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Green Communication in IoT for Enabling Next-Generation Wireless Systems

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Abstract: Recent developments and the widespread use of IoT-enabled technologies has led to the Research and Development (R&D) efforts in green communication. Traditional dynamic-source routing is one of the well-known protocols that was suggested to solve the information dissemination problem in an IoT environment. However, this protocol suffers from a high level of energy consumption in sensor-enabled device-to-device and device-to-base station communications. As a result, new information dissemination protocols should be developed to overcome the challenge of dynamic-source routing, and other similar protocols regarding green communication. In this context, a new energy-efficient routing protocol (EFRP) is proposed using the hybrid adopted heuristic techniques. In the densely deployed sensor-enabled IoT environment, an optimal information dissemination path for device-to-device and device-to-base station communication was identified using a hybrid genetic algorithm (GA) and the antlion optimization (ALO) algorithms. An objective function is formulated focusing on energy consumption-centric cost minimization. The evaluation results demonstrate that the proposed protocol outperforms the Greedy approach and the DSR protocol in terms of a range of green communication metrics. It was noticed that the number of alive sensor nodes in the experimental network increased by more than 26% compared to the other approaches and lessened energy consumption by about 33%. This leads to a prolonged IoT network lifetime, increased by about 25%. It is evident that the proposed scheme greatly improves the information dissemination efficiency of the IoT network, significantly increasing the network's throughput.

Keywords: IoT; energy optimization; genetic algorithm; antlion optimization; routing protocol; DSR; energy consumption

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1. Introduction

Internet of Things (IoT) devices have become a main subject of interest for different types of applications. Due to their extraordinary capabilities, they have become popular and common [1]. IoT is rapidly emerging as an important and influential factor in mobile computing, wireless systems, and vehicular ad hoc networks [2]. IoT devices consist of small sensing devices called sensor nodes. Sensors are tiny devices that consist of a central processing unit (for data processing), a small memory card (working as a storage device), a small battery (an energy source), and a transceiver, as shown in Figure 1 [3]. A transceiver sends and receives data or signals from one sensor node to another. Sensors gather and exchange information by communicating with each other to accomplish a common task. These sensors report the collected data to a base station [4,5].

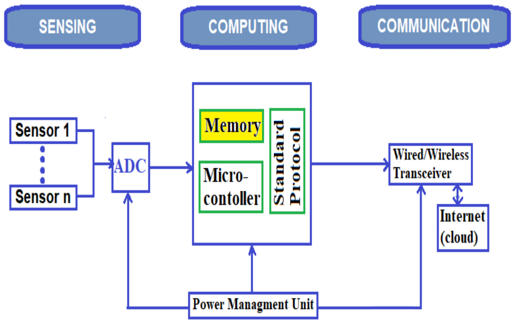

Figure 1. IoT architecture for next-generation wireless systems.

Sensors vary in their sizes due to the types of applications. The cost of these sensors also depends on their specifications, such as CPU speed, battery size, and memory size [6]. To complete a specific task, IoT devices are deployed over a specific sensing region [7–9]. Monitoring, analyzing, combining, and responding to the data sensed by hundreds or thousands of nodes are the primary goals of IoTs [10]. Each sensor node has a coverage area depending on its sensing range (Rs). The network coverage can be explained as the total coverage by all the active nodes in the network. Furthermore, each of these sensors has radio coverage depending on its communication range (Rc), which is the area where an active sensor node can communicate with another sensor node. Sensing coverage guarantees convenient event monitoring, while radio range guarantees convenient data transmission [11].

IoT devices suffer from different resource constraints, such as limited energy and memory size. Energy consumption remains the most important challenge that limits the IoT devices' lifetime and reliability [12,13]. The sensor nodes' limited energy supply can be depleted by performing computations and wireless data transmission. Therefore, it is essential to use energy-efficient computation and communication methods. The lifespan of sensor nodes is significantly impacted by battery life. Compared to computations, data transmission uses more energy [14]. Therefore, minimizing data transmission costs is the most important factor affecting IoT device lifetime. As a result, many researchers have proposed different routing techniques to achieve this goal. Indeed, a new energy-saving routing protocol that is intelligent and effective for IoT networks is required. Many researchers have proposed different protocols to save energy in IoT networks. However, this problem still exists, which in turn negatively affects the IoT network lifetime. So, we need to develop new solutions to tackle this challenge. Figure 2 illustrates an example of a flat multi-hop IoT network [15]. In these kinds of networks, the sensor nodes can communicate with the base station (BS) thanks to the other joined nodes in the environment. For large-scale IoT networks with numerous sensor nodes and one BS, the multi-hop IoT network topology is recommended.

The contributions of this paper are as follows:

- An energy-efficient protocol has been proposed in this work, in order to find the optimal routing protocol between the sensor nodes and the base station in IoT networks, considering various parameters and constraints.
- A hybrid GA-ALO metaheuristic optimization technique has been utilized in order to find the optimal path for each communication in the network.
- Haversine equation has been incorporated with the proposed approach as a separate model. The results obtained from the proposed approach will be compared against other benchmark techniques, i.e., the Greedy technique and DSR routing protocol.

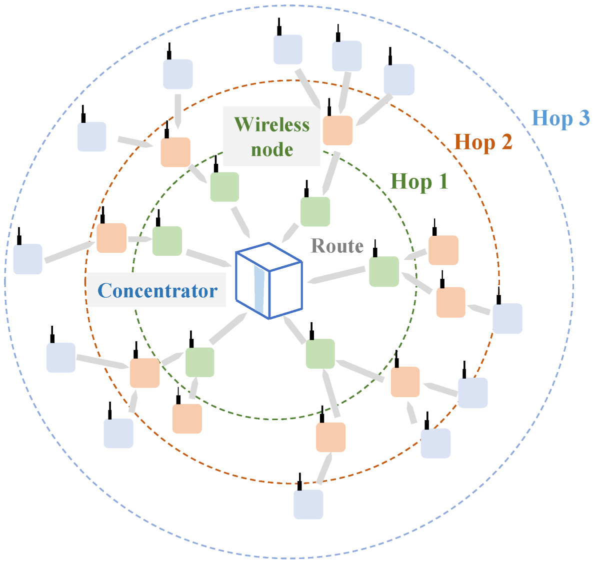

Figure 2. An example of a multi-hop of flat-based architecture in an IoT network.

The rest of the paper is organized as follows. Section 2 presents related works. The proposed routing protocol is described in Section 3. Section 4 shows the numerical results and validation of our proposed routing protocol. Finally, the conclusion is given in Section 5. The notations used throughout this paper are listed in Table 1.

Table 1. Notations.

Notation	Description
ALO	Antlion Optimization
GA	Genetic Algorithm
SLD	Straight Line Distance
Dis_t	Total distance from a sensor to the BS
$dis_{(s)}$	Distance between two sensors
$dis_{(bs)}$	Distance between a sensor to the BS
ψ_{bs}, ψ_i	The latitude of the BS and sensor i, respectively
ζ_{bs}, ζ_i	The longitude of BS and sensor i, respectively
Dis_t	Distance from sensor to the BS
D	Distance between the transmitter and receiver
η_{fr}	The free-space energy loss
η_{pr}	The multipath energy loss
D_0	The threshold distance which controls the situation to select η_{fr} or η_{pr}
nx	The next hop (next sensor)
ss	Total number of nodes participating in the path from i to the BS
i	Index of sensors that want to communicate with the BS

2. Related Work

Due to the importance of using IoT technologies in our daily lives, several papers have focused on earthquake prediction using IoT, particularly after the Turkey–Syria earthquake disaster [16–18]. Many routing protocols and algorithms attempt to mitigate the impact of energy problems, lifetime, and reliability in IoT networks. However, these protocols face various challenges due to the limited resources of sensor nodes. These issues have garnered considerable interest from the researchers, who have proposed numerous routing protocols and mechanisms to address these problems. Here are some of these protocols, categorized into artificial intelligence (AI) and traditional-based protocols.

