Indonesian Journal of Electrical Engineering and Computer Science
Vol. 29, No. 2, February 2023, pp. 911~920
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v29.i2.pp911-920

Energy-efficient routing protocol in wireless sensor networks based on bacterial foraging optimization

Abdulmalik Adil Abdulzahra[1], Baida'a Abdul Qader Khudor[2], Imad S. Alshawi[2]
[1]Department of Computer Technology Engineering, Al-Kunooze University College, Basrah, Iraq
[2]Department of Computer Science, College of Computer Science and Information Technology, University of Basrah, Basrah, Iraq

Article Info

Article history:

Received Feb 2, 2022
Revised Oct 11, 2022
Accepted Oct 17, 2022

Keywords:

Bacterial foraging
Energy-efficient network
Network lifetime
Optimization
Routing
WSNs

ABSTRACT

Reserve the wireless sensor networks (WSNs) lifetime for as long as possible is a current goal. In WSNs, sensors are often limited in power. However, uneven power consumption (UPC) reduces lifetime, and its deterioration is considered one of the most critical problems. Therefore, balancing the energy consumption is a significant issue in the WSN, necessitating a routing protocol that is energy-efficient that extends the life of the network. A few protocols have been used to balance energy use across network nodes. This paper proposed a routing protocol energy-saving called Bacterial foraging optimization routing protocol (BFORP). BFORP attempts to investigate the problem of the life of WSNs. It can decrease the routing of excessive messages that may result in severe energy waste by recycling the information that frequents the source node into the sink. In the proposed method, the preferable node in the sending routes may be chosen by prioritizing the lowest traffic load, the highest residual energy, and the shortest path to the sink. In comparison to the known protocols used in routing, the results of the simulation have proven the efficacy of the suggested protocol in lowering energy employment and reducing the delay of end-to-end.

Corresponding Author:

Imad S. Alshawi
Department of Computer Science, College of Computer Science and Information Technology
University of Basrah, Basrah, Iraq
Email: emadalshawi@gmail.com, emad.alshawi@uobasrah.edu.iq

1. INTRODUCTION

Sensor nodes are usually deployed densely in wireless sensor networks (WSNs) to assist in communication, sensation, computing, and data processing. WSNs are used for various functions, applications, and capabilities; for example, any process requires information connection and sensing, such as atmospheric monitoring and video surveillance. WSNs may be placed in open places such as roadways, parks, combat grounds, machines, commercial structures, and human bodies [1]. Generally, these sensor nodes within large-scale operations networks for data collection are powered by small and cheap batteries and are usually low-power [2].

Due to many-to-one traffic patterns and multi-hop routing, WSNs struggle with uneven energy distribution. So this leads to the period of network life being significantly shortened. For data transmission [3], [4], the routing algorithms often choose the optimum route between the source node and the destination node. The sensor node is made up of several parts; a processing part, a sensing part, a power part, and a transmission part. There are elective components such as a mobilizer and position locating system. The sensor construction is depicted in Figure 1. The sensors usually act on their jobs, such as communication, computation data, energy sources, and current information [5]. The sensor can perform two purposes:

communicate the data obtained via sensing or serve as a relay for data gathered by other networked sensors. Energy conservation is crucial to solving the issue of sensor networks that use limited power to detect data. Therefore, the fact of waste of energy must be highly valued and calculated to extend the life of the network [6].

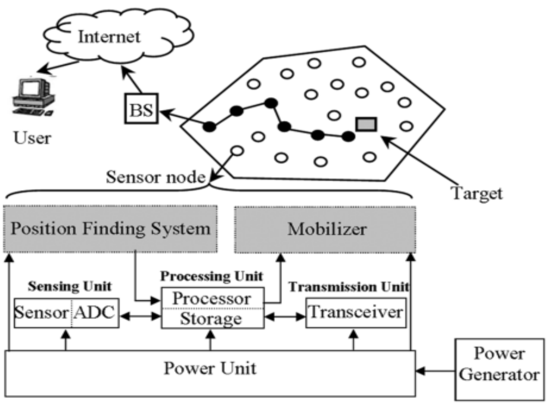

Figure 1. Sensor parts

The behavior of some routing algorithms is similar when it comes to reducing the total energy consumption in the network, particularly draining the network's regular energy [7]. These behaviors lead to network segmentation, as nodes connected to several parts waste battery energy more quickly than nodes connected to only one part of the network [8]. As a result, the transmission delay is typically reduced by using the same route in a protocol for subsequent connections. Therefore, the nodes' energy in this route is rapidly depleted [9], [10]. Due to their ability to decrease the overall energy drain, these algorithms often result in varying WSN energy usage. Therefore, using these algorithms results in a network partition that negates the advantages of WSN [9]. When specific nodes are inaccessible, the network part problem shows in Figure 2.

