintain adjacent ROR results.
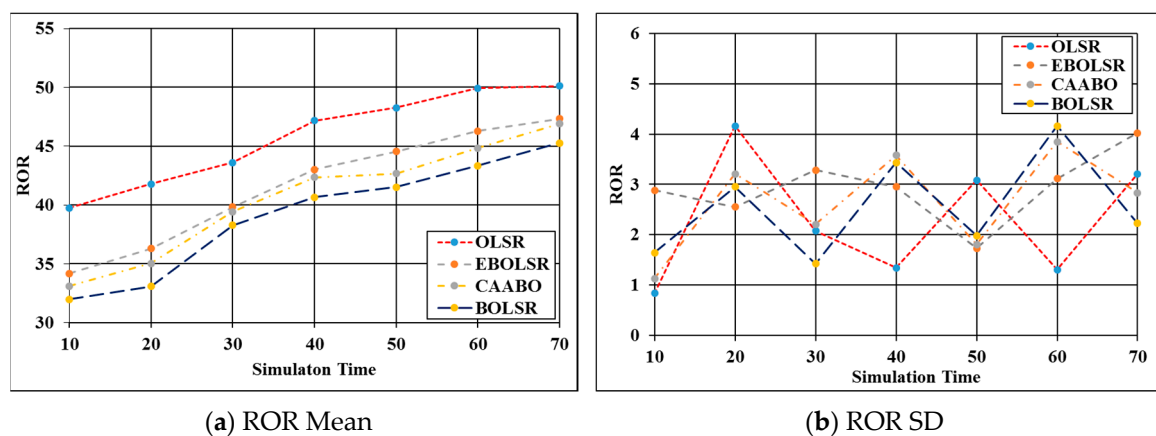

(**a**) ROR Mean

(**b**) ROR SD

Figure 14. The ROR vs. simulation time.

The effect of the simulation time is shown in Figure 15. Like the first and second scenarios, the EC of the nodes increases when the simulation time is increased. The BOLSR routing protocol consumes less energy compared to the CAABO, OLSR, and EBOLSR. The BOLSR protocol chooses a stable path with the highest energy for the same reasons mentioned previously.
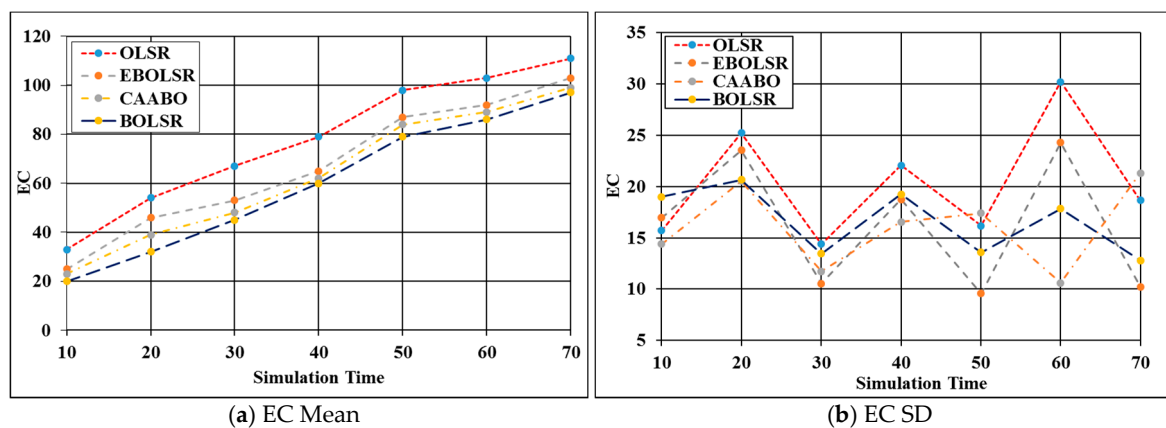

(**a**) EC Mean

(**b**) EC SD

Figure 15. The EC vs. simulation time.