2.1. Artificial Intelligence-Based Routing Protocols (AIRP)

The authors in [19] introduced a novel routing protocol, utilizing the Breadth-First Search (BFS) algorithm. The simulation results showed that the proposed protocol extends the lifespan of IoT networks, and outperforms established protocols in terms of transmission delay, throughput, and packet delivery ratio.

To enable effective data transmission, wireless technology adheres to standards like IEEE 802.15.4 [20]. These standards ensure optimal communication between endpoints by utilizing the Energy Optimization Algorithm. The proposed algorithm in [20] boosts data packet transmission efficiency by up to 25%. Furthermore, it extends the lifespan of IoT networks, facilitating efficient data transmission for healthcare monitoring purposes.

The authors introduced the ECQSR routing protocol in [21]. The main goal of the proposed scheme was achieving quality of service in sensor networks while maximizing the network's lifetime. The protocol incorporates service differentiation, utilizes the nearest neighbor algorithm for finding low-cost paths, and imposes delay constraints for real-time data.

In [22], the authors have presented a genetic-algorithm-based unequal clustering and routing protocol for wireless sensor networks (GA-UCR) protocol for IoT networks that focuses on unequal clustering and routing and makes use of genetic algorithm techniques. The protocol employs the genetic algorithm for cluster head (CH) selection and inter-cluster multi-hopping, effectively addressing the challenging NP-Hard nature of the problem. By incorporating fitness functions such as remaining energy, distances, and inter-cluster separation, GA-UCR surpasses existing algorithms such as direct propagation, Low-energy Adaptive Clustering Hierarchy (LEACH), Two-Level Hierarchy for Low-Energy Adaptive Clustering Hierarchy (TL-LEACH) protocol, Gateway Classification Algorithm (GCA), Energy-aware Evolutionary Routing Protocol (EAERP), and genetic algorithm-based energy-efficient clustering hierarchy (GAECH) in terms of energy consumption, network lifetime, and scalability.

In [23], the authors propose routing algorithms for 3D IoT networks to extend the lifespan of sensor nodes. These algorithms utilize GA instead of a Greedy algorithm to construct chains based on the Power-Efficient Gathering in Sensor Information System (PEGASIS) routing technique. The authors also incorporate a CH selection technique that considers energy and distance for improving load balance in IoT networks. The simulation results indicate significant improvements in node lifespan compared to PEG-ASIS, with increases of 817% and 420% for the base station inside and outside the network, respectively.

The authors in [24] suggested the Multi-Channel (MC) scheme as a solution for heterogeneous IoT networks, employing super nodes such as cluster heads (CHs) with multiple radios for transmitting data. The authors used the GA to achieve efficient clustering, routing, and channel assignment. The extensive simulations validated the superiority of the proposed approach to prolong the network lifetime, enhancing throughput, and reducing energy consumption compared to previous approaches.

The authors introduced antlion optimization (ALO) as a method for selecting optimal sink placement locations in [25]. Inspired by the hunting behavior of antlions, ALO incorporates distance and hop count in its energy efficiency calculations for sensor networks. Experimental results demonstrate superior performance compared to the Bacteria-Forging Algorithm (BFA) and Gray Wolf Optimizer (GWO). The proposed approach effectively reduces network delay, conserves energy, and enhances the overall network lifetime.

The authors in [26] present non-dominated sorting multi-objective antlion optimization (NSIMOALO), an enhanced version of the multi-objective antlion optimization (MOALO) algorithm designed for multi-objective optimization. Non-dominated sorting multi-objective antlion optimization (NSIMOALO) incorporates fast non-dominated sorting and an elite strategy inspired by the non-dominated sorting genetic algorithm (NSGA-II) to improve solution accuracy and prevent convergence to local optima. It introduces a more effective congestion calculation equation to enhance population diversity and incorporates Lévy flight for improved global optimization capabilities. Simulation results demonstrate superior convergence and coverage compared to alternative algorithms. In a sensor node deployment scenario, NSI-MOALO surpasses MOALO, NSGA-II, and the non-dominated sorting multi-objective flower pollination algorithm (NSMOFPA) in terms of coverage rate and average sensor node movement distance.

2.2. Approach-Based Routing Protocols (ARP)

A new routing protocol called State-Aware Link Maintenance Approach (SALMA) has been proposed in [27]. The SALMA protocol is combined of two existing protocols, dynamic-source routing (DSR) and optimized link state routing (OLSR). This novel protocol places emphasis on the activity of sensor nodes in IoT operations, classifying them into three states: black, white, and gray. According to the findings of this study, the SALMA protocol demonstrates improvements in various quality of service (QoS) metrics. It exhibits a lower routing overhead compared to OLSR, shorter delays than DSR, and ensures low energy consumption for all sensor nodes in the network.

Sequential Assignment Routing (SAR) was introduced as an innovative routing protocol that tackles the issues encountered in routing protocols, striving to cater to the diverse quality of services. SAR operates as a multi-path routing protocol that assists in determining optimal routing decisions. Its design revolves around three key phases: assessing the quality of service on each path, considering energy resources, and factoring in the priority level of the packet. Nonetheless, SAR faces a number of problems and limitations, including its challenge of maintaining routing tables and the complexity of efficiently monitoring quality of service metrics at each individual sensor node [28]. The Low-Energy Adaptive Clustering Hierarchy (LEACH) routing protocol was introduced in [29]. LEACH is a routing protocol based on clustering, where cluster heads are randomly selected to evenly distribute the power load among sensor nodes in the IoT networks. This protocol uses localized coordination to ensure resilience and scalability in dynamic IoT networks. Furthermore, it implements a data fusion mechanism to reduce the volume of transmitted data to the sink node.

In [30], the authors introduced an adaptive threshold-sensitive energy-efficient sensor network protocol (APTEEN). APTEEN was designed for an all-encompassing information retrieval approach. Within this network, the sensor nodes not only react to critical time events but also periodically share comprehensive network details while minimizing energy consumption. In such a system, users have the flexibility to make requests for current, past, and future data using persistent, one-time, or historical queries.

The authors in [31] presented a novel routing protocol known as Geographical and Energy-Aware Routing (GEAR) in their paper. GEAR selects the next hop in the path, based on either geographical location proximity or cost. In [32], researchers introduced Geographic Adaptive Fidelity (GAF), a routing protocol primarily designed for MANET networks but also applicable to IoT networks. The main concern of GAF is to address power consumption issues within the network. This is achieved by intelligently turning off unnecessary sensor nodes while maintaining the stability of process fidelity. The GAF protocol divides the sensor node field into grid squares, with each sensor node utilizing location information, either from the GPS or any available location system. Figure 3 depicts the diagram of state transitions for Geographic Adaptive Fidelity, consisting of three states: active, sleeping, and discovery. In the sleeping state, sensor nodes turn off their radios to conserve energy. During discovery mode, sensor nodes send messages to gather information about other nodes within the same grid. Even in active mode, sensor nodes periodically send messages to inform others about their current state. The primary objective of this protocol is to prolong the IoT networks' lifetime by ensuring only one active sensor node exists in each grid [33].