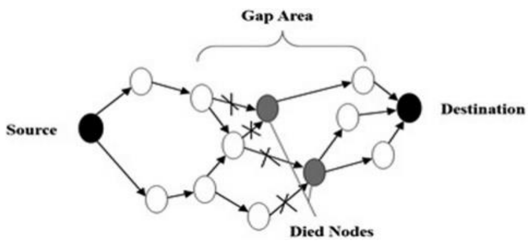

Figure 2. The network field partitioned because of the death of some nodes

WSNs lifetime is consumed immediately after the battery's energy is depleted in the critical nodes. Critical sensor nodes are usually located on many routes. The best route behavior minimizes energy consumption and distributes it proportionally across nodes so all network nodes are fatigued simultaneously [6]. Once the sensors' batteries are exhausted, they lead to a divide in the network and the end of its life. To develop a suitable route for these signals or to extend the network lifetime, it is necessary to provide a set of procedures for building a path for each node that allows it to send the data based on predetermined criteria [11], [12]. Consequently, the suggested approach tries to address the issue of balancing energy consumption while simultaneously decreasing the end-to-end delay and increasing the WSN's lifespan. To identify the best path from the node source to the destination node, this method employs the bacterial foraging optimization (BFO) algorithm. This is performed by picking the energy of the battery that has the longest lifetime and most power, as well as the lowest data transmission load. As a result, such intelligent network behavior would minimize the delay caused by arranging the data route each time. In the meantime, the consumption of energy is evenly distributed among the new paths discovered.

The rest content of this paper is as follows. The second section delves into related works and concepts. Section 3 summarizes the BFO algorithm. In section 4, the researchers discuss the route's suggested approach and its possible utility. The simulation results are described in section 5. The findings are listed in section 6 as the final stage.

2. RELATED WORKS

The lifespan factor in these networks is of great attentiveness to the performance calculation of their routing behavior [5]. Now, concentrating researchers are on the ways to reduce network energy consumption by proposing various types of protocols for the routing of WSNs. Therefore, the protocols have been suggested to choose the better route in the network for collecting and sending the detected data.

Tsai *et al*. [9] suggested that the distance of any route's hop must be reduced. As a result, the ratio of hop distance to the shortest path has declined. The proportionate decrease reduced the energy used to receive and send data across a network. Rana and Zaveri [13] proposed a routing transmission method to get a prolonged WSN lifetime. This method is designed by using the A-star algorithm to acquire an optimized route starting from the resource node to the destination node. The authors utilized the high-weight evolutionary algorithm (GA) in [14] as part of a transmission strategy in which the nodes control and monitor the volume of data transfer to identify and address network overpopulation. Wang *et al*. [15] tried to overcome the challenge of dynamic deployment by adopting a binary detection paradigm with two kinds of nodes inside the WSNs, mobile and fixed, relying on the binary detection model. The biogeography-based optimization (BBO) algorithm was the method they used. Hsu *et al*. [16] introduced the technique known as asynchronous sleep-wake scheduling opportunistic routing technology (ASSORT). The design proposed combined the opportunistic routing advantages with asynchronous sleep-wake scheduling. That enhances the reliability of transmission over the route of diverting. So, such transmission path behavior improves data transfer by extending the lifespan of WSNs. Alshawi [17] also provided a routing method that combines fuzzy logic and an artificial bee colony. In this protocol, it is used these two directions determine the route best by finding the next optimal node to generate the optimum path from the source node to the sink node.

The energy-aware spatial routing mechanism in the WSN was introduced by Huang *et al.* [18]. The method considers trying to decrease the energy loss during the routing end-to-end. The proposed protocol accommodates different geo-protocol to satisfy the list of anchors that rely on sensor nodes' projection distance to route data retransmission. The node sending a message depends on three elements to determine the routing: the characteristics of how energy is consumed, the measurement model for calculating the advanced energy cost, and geographic information. Therefore, it conforms to the value of the significance of conveyance to get the defined node. Shi *et al.* [19] suggested a successful strategy known as the data-driven routing protocol, which looked at the complications of mobility inside network fields that have portable sinks. The goal of the Data-driven Routing technique was to reduce the path planning overheads caused by sink movement. The high-level performance of packet delivery is maintained.