The effect of the simulation time of the four protocols on the E2E delay is shown in Figure 16. Whilst, the simulation time increases the E2E delay increases too. Consequently, the BOLSR protocol has less E2E delay when compared with CAABO, OLSR, and EBOLSR as it selects a steady path with the maximum energy which increases the network lifetime and ultimately decreases the E2E.
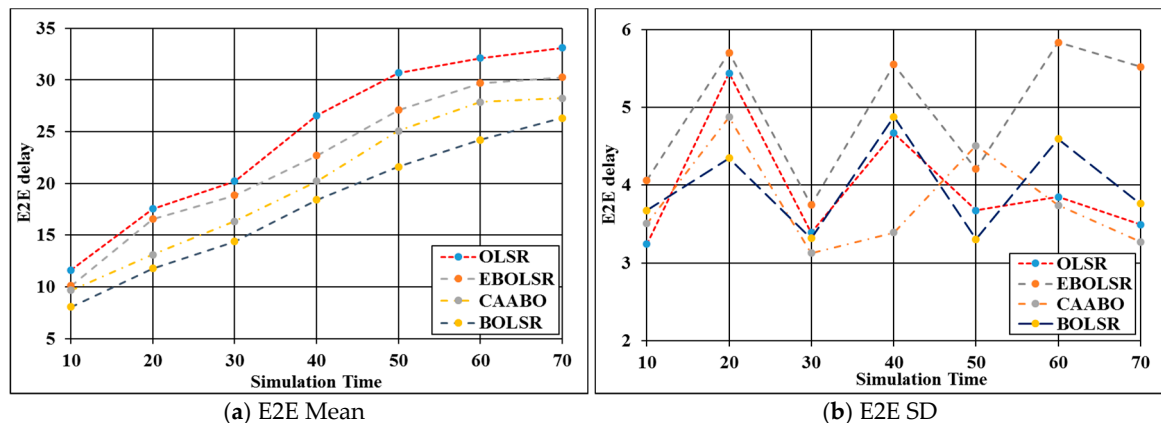

(**a**) E2E Mean   (**b**) E2E SD

Figure 16. E2E delay vs. simulation time.

6. Discussion

This work proposes an improved BOLSR routing protocol based on the OSLR protocol. It is compared with the performance of the CAABO, EBOLSR, and OLSR according to the number of nodes, node speed, and simulation time scenarios in terms of energy consumption, end to end delay, and routing overhead ratio. These comparisons are made to check and evaluate the ability and the performance of the BOLSR in MANET. The BOLSR maintains the lowest overhead ratio, delay, and energy among the rest which implies its ability to find the optimal path based on three quality parameters (energy, overhead, and delay). This in return ensures producing a stable network by decreasing the probability of the link failure and ensuring the successful transmission for the highest amount of data to the destination nodes.

The results of energy consumption, overhead ratio, and E2E delay for all routing protocols in the three scenarios reveal that every scenario has a different impact on the performance of the routing protocols. In all routing protocols, the energy consumption and overhead ratio increases with the increase of the number of nodes, node speed, and simulation time. It is because the nodes need to exchange information through flooding mechanisms for route discovery. Subsequently, the route discovery process consumes higher energy compared to the normal data exchange between MANET nodes. On the other hand, the E2E delay decreases when increasing the number of nodes, as the connections between nodes are becoming easier and require less time. Whilst, when increasing the node speed and simulation time the delay is increased because the node speed and the simulation time have negative effects on the link stability which, in turn, increases the delay. The results clearly show that the node speed scenario has a greater negative impact on the performance of the four routing protocols in which it tremendously increases the probability of link failure. The stability of the network under the node speed scenario depends on the mobility of the node in which the best stability is when the nodes are staying near their initial position (static network). This issue reduces the need for reconstructing new routes. On the other hand, the change in node speed changes the topology of the network and makes the network unstable.

The standard deviation values of the five runs state the variance in the performance of the protocols. The protocols aim to find the optimal routes from all possible routes within the network dynamics. The lesser variation in the SD values refers to the high stability of the network, and vice versa. The performance metric assessed for each routing protocol under three different scenarios and the results show that the SD of the metrics is lower in the number of nodes, and simulation time

scenarios than the node speed scenario. As a result, node speed represents the bottleneck of the test. As the node speed decreases, the stability of the network increases until the nodes become near to their initial position and the network reaches the static state. The static network has stable routes and less route reconstruction. However, one of the most advanced features of the MANET is node mobility and hence the routing protocols should be resistant to node speed.

The research scope limited this paper to focus on energy consumption, delay, and overhead parameters in finding the best route. Nevertheless, the BOLSR maintains the shortest route and a maximum number of connections of the conventional OLSR. There are some other parameters studied in the literature such as the number of hops and bandwidth that are not covered in this work.

7. Conclusions and Future Work

The technology of MANETs has evolved into a fascinating field of research because of its many promising characteristics. The MANET is popularly employed as wireless networking technology due to its simplicity, cost-effectiveness, and ease of use. MANET technology has been used by many researchers to improve energy usage and bandwidth. The development of the MANET can be useful in many applications in which traditional networks are less efficient. In this paper, a BOLSR protocol was proposed and simulated in the MANET environment using MATLAB. Four different performance metrics of PDR, EC, ROR, and E2E delay were estimated to evaluate the performance of the protocols. Based on the simulation results, the BOLSR protocol outperforms three other protocols which are CAABO, EBOLSR, and the conventional OLSR protocols for all the studied parameters. It is because the BOLSR protocol chooses a robust path of nodes that have the highest energy. Future research should focus on the security problems in the routing protocols such as black hole attack.

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