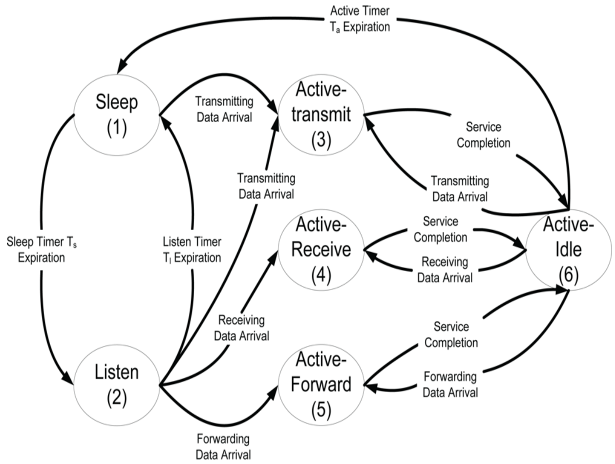

Figure 3. GAF state transitions.

In [34], the authors introduced a Stateless Protocol for Real-Time Communication (SPEED) for IoT networks. This protocol offers backing for three categories of real-time transmission services: real-time area multicast, real-time area anycast, and real-time unicast. An essential characteristic of SPEED is its stateless architecture, which contributes to its exceptional scalability and efficiency, especially in IoT networks where sensor node resources are constrained.

Several surveys have discussed different protocols that have been used in IoT networks. Table 2 summarizes the most common IoT networks' routing protocol and classifies each one of them to AI or traditional-based protocols.

Table 2. A comparison between most common routing protocols in IoT networks.

Routing Protocol	Classification	Contribution/Methodology
BFS	AIRP	Reducing energy consumption, extending the lifespan of IoT networks
ECQSR	AIRP	Utilizing the NN algorithm for finding low-cost paths, and imposing delay restrictions for real-time data
GA-UCR	AIRP	Focusing on unequal clustering incorporating Genetic Algorithm technique
NSI-MOALO	AIRP	Designed for a multi-objective optimization
SALMA	ARP	Focusing on the activeness of sensor nodes in the IoT networks operations, and it is defined three states of sensor nodes, which are black, white, and gray
SAR	ARP	Multiple paths routing protocol that assists in routing decisions
LEACH	ARP	A clustering based protocol that applies a randomized selection the CH to distribute the power load between the sensor nodes in the IoT networks evenly
APTEEN	ARP	Sensor nodes not only react to critical time events but also periodically share comprehensive network details while minimizing energy consumption
GAF	ARP	Turning off useless sensor nodes at the same time maintaining the stability of process fidelity
GEAR	ARP	Selecting the next hop of the path according to the geographical location closeness or cost
SPEED	ARP	Supports three classes of real time transmission services, namely, real-time area multicast, real-time area anycast and real-time unicast

3. Proposed Routing Protocol

This section discusses the process of data transmission between the sensor-to-sensor and the sensor-to-base station using our proposed EFRP protocol. The first step that we considered in our proposed algorithm is the distribution of sensors in the investigated area (initialization phase). We assume all the sensors are randomly distributed. Second, our scheme finds all available paths using the genetic algorithm (GA) as an outer loop. Then, ALO is used to extract the optimal path, considering the multi-objective function. Finally, the BS updates all nodes (sensors) with the current state-of-charge for all the nodes in IoT network.

3.1. Routing Protocol

This paper proposes a new routing protocol in order to deliver the messages from the sensors to the BS, considering the proposed objective function which aims to minimize the total energy consumption. GA and ALO will be incorporated to solve this problem.

3.1.1. Network Model and Preliminary

We consider IoT networks composed of sensor nodes and one single base station. The set of sensors is denoted by n_S = {1, . . . , i, . . . , N}. The cardinality of n_S is N, i.e., there are N sensors in the study. Each sensor in n_S has two attributes; i = (p, g), where p, and g are the coordinates of the sensor and the residual energy in the sensor. BS has one attribute which is the position (coordinate) where it is located. All sensors send their current characteristics in terms of the amount of residual energy with the messages that go through these sensors or even when the sensor wants to communicate with the BS. Once the BS gets these messages from sensors, it broadcasts a beacon to all sensors to notify them about the current circumstances of all sensors in the environment.

3.1.2. Energy Model

To send the message from a sensor to the BS, the objective function should be calculated based on minimizing the total amount of the energy consumption of all sensors participate to deliver the message to the BS. To select the next hop of the message, two parameters should be considered: the distance to the next sensor, and the straight-line distance (SLD) between the next sensor and the BS as shown below.

$$Dis_t = dis_{(s)} + dis_{(bs)} \tag{1}$$

where Dis_t is the total distance from the sensor wants to communicate with BS to the BS, $dis_{(s)}$ represents the distance to the next sensor (next hop), and the $dis_{(bs)}$ is the SLD from next node.

In the literature, all the proposed approaches used the Euclidian distance, as shown in the following equation, in order to find the distance (shortest distance) between sensor-to-sensor, or sensor-to-BS.

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{2}$$

In this work, the distances are calculated using a haversine equation which is utilized to find the shortest distance between two points on a sphere, using their coordinates (longitudes and latitudes) measured on the surface as shown in Figure 4.

$$haversine\ (\alpha) = sin^2\ (\alpha/2) \tag{3}$$

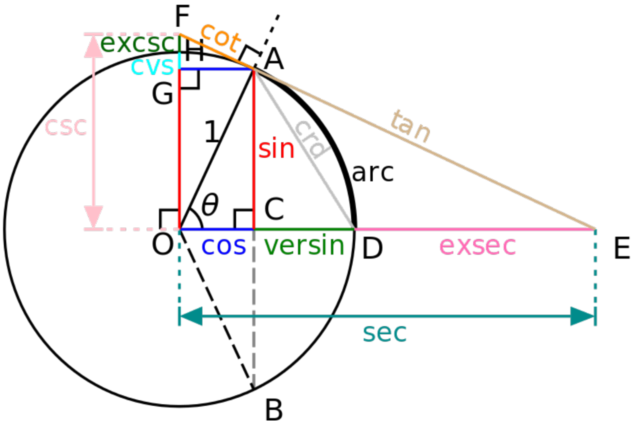

Figure 4. Law of cosine spherical geometry.