Abdulridha *et al.* [20], the routing technique focuses on the WSNs propagation. The fast simple flooding approach is the name of the routing protocol. It emphasizes energy efficiency as a critical design consideration for the WSN routing methods. After that, it shall not give any importance to other facets of the appointment. It reduces the end-to-end latency.

Moreover, this novel method of data routing into the sink is straightforward and quick. In addition, it doesn't need the usage of new instruments and also may implement with a simple arithmetical method. This protocol is one of the flat routing protocols and effectively addresses the principal impediments of flooding and conventional gossiping.

3. BACTERIAL FORAGING OPTIMIZATION ALGORITHM

The bacterial foraging optimization (BFO) algorithm is a newly discovered nature-inspired meta-heuristic optimization approach replicating the foraging behavior of Escherichia coli (i.e., E. coli) bacteria. Passino [21] first proposed it in 2002 while observing and analyzing the foraging behavior of E. coli bacteria. Foraging activity should occur so that the energy expended in searching for food is less than the energy acquired from eating it. Bacteria get their nutrients in the most efficient way possible to get the most energy per unit of time. One species of animal's foraging behavior may be very different from another's. Bacteria with a poor foraging strategy are destroyed from nature or relocated to other locations.

On the other hand, nature prefers bacteria with a good foraging approach. The bacterium contains from eight to ten tiny flagella that aid in the quest for food. Due to sensing the nutrient density in the environment, the flagella can move in either a clockwise or anticlockwise orientation. If the proper nutrients are sensed, the bacteria swim in that direction, and if sensing a harmful environment, they move away.

Chemotaxis, swarming, reproduction, and elimination-dispersal are four processes in the BFO model of bacteria's food-seeking behavior [22]. Chemotaxis is the movement of microorganisms toward a nutrient-rich site and avoids a potentially dangerous place. This is achieved by two sorts of motions, namely:

swimming and tumbling. During swimming, the bacteria will travel in the direction that was used in the previous stage, but the tumbling will trail in a different direction than the previous one. Bacteria in a swarming model move to a suitable or unsuitable environment. The Bacteria follow a collective behavior in which bacteria can be attracted to or estranged from the other bacteria by sending signals between cells [23]. Reproduction demonstrates a decrease in the number of bacteria that is less healthy. The bacteria population is affected if changes in nutrient concentration, the flow of water, and temperature. The elimination and dispersal step simulates the eradication and spread of bacteria due to abrupt environmental changes. It introduces some population diversity.

The working of the BFO algorithm depends on the accumulative efforts of all bacteria in a group for food searching. Every bacterium must be responsive to inducements in its foraging environment. The bacteria should be able to communicate with the other bacteria in the group. Each bacterium searches for its food by chemotaxis procedure, and chemotactic movement simulation is the basic working of this algorithm. The movement of Chemotaxis is a complicated combination of swimming and tumbling that keeps bacteria in regions where there's a good chance of getting nutrients in large quantities. This movement demonstrates the foraging ability of bacteria when they are in a group. Like the other strategies optimizations nature-inspired, this strategy also is based on the "survival of the fittest" philosophy. Animals' foraging changes their behavior of foraging. These changes simulate the action and response required to decrease energy waste per unit of time by following all constraint types. Bacteria with poor foraging behavior are eliminated in the next generation, or they may improve to a better age.

3.1. Chemotaxis

Chemotaxis is the strategy by which way any bacteria move to search for food. The bacteria movement is modeled based on the flagella's activity, which is divided into two kinds: tumbling and swimming. By using these two steps, bacteria can obtain an area containing nutrients in high concentrations while showing an improvement in fitness value [24]. If x represents the bacteria location, then *j(x)* represents the objective function that should be reduced. After the j^{th} chemotactic step, the position is updated as shown in:

$$x_i\,(j+1,k,l) = x_i\,(j,k,l) + C_i.\frac{\Delta i}{\sqrt{\Delta_i^T.\Delta_i}} \tag{1}$$

where *xi (j, k, l)* represents the i^{th} bacteria at the j^{th} chemotactic, k^{th} reproductive, and $l^{\,th}$ elimination-dispersal steps. *C(i)* is a scalar known as the run-length unit, which specifies the tumbling step size in random directions.