The haversine of central angle (D_t/R) is calculated as follows:

$$Dis_t/R = haversine(\psi_{bs} - \psi_i) + cos(\psi_i)\,cos(\psi_{bs})\,haversine(\zeta_{bs} - \zeta i) \tag{4}$$

where R is the earth's radius (∼6371 km), Dis_t is calculated using the inverse of sin function or haversine as follows:

$$Dis_t = Rhav^{-1}(h) = 2Rsin^{-1}(h) \tag{5}$$

$$Dis_t = 2Rsin^{-1}(h) * \sqrt{sin^2(\frac{\psi_{bs} - \psi_i}{2}) + cos(\psi i)\,cos(\psi_{bs})\,sin^2(\zeta_{bs} - \zeta_i)} \tag{6}$$

When a sensor transmits or receives data, it consumes a certain amount of energy (E_n), which depends on the size of data, and the distance (in transmission mode) that the sensor needs. Energy consumption model can be mathematically represented as follows:

$$E_n(L,\ D) = \begin{cases} LE_{n(elc)} +\ L\eta_{fr}D^2,\ D < D_0 \\ E_{n(elc)}\ \ +\ L\eta_{pt}D^4,\ D \geq D_0 \end{cases} \tag{7}$$

where L represents the size of data packet, D is the distance between the transmitter and receiver, η_{fr} represents free space energy loss, η_{pt} denotes the multipath energy loss, D_0 is the threshold distance which controls situation to select η_{fr} or η_{pt}. D_0 can be calculated the following equation:

$$D_0 = \sqrt{\frac{\eta_{fr}}{\eta_{pt}}} \tag{8}$$

3.1.3. Optimization Problem

Extracting the optimal path that can reduce the sensors' energy in IoT networks can be formulated as follows:

$$\sum_{i=1}^{ss} E_n(L,D)_{i,nx} \times x_{i,nx} \tag{9}$$

Subject to

$$ds < 10m,\ \sum_{i=1}^{ss} i < 15,\ \sum_{i=1}^{ss} E_r(i) < T_e,\ E_{nx} >= T_{nx}, P_{size} <= S_M \tag{10}$$

$$x_{i,\ nx} \in \{0,1\}, \qquad\qquad \forall_i \in N \tag{11}$$

where the objective function in (9) finds the best path (route) from the source (current sensor) to the next sensor until reaching the BS, based on the minimum overall energy consumption of all nodes participating in communication (ss), subject to the system constraints that have been incorporated in (10). These constraints have been considered to ensure that the solution which is determined by the proposed routing algorithm in each communication process is efficient and accurate. Then constraint ds < 10 m illustrates that the assumed distance between the two sensor nodes involved in the communication should not exceed 10 m. At each transmission process, the number of sensor nodes should not be more than 15 sensor nodes. There is a threshold for the total amount of energy consumption in each transmission. Moreover, the current sensor node which tries to communicate with the other sensor node in the next hop should also consider the amount of residual energy of this node, i.e., state-of-charge (SoC). The SoC should not be less than a threshold (it is assumed to be no less than 10% of the initial energy of the node to be selected). The reason behind this is to maintain as many alive sensor nodes as possible in the network, which in turn achieves the goal of the study, which is to increase the lifetime of the network.

In case there is more than one possible path for a message that needs to be sent to the BS, i.e., more than one path has the same cost (energy consumption value), the algorithm should select the path has a higher number of nodes participating in the selected path. The reason behind this is to distribute the level of energy consumption for each path among the largest possible number of nodes, which positively affects the lifespan of the network. The binary decision variable $x_{i,nx}$ is used to indicated whether the current node (sensor) selects the next node or not, the value of $x_{i,nx}$ is 1 if a sensor is involved in the next hop, otherwise it is set to 0 as shown in (11).

3.1.4. GA and ALO

The objective function in (9) and the system constraints in (10) form a Mixed-Integer Linear Programming (MILP) problem, where the decision variable $x_{i,nx}$ has only binary values 0, 1 and all system constraints are linear. To solve this problem, two loops are introduced in this paper. The first loop (outer) works by proposing different possibilities of paths, then evaluates each proposed solution (generation) in the second loop (inner) based on Equations (9)–(11). The GA works as an outer loop. In each iteration, several solutions are extracted using GA's operators (crossover and mutations) utilizing the fitness value of the proposed objective function, then the ALO algorithm (i.e., inner loop) produces the best path with the minimum fitness value of the current iteration. The GA keeps generating new solutions, and ALO picks out the best one till the process is finished. Figure 5 shows the flowchart of the proposed routing algorithm. Algorithm 1 shows how the proposed routing algorithm works to determine the optimal path and the best fitness value of the system, which in turns extends the lifetime of the network of IoTs. During the implementation process, we have tried another MILP solver to solve the problem, but the problem was mainly with the high final fitness value that resulted from other solvers that have been used. As mentioned previously, the aim of this study (optimization problem) is to minimize the total amount of energy consumption for each path, which in turn leads to minimizing the total energy consumption for the system as a whole. Among the other MILP solvers that have been incorporated with GA to solve the problem is the Branch and Bound (B&B) algorithm. The Particle Swarm Optimization (PSO) was also used with the GA as well. However, based on the implementation results, the lifetime of the network was less than the (GA-ALO) solvers by 10–15%.

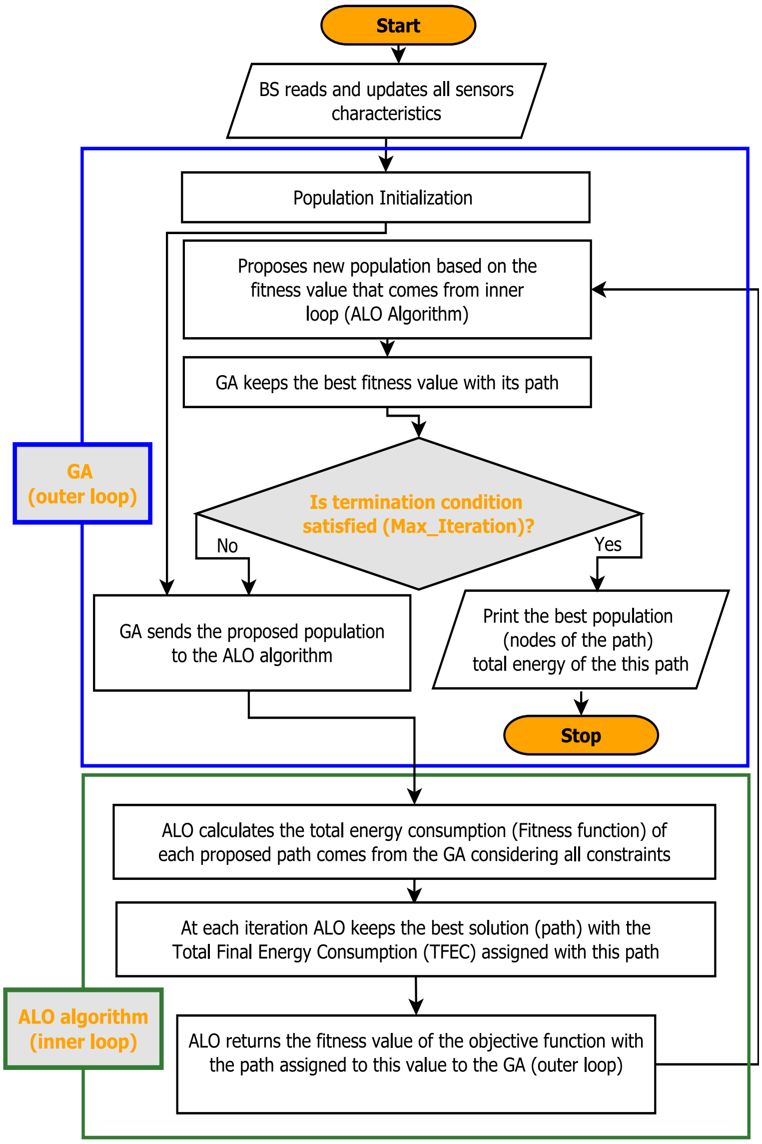

Figure 5. Flowchart of our proposed protocol.

Algorithm 1 The proposed routing protocol (EFRP)

Require: $N\ and\ BS\ (characteristics),\ S_r\ sends\ P_k\ to\ BS$
Ensure: $Optimal\ path, E_n(L, D)$
Initialization
K = max # (GA iterations)
S = current GA's population set
ii = 1
while $ii < K$ **do**
    GA generates initial population (S)
        ALO calc En (L, D) for S
        ALO returns best fitness value with its path to GA
    GA saves optimal $(E_n(L, D)_{i,nx}$ & path) comes from ALO
    GA updates S using crossover and mutation
    $ii++$
end while
GA returns optimal value with its path

4. Numerical Results and Discussion

This section discusses the evaluation of the proposed approach, in order to demonstrate its ability to extend the network lifetime compared to other proposed approaches in the literature.

4.1. Base Scenario Experimental Settings

The proposed routing protocol has been applied to the study area, where the sensor nodes were distributed randomly. Therefore, the proposed protocol can be applied in any area regardless of the geographical characteristics. Figure 6 shows the distribution of sensor nodes in the initialization phase of the system. Table 3 shows the parameters of the network. The proposed EFRP and the DSR routing protocols are implemented using MATLAB environment R2023a—an academic use platform on a HP-PROBOOK laptop with 1.6 HGz (8 CPUs) and 8 GB of RAM. This machine is produced by HP company, Boeblingen, Germany.

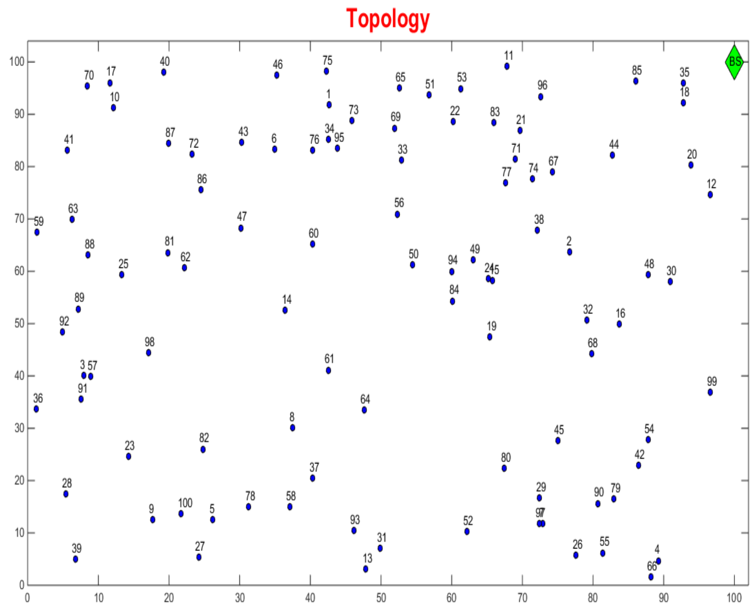

Figure 6. The distribution of sensor nodes in the study area.

Table 3. Base scenario parameters.

Parameter	Value
System Initialization	Random
Area (x, y)	100×100
BS position	100, 100
Nodes (N)	100
Initial energy	18,725 J
Transmitter energy	50×10^{-9}
Receiver energy	50×10^{-9}
Free space	10×10^{-13}
Multipath	0.0013×10^{-13}
Effective data aggregation	5×10^{-9}
Maximum lifetime	2500
Data packet size	4000

4.2. Base Scenario Results

In this scenario, we assume that the system intends to deliver one packet from the source to the destination with a size of 4000 using our proposed protocol (EFRP). Moreover, we consider only the energy consumption of transmission process only. Other forms of energy consumption due to other parameters will be neglected here (such as, data aggregation, data processing, etc.). Table 4 shows the residual energy of some of the alive sensor nodes in a given time before sending the desired packet.

Table 4. Residual energy of sensor nodes before transmission.

Node ID	23	96	14	50	49	2	43	20
Residual Energy (J)	132.2	120	125.2	133.1	138	129	121.9	118

Table 5 shows the residual energy in sensor nodes that participated in the communication process between the source sensor node (S) and the (BS) using the proposed EFRP.

Table 5. Residual energy for path 1 after transmission using EFRP.

Node ID	23	96	14	50	49	2	43	20
Residual Energy (J)	128.2	118.5	122.6	131.5	136	126.7	118	116.4

Figure 7 shows the optimal path that has been selected using our proposed protocol (EFRP). It is clear that the nodes included in the extracted path have a large level of residual energy. This is a result of the restriction that we made the system adhere to. We account for each sensor node's SoC in our suggested protocol. Therefore, the GA chooses the next hop based on the shortest distance between the sensor node that plans to transfer the packet and the next node (next hop), as well as the SLD between the next sensor node and the BS. In order to use less energy, the EFRP splits the large packet into a small packet, as shown in Figure 7. To achieve this, in our experiments, the data packet is limited to a specific threshold as seen in Table 3.

Figure 8 shows the comparison between the residual energy at each sensor node before and after transmission using our proposed protocol (EFRP). It is obvious that the amount of energy consumption of each sensor node is low. This is due to the effectiveness of objective function and system constraints of the proposed algorithm, which aim to minimize the energy consumption of the network after each transmission process.

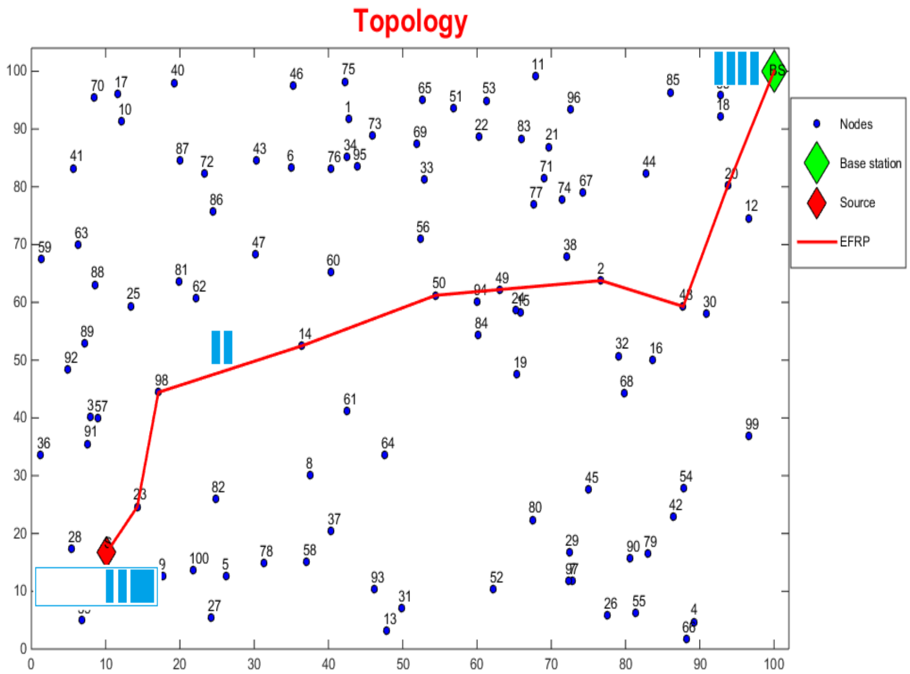

Figure 7. Finding the optimal path using EFRP.