3.2. Swarming

If bacteria discover a nutrient-rich location, they should transmit a signal to other bacteria telling them to gather in this nutrient-rich area. In BFO, Swarming is used to model this strategy. Depending on the environment, bacteria send attractively or repelling signals to other bacteria depending upon the surroundings. The attraction and repelling of cell-to-cell are illustrated as follows:

$$J_{cc}(x, xi\,(j,k,l)) = \sum_{i=1}^{S}[-d_{attractant}.\exp\,(-W_{attractant}\sum_{m=1}^{d}(x_m - x_m^i)^2\,] + \sum_{i=1}^{S}[-h_{attractant}.\,exp\,(-W_{attractant}\sum_{m=1}^{d}(x_m - x_m^i)^2\,] \tag{2}$$

where *wattractant*,*dattractant*,*hrepellent*, and *wrepellent* are various coefficients representing the signal repulsion strength and attraction. The issue dimension is *d*, the overall swarm size is *s*, the point x_m in the *d*-dimensional search space, and the position of the i^{th} bacteria is x_m^i. After swarming, the resulting fitness value is added to the existing fitness value as:

$$J\,(i,j,k,l) = J\,(\mathrm{i},j,k,l) + jcc(x, xi\,(j,k,l)) \tag{3}$$

3.3. Redistribution

After the stage of Chemotaxis, the bacteria in a swarm are assumed to be nutrient-sufficient. The fitness value of each microbe shows its overall health. A high fitness rating indicates that a microorganism obtained adequate nourishment during its life cycle. Under the right conditions and temperature, this healthy bacterium can reproduce. They get longer and separate into two parts. These parts are identical to one another.

On the other hand, if the fitness value is poor, the bacteria do not get enough nutrients in their life cycle and are not healthy for reproduction; hence, they cannot continue. To simulate this stage, the population of bacteria is sorted based on the fitness value. One-half of the population with a low value of fitness will be filtered out. At the same time, the remaining bacteria will divide into two groups and begin discovering the foraging space from the same spot. After reproduction, the freshly created bacteria will replace the swarm's deceased bacteria, ensuring that the swarm's size remains constant.

3.4. Dispersal and elimination

The microbial environment changes abruptly or gradually. This harmful environment may cause some bacteria to die or spread to other places. Overall, the probability of dispersion is relatively low. Dispersed bacteria follow diverse pathways, so this process generates a swarm with a new group of bacteria. Pseudocode 1 shows the BFO Algorithm.

Pseudocode 1. The essential bacterial foraging optimization

```
Determine the objective function OF (.)
set the algorithm parameters such as p=dimensions; NC=chemotactic steps; Ns= swimming
 length; S=bacterium; Ned=elimination; Nr=reproduction steps; ped =elimination
 probability etc.
Set the lower and upper bounds [LB, UB] for each variable/dimension p
Randomly generate an initial population of bacteria, as follows
for each k^th reproduction step do
 for each j^th chemotactic step do
    for each i^th bacterium do
       for each d^th dimension do
pp (d, k, j, i) LB (d) + rand ∗(UB (d) - LB (d))
       end for
       apply correction algorithm to i-th bacterium, if infeasible
       calculate the fitness value of i-th bacterium
    end for
 end for
end for
Start the elimination or dispersal step...
for each l^th elimination-dispersal step do
 for each k^th reproduction step do
    for each j^th chemotactic step do
       for each i^th bacterium do
          Update the i^th bacterium by using (3.2) and (3.3), as
          ppi (j + 1, k, l) = ppi (j, k, l) + Ci(Δi/√(Δ_i^T.Δ_i))
          apply correction algorithm to i^th bacterium, if infeasible
          calculate the fitness value of newly generated bacterium i
       end for
       apply the swimming operation for Ns bacteria
       apply reproduction-elimination by sorting bacteria according to their fitness
       values and then split the top 50% and eliminate the remaining
    end for
 end for
end for
return the best result.
```

4. BACTERIAL FORAGING OPTIMIZATION ROUTING PROTOCOL (BFORP)

This paper's network topology is abstracted as a directed graph G (N, A). N represents all sensors in the network, and the links between nodes are represented by A. The sink collects data from all nodes within its transmission range [7]. In the sink, counts the routing table. Calculates and broadcasts the best routing table. Each node follows this table. The finding optimal path process is frequently broadcast via a network, sending data toward the sink from each node by following this routing table per round.

The routing table is calculated considering the current level of specific parameters in the node. So, the sensors must frequently submit reports on their value of parameters to the node of the sink. Then, a routing table can be chosen by the sink based on the updated data. A network's lifetime is an essential metric for WSN. When the sensor node exhausts the energy related to the proposed model, the communication links between the sink and the various sensor nodes are broken. This indicates the end of the life of the network. Since node survival relies on energy exhaustion, conserving the energy of the remaining sensors expands the network lifetime. The working steps of the proposed approach are assumed as shown in: i) Deployed the nodes randomly into the work field, and each sensor node is supposed to identify its position, neighbors, and sink. ii) Each sensor has the same amount of beginning power and a similar transmission range. iii) Every sensor node contains a certain amount of pending traffic in the sensor node's queue. A sensor node's queue contains traffic that the node has already committed to forwarding and the traffic of the applications.

The primary purpose of this study is to develop an energy-efficient routing protocol known as a bacterial foraging optimization routing protocol (BFORP). By lowering energy expenditures and distributing its uses fairly, the suggested strategy can lengthen the lifespan of WSNs. BFORP calculates and selects the best path from the source node to the sink based on the routing criterion (i.e., maximum remaining energy (RE), the minimum number of hops (MH) to the sink, and the lowest traffic load (TL)). The specified routing path is then utilized in the subsequent send processes; after each round, the state of each node engaged in that path is checked to see if the same path should be used for the following round. Thus, the suggested routing technique determines the route path of the sensor node that contains the data packet to be sent toward the sink shown in pseudocode 2 and the following steps:

a. Beginning at the source sensor nodes (the current sensor node) as the Bacterial Cell (BC) is to be expanded by locating all nearby nodes capable of immediate communication with the BC (in other words, BC is inside their broadcast range.).
b. When the sink is identified as a BC neighbor, it can relay the data it has gathered without making a further hop.
c. Calculating the fitness value for each sensor node that has been found and designating the BBC (best bacterial cell) with a high chemical concentration as the best BC neighbor node:
   - The distance (d) between each node (n) and the sink may be computed using the network's nodes coordinates (x, y) as follows:

$$d(n) = \sqrt{(x_s - x_n)^2 + b(y_s - y_n)^2} \quad (4)$$

   The coordinates (x, y) for the sensor nodes (n) and sink (s) are represented by the values (xn, yn) and (xs, ys), respectively.
   - Eq. (5) is used to get the fitness value for the next node (n):

$$fitness\ (n) = \alpha * RE\ (n) + \beta * 1/TL\ (n) + \gamma * 1/d\ (n) \quad (5)$$

   RE (n) represents the remaining energy of sensor node n; As for TL(n), it means the current traffic load for sensor node n; and the user defines the integer coefficients (α, β, and γ) to control each variable's effectiveness (metric).
d. Following that, BBC evaluates the data gathered from all nodes close to the BC node of the bacteria cell and selects the best node with the highest probability P concerning the probability given by:

$$P\ (ni) \frac{fitness\ (ni)}{\sum_J^N fitness\ (nj)} \quad (6)$$

   n is the neighbor sensor node, P (si) is the probability value of the sensor node (ni), and P (si) is the fitness value of the sensor node (ni).
e. When a collection of sensor nodes is found during the same expansion procedure, they are interchangeable and added to the expanded sensor node. The pack pointer is assigned to the expanded node for every node specified throughout the extension procedure.
f. Repeating steps 1 through 4 until the sink is identified, the packets after that are transmitted to the sink using the optimal route.

Pseudocode 2. BFORP for WSNs
```
1: n ← 0
2: if detect sensor (Starting from the source node)
3: BC ← current sensor
4: if BC <= sink ranges then
5: send the packet to the sink
6: else
7: determine N neighbor of BC bacteria cell sensor (when all N is within its range)
8: if N = 0 then
9: fail: drop this packet
10: else
11: assign N nodes to the BC bacteria cell
12: Fitness (n) ← a RE (n) + B 1 / TL (n) + Y 1/d (n) (calculate fitness for all nodes)
13: P ← fitness (node (i))/fitness (all rest nodes j to n) (Evaluate the probability
values for all BC)
14: Choose the best fitness
15: update the BC by taking the BBC information
16: Go to step 4
```

5. PERFORMANCE EVALUATION

To demonstrate the BFORP performance in maximizing network lifetime and balancing energy consumption. The simulation results of the proposed protocol are compared with those of both known protocols, namely PEGASIS [25] and LEACH [26], according to the same routing criteria. MATLAB software is utilized to carry out the system simulation processes.