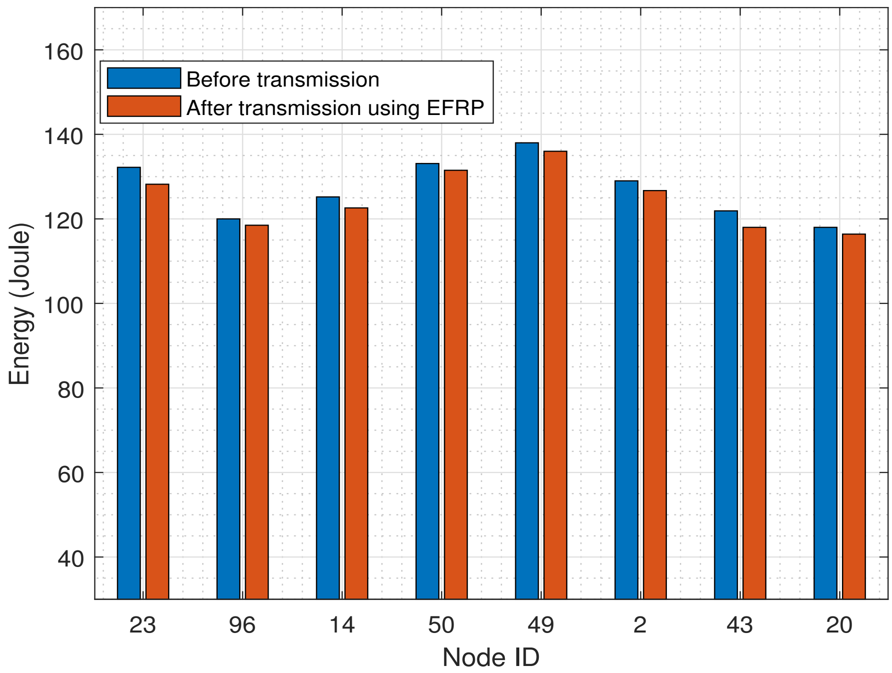

Figure 8. Residual energy after sending a packet using EFRP.

4.3. System Evaluation

In this section, we evaluate the performance and robustness of our proposed routing scheme. First, we compare our proposed EFRP with the Greedy approach which selects the next hop based on the shortest distance. Then, we validate our proposed protocol by comparing it with one of the most known routing protocols, i.e., DSR routing protocol.

4.3.1. Explainability of the Proposed Protocol

Figure 9 shows the convergence of EFRP, and how the optimal path between the source and destination was finally determined, taking into consideration the proposed objective function and the system constraints, i.e., minimizing the total amount of energy consumption for all IoT devices that participated in the results path. The X-axis shows the number of iterations, and the Y-axis shows the value of best values of the proposed objective function in each iteration.

4.3.2. A Comparison between EFRP and Greedy Technique

This section introduces the results of the comparison between our proposed protocol EFRP and the Greedy approach. Tables 4 and 6 show the number of sensor nodes participating in the path between the source node and destination, and also the residual energy in these sensor nodes before sending the desired packet in both approaches (EFPR and Greedy). Tables 5 and 7 show the total of residual energy in each sensor node that participated in the path after sending a packet from the source (S) to the BS using both techniques, respectively. It is easy to notice that the number of nodes participated in the path from the source to the destination using Greedy approach is more, and the total energy consumption is more as well, and the reason for this is, of course, the objective function that the Greedy approach uses to determine the next hop, which is only aiming to select the next node based on the shortest distance among all available sensor nodes, regardless of the straight line distance between the next sensor node and the BS.

Figure 10 shows the total residual energy in each sensor node participated in the transmission process using the Greedy approach. Figure 11 shows a comparison between the two protocols (EFRP and Greedy) in terms of the total energy consumption of whole the system. It is clear that the energy consumption rate of the sensor nodes involved in the transmission process when using the Greedy scheme is higher than the overall energy consumption, which is the result of utilizing EFRP. Figure 12 shows the two different paths to deliver the packet from the source to the destination using the EFRP (red path), and the Greedy approach (blue path).

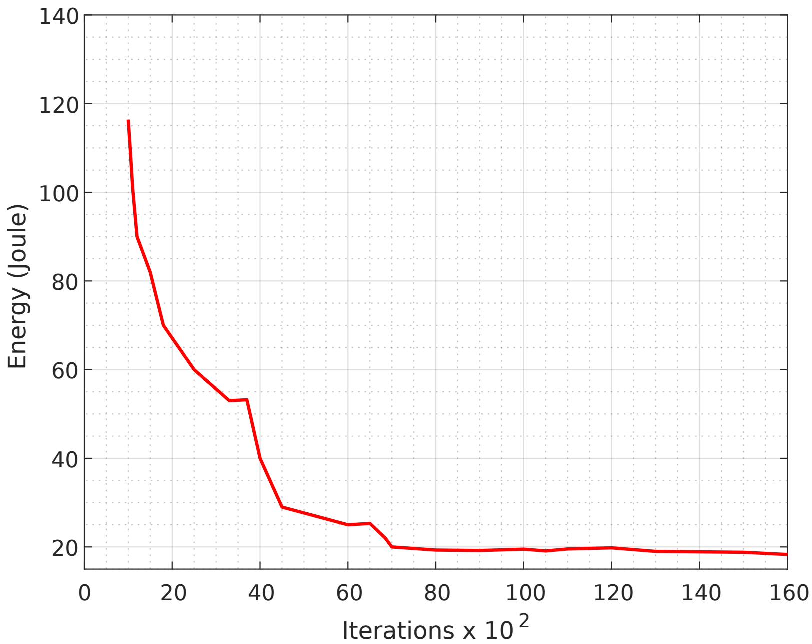

Figure 9. Convergence of the proposed routing protocol during 16,000 iterations.

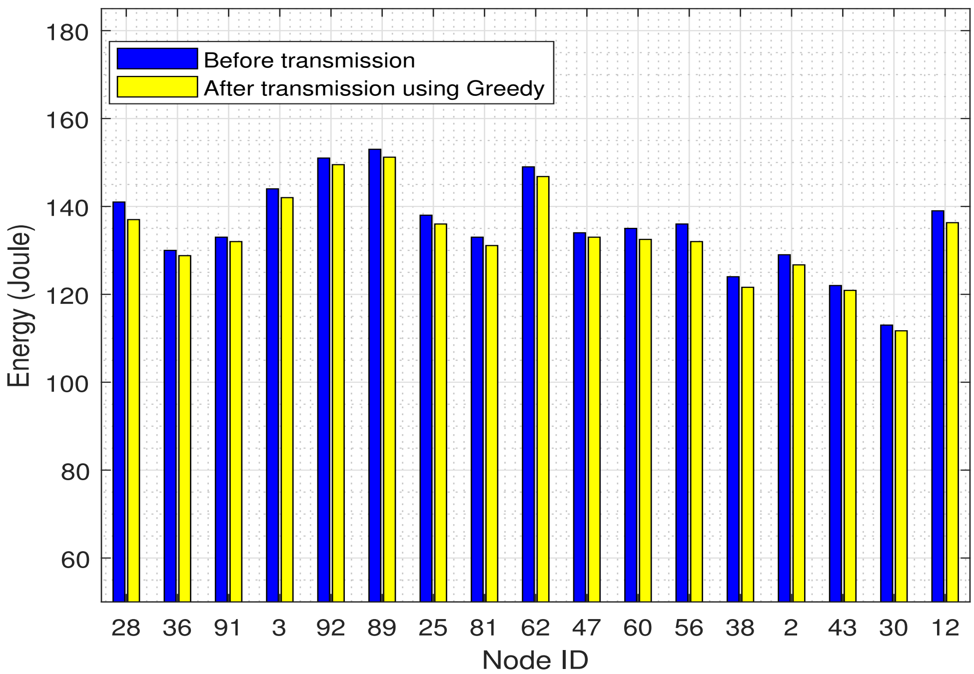

Figure 10. Residual energy after sending a packet using Greedy.