5.1. Simulation setup

A hundred nodes are spread out in a topographical space with a 100 m^2 dimension. The nodes are deployed randomly with a transmission range of 20 m. A sink is located at (90 m, 90 m). Each sensor node in the network starts with an energy of 0.5 J. In all methods, the first-order radio model is employed, which is widely used in the routing protocol assessment area in WSNs [26]. In this model, receiving and transmission costs are defined by the formulas EnT(k)=Eelec•k+Eamp•k.d2 and EnR(k)=Eelec•k, respectively, k represents the amount of bit for each packet, the distance between the senders and receiver's nodes is represented by d. Eelec and Eamp are each bit energy dissipation in transmitting or receiving circuitry and the energy required for each bit each square meter for the amplifier to achieve a sensible signal-to-noise ratio (SNR), respectively. Simulations are prepared to apply the 50 nJ/bit and 100 pJ/bit/m2 values for Eelec and Eamp, respectively. The traffic load is assumed to be randomly generated with a range of [0...10] values at each node. Table 1 shows the parameters of the system in detail.

Table 1. Simulated variables

Variable	Value
Topographical Area (meters)	100 m × 100 m
Sink location (meters)	(90, 90)
Number of nodes	100
Limit of transmission distance (meters)	20 m
The initial energy of the node	0.5 J
Eelec	50 nJ/bit
Eamp	100 pJ/bit/m2
Packet	data size 2k bit
Number of transmission packets	2 x 103
Maximum traffics in the node's queue	10

5.2. Results of the simulation

Figure 3 shows the number of live nodes for each round of sending using three distinct ways. The proposed BFORP preserves more nodes live than LEACH and PEGASIS techniques after the same amount of packets are transferred. When all 2,000 packets are transmitted within the area, the suggested approach achieves a network lifetime that is almost nearly 60% higher than LEACH and higher than PEGASIS by practically 50%. Additionally, as demonstrated in Figure 3, the proposed way maintains a more significant number of nodes live than LEACH and PEGASIS techniques. Table 2 displays the time variance associated with the first dead sensor node using the three alternative protocols. Notably, the first dead sensor node appears significantly later in the proposed protocol than in other protocols.

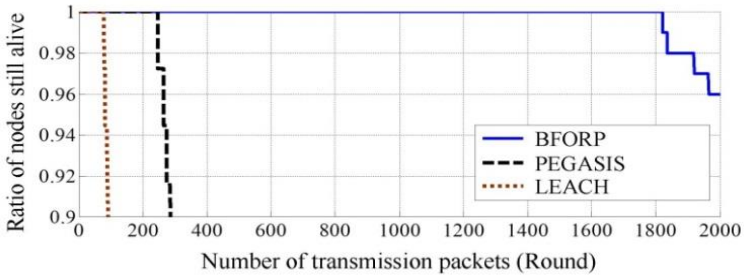

Figure 3. The sensors ratio remains alive

Table 2. The number of rounds that have died the first node

Approaches	LEACH	PEGASIS	BFORP
The first sensor that died	78	246	1820

Figure 3 and Table 2 show that the proposed strategy is more effective in balancing energy consumption and increasing network lifetime than LEACH and PEGASIS approaches. The average energy residual of the WSNs diminishes as the number of sending increases. Since the number of delivered packets increases, the suggested technique in terms of values produces higher average energy residual than LEACH and PEGASIS techniques. The proposed protocol makes the best energy balance in a WSN, as shown in Figure 4.

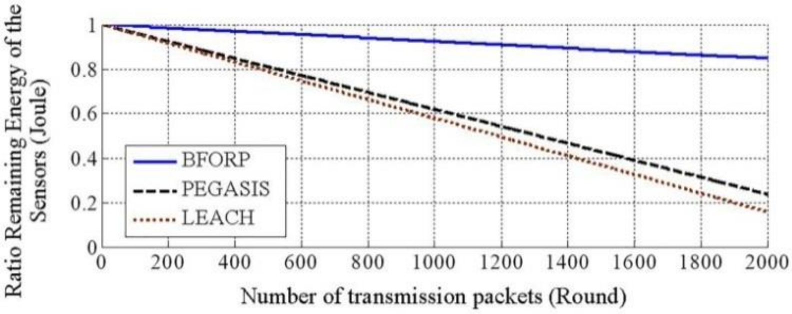

Figure 4. The ratio of residual power of nodes

The delay caused by the data packet transmission is an essential parameter for some applications where data must be collected in a short time. Figure 5 shows the proposed protocol overcomes others in terms of transmission speed. In addition, as demonstrated in Figure 6, the suggested protocol performs with less end-to-end latency than existing protocols. The shorter delay indicates energy savings and efficiency in transmitting crucial and secure data.

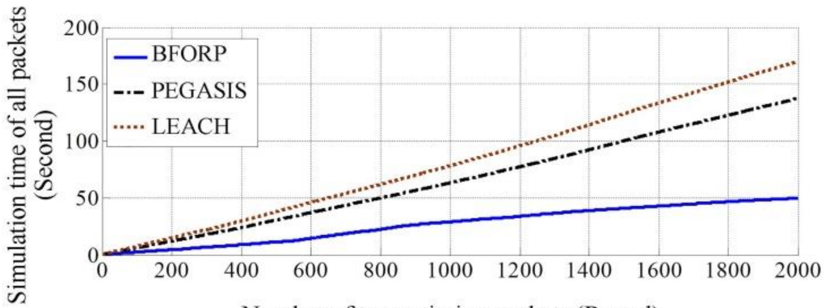

Figure 5. The time of simulations

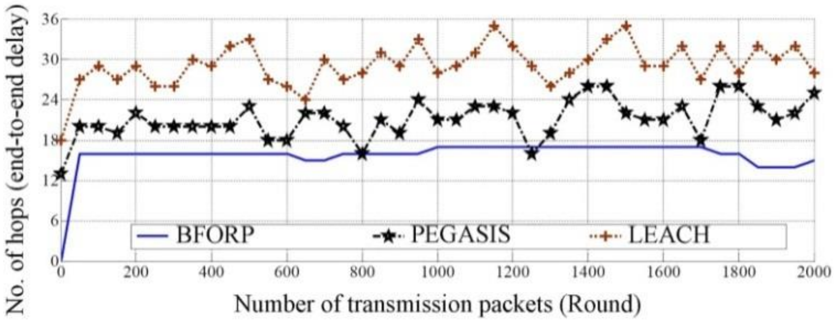

Figure 6. The delay of end-to-end

6. CONCLUSION

In WSNs, nodes have limited power from the battery. Thus, it's necessary to select techniques that perform the best use of available energy. The ways for determining routing paths significantly impact network lifetime, and this is one of the main WSNs features. Uneven power consumption is an A WSN's intrinsic issue. For performing the process transmission of data via a routing path that has been determined to be the best path to increase the network's total lifetime while minimizing the delay caused by the pathfinding process, a new method named bacterial foraging optimization routing protocol (BFORP) is proposed in this study. This new method is capable of determining the best routing path to be employed in the data transmission from the source node to a node of the sink, including one or more medium nodes, by selecting one node which contains the most excellent residual power, most negligible pending traffic load, and fewest hops. When the proposed method is compared to the other two ways, the findings reveal the performance of the proposed method, based on the same criteria, is significantly better than the two ways in terms of network lifetime and delay of the transmission.

REFERENCES

[1] N. Mittal, U. Singh, R. Salgotra, and B. S. Sohi, “A boolean spider monkey optimization based energy efficient clustering approach for WSNs,” *Wireless Networks*, vol. 24, no. 6, pp. 2093–2109, Aug. 2018, doi: 10.1007/s11276-017-1459-4.

[2] Z. Han, J. Wu, J. Zhang, L. Liu, and K. Tian, “A general self-organized tree-based energy-balance routing protocol for wireless sensor network,” *IEEE Transactions on Nuclear Science*, vol. 61, no. 2, pp. 732–740, Apr. 2014, doi: 10.1109/TNS.2014.2309351.

[3] V. Chauhan and S. Soni, “Mobile sink-based energy efficient cluster head selection strategy for wireless sensor networks,” *Journal of Ambient Intelligence and Humanized Computing*, vol. 11, no. 11, pp. 4453–4466, 2020, doi: 10.1007/s12652-019-01509-6.

[4] N. Wang and Z. Hong, “An energy-efficient topology control algorithm for earth building monitoring using heterogeneous wireless sensor networks,” *IEEE Access*, vol. 7, pp. 76120–76130, 2019, doi: 10.1109/ACCESS.2019.2921727.