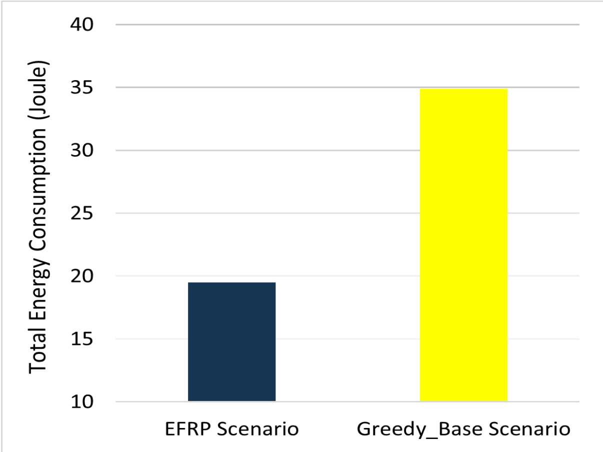

Figure 11. A Comparison between the EFRP and Greedy approach in terms of total energy consumption of sensor nodes participated in the path.

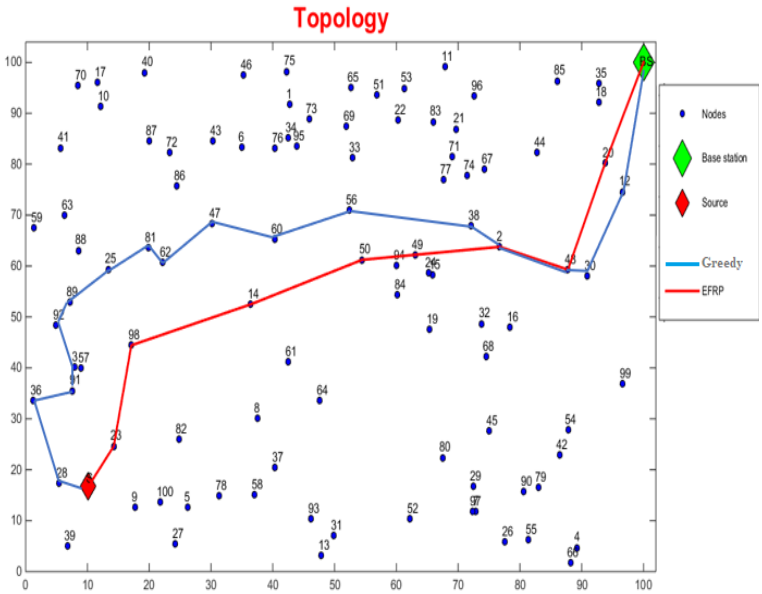

Figure 12. Finding the optimal path using EFRP and DSR.

Table 6. Residual energy of sensors before transmission (Greedy).

Node ID	**28**	**36**	**91**	**3**	**92**	**89**	**25**	**81**	**62**
Residual Energy (J)	141.1	132.9	133	144	150.8	153	138	133.2	149
Node ID	47	60	56	38	2	43	30	12	-
Residual Energy (J)	134	135	136	124	129	122	113	139	-

Table 7. Residual energy for path 2 after transmission using Greedy.

Node ID	**28**	**36**	**91**	**3**	**92**	**89**	**25**	**81**	**62**
Residual Energy (J)	137	128.8	132	142	149.5	151.2	136	131.1	146.8
Node ID	47	60	56	38	2	43	30	12	-
Residual Energy (J)	133	132.5	132	121.6	126.7	120.9	111.7	136.3	-

4.3.3. A Comparison between EFRP and DSR Algorithm

To demonstrate the effectiveness of our proposed protocol (EFPR) and show how it is able to overcome the DSR protocol, a comparison from two different perspectives will be introduced. First, the comparison will be made based on the total energy consumption that the system needs to spend to deliver a packet from a given source to the destination (BS). Then, we will present a comparison between both protocols based on the total number of alive nodes in the system during the lifetime of the network.

A. Energy Consumption

In this section, a comparison in terms of the transmission energy consumption will be discussed between the EFPR and DSR routing protocols. Tables 4 and 8 show the number of sensor nodes participating in the path between the source node and destination, and also the residual energy in these sensor nodes before sending the desired packet in both approaches (EFPR and DSR protocol), where Tables 5 and 9 show the total of residual energy in each sensor node that participated in the path after sending a packet from the source (S) to the BS using both techniques, respectively. Based on the readings in Table 9, it is observed that the total energy consumption using the DSR protocol is high, and the reason for this is, of course, the technique that the DSR protocol adopts to select the next hop.

Table 8. Residual energy before transmission (DSR).

Node ID	82	61	84	15	38	67	44	18
Residual Energy (J)	96.2	104.1	119.7	103.8	98	111.7	88.7	31.3

Table 9. Residual energy for path 3 after transmission using the DSR.

Node ID	82	61	84	15	38	67	44	18
Residual Energy (J)	91.8	100.15	115.9	101.2	96.1	109.1	86.3	29.2

Figure 13 shows the two different paths to deliver the packet from the source to the destination using the EFRP (red path), and the DSR approach (black path). Figure 14 shows the total residual energy in each sensor node that participated in the transmission process before and after (using the DSR approach). Despite the low residual energy in sensor node 18, the DSR protocol has selected it in the route towards the BS. The reason for this is that the DSR algorithm did not take into consideration the residual energy of sensor nodes before involving them in the transmission process.

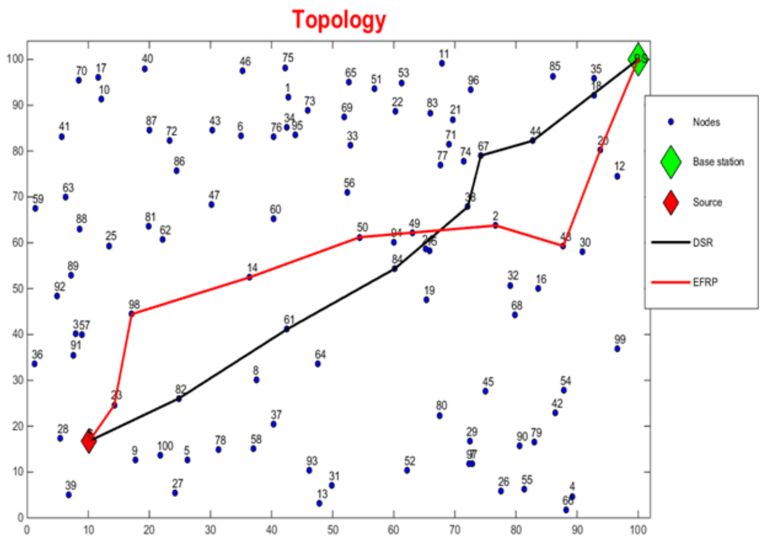

Figure 13. Finding the optimal path using EFRP and Greedy.

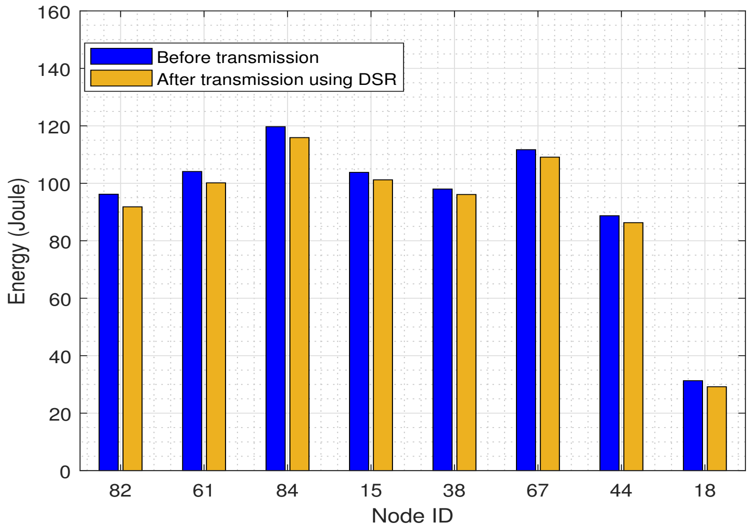

Figure 14. Residual energy after sending a packet using DSR.

Figure 15 illustrates a comparison between the EFRP and DSR routing protocol in terms of the total energy consumption. It is obvious that the energy consumption rate of the sensor nodes used in the transmission process using DSR approach is higher than the total energy consumption that resulted from the use of EFRP. The reason behind this is that the packet header size in DSR increases with route length due to source routing. It is easy to see that the source sensor node has spent a considerable amount of energy in order to deliver the packet to the next sensor node (18) in the study area. Furthermore, we see that each sensor node needs to send the packet a very long distance in order to deliver it to the next hop.

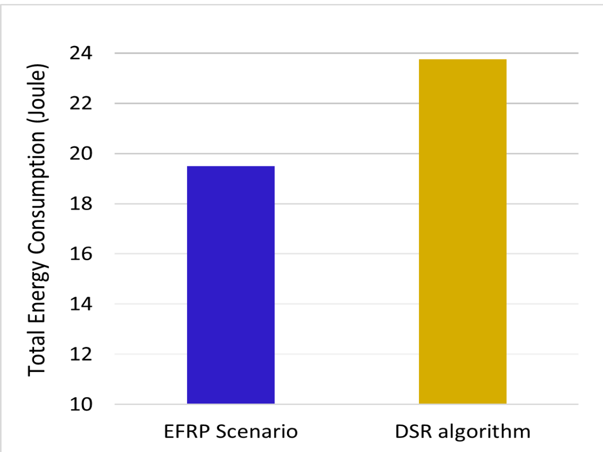

Figure 15. A comparison between the EFRP and DSR algorithm in terms of the total energy consumption of sensor nodes participated in the path.

B. Number of Alive Nodes

In this section, we compare the EFPR and DSR routing protocols in terms of alive nodes in the network after different round times. Figure 16 portrays the number of alive nodes in the field. The proposed EFRP protocol is alive with 28 nodes after 11,484 rounds, while the number of alive nodes in the network is 0 using the DSR routing protocol. The main reason behind this noticeable gap between the two routing protocols is the parameters and constraints that are included in the objective function used in EFRP protocol, which considers not only the distances between nodes and the BS, but also the SoC for sensor nodes, the SLD to the BS, and the other system constraints that were discussed before in the previous section, Section 3.1. Thus, the lifetime of IoT networks using our proposed routing protocol will last longer than that of the DSR routing algorithm, and even the throughput of the system will be more efficient and reliable when using EFRP protocol compared to the DSR routing protocol.

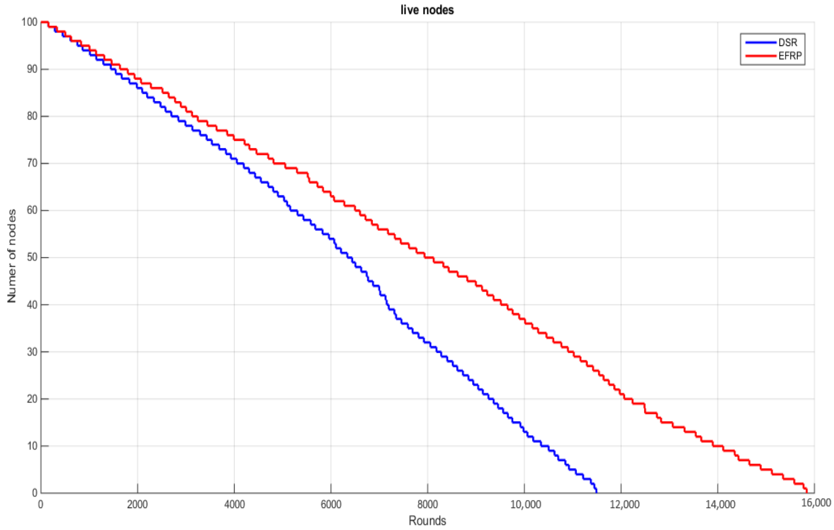

Figure 16. A comparison between the EFRP and DSR algorithm in terms of no. of alive nodes in the system.

Table 10 shows the number of alive nodes over the given number of rounds for both protocols EFRP and the DSR. It is easy to notice that when the system uses the EFRP for data transmission, there are more alive nodes than the DSR at all the transmission rounds. This is because the EFPR routing protocol always tries to consider the threshold of residual energy at each sensor node before considering it in the transmission process, which in turn prolongs the network of IoT lifetime. Moreover, it is also obvious that the gap between the two routing protocols has increased during this time. The reason behind this is the technique that the DSR follows to select the next hop. The DSR continuously chooses the same sensor nodes to transmit data to the next nodes while disregarding their remaining energy, which causes a progressive increase in the number of dead nodes. Constantly using the same nodes for transmission of data will significantly drain their energy. Using such a technique will negatively affect the lifetime and the throughput of the network. As shown in Table 10, the number of alive sensor nodes in our proposed protocol has increased by more than 25% compared to the other approaches. Furthermore, energy consumption is reduced by about 33% in one round of transmission.

Table 10. Alive nodes during the rounds of the system.

Routing Protocol	2000	4000	8000	11,484
EFRP	89	77	50	28
DSR	87	70	32	0

5. Conclusions

Energy consumption is considered a constraint for the management, design, and implementation of the communication aspect of the networks in IoT. In this paper, a novel hybrid metaheuristic optimization technique using a genetic algorithm and antlion optimization has been proposed. The main objective of this study is to prolong the lifetime of IoT networks by introducing an intelligent and efficient flat-based routing protocol (EFRP) aimed to reduce the energy consumption of the sensor nodes during the communication process. The experimental results show that the proposed EFRP protocol outperforms the Greedy approach and the DSR protocol in terms of the energy consumption and the number of alive nodes. As shown in the results, the number of alive sensor nodes in our proposed protocol increased by more than 26% compared to the other approaches, and reduced energy consumption by about 33%, which in turn extended the network of IoTs' lifetime by about 25% and increased the efficiency and reliability of the system through maximizing the throughput of the network.

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