[5] I. S. Alshawi, Z. A. Abbood, and A. A. Alhijaj, “Extending lifetime of heterogeneous wireless sensor networks using spider monkey optimization routing protocol,” *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 20, no. 1, p. 212, Feb. 2022, doi: 10.12928/telkomnika.v20i1.20984.

[6] I. S. Alshawi and I. O. Alalewi, “Lifetime optimization in wireless sensor networks using fdstar-lite routing algorithm,” *International Journal of Computer Science and Information Security (IJCSIS)*, vol. 14, no. 3, pp. 46–55, 2016.

[7] M. D. Aljubaily and I. Alshawi, “Energy sink-holes avoidance method based on fuzzy system in wireless sensor networks,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 2, p. 1776, Apr. 2022, doi: 10.11591/ijece.v12i2.pp1776-1785.

[8] M. Raghavendra and D. U. B. Mahadevaswamy, “Energy efficient routing in wireless sensor network based on mobile sink guided by stochastic hill climbing,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 6, p. 5965, Dec. 2020, doi: 10.11591/ijece.v10i6.pp5965-5973.

[9] M.-J. Tsai, H.-Y. Yang, and W.-Q. Huang, “Axis-based virtual coordinate assignment protocol and delivery-guaranteed routing protocol in wireless sensor networks,” in *IEEE INFOCOM 2007 - 26th IEEE International Conference on Computer Communications*, 2007, pp. 2234–2242, doi: 10.1109/INFCOM.2007.258.

[10] C. Wu, R. Yuan, and H. Zhou, “A novel load balanced and lifetime maximization routing protocol in wireless sensor networks,” in *VTC Spring 2008 - IEEE Vehicular Technology Conference*, May 2008, pp. 113–117, doi: 10.1109/VETECS.2008.36.

[11] S. Savitha, S. C. Lingareddy, and S. Chitnis, “Energy efficient clustering and routing optimization model for maximizing lifetime of wireless sensor network,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 5, p. 4798, Oct. 2020, doi: 10.11591/ijece.v10i5.pp4798-4808.

[12] I. Daanoune, A. Baghdad, and A. Ballouk, “An enhanced energy-efficient routing protocol for wireless sensor network,” *International Journal of Electrical and Computer Engineering*, vol. 10, no. 5, pp. 5462–5469, 2020, doi: 10.11591/IJECE.V10I5.PP5462-5469.

[13] K. M. Rana and M. A. Zaveri, “ASEER : A routing method to extend life of two-tiered wireless sensor network,” *International Journal of Advanced Smart Sensor Netwrok Systems (IJASSN)*, vol. 1, no. 2, pp. 1–16, 2011.

[14] C. Park and I. Jung, “Traffic-aware routing protocol for wireless sensor networks,” in *2010 International Conference on Information Science and Applications*, 2010, pp. 1–8, doi: 10.1109/ICISA.2010.5480571.

[15] G. Wang, L. Guo, H. Duan, L. Liu, and H. Wang, “Dynamic deployment of wireless sensor networks by biogeography based optimization algorithm,” *Journal of Sensor and Actuator Networks*, vol. 1, no. 2, pp. 86–96, Jun. 2012, doi: 10.3390/jsan1020086.

[16] C.-C. Hsu, M.-S. Kuo, S.-C. Wang, and C.-F. Chou, “Joint design of asynchronous sleep-wake scheduling and opportunistic routing in wireless sensor networks,” *IEEE Transactions on Computers*, vol. 63, no. 7, pp. 1840–1846, Jul. 2014, doi: 10.1109/TC.2012.282.

[17] I. S. Alshawi, “Balancing energy consumption in wireless sensor networks using fuzzy artificial bee colony routing protocol,” *International Journal of Management & Information Technology*, vol. 7, no. 2, pp. 1018–1032, 2013, doi: 10.24297/ijmit.v7i2.3354.

[18] H. Huang, G. Hu, and F. Yu, “Energy-aware geographic routing in wireless sensor networks with anchor nodes,” *International Journal of Communication Systems*, vol. 26, no. 1, pp. 100–113, Jan. 2013, doi: 10.1002/dac.1335.

[19] L. Shi, B. Zhang, H. T. Mouftah, and J. Ma, “DDRP: An efficient data-driven routing protocol for wireless sensor networks with mobile sinks,” *International Journal of Communication Systems*, vol. 26, no. 10, p. n/a-n/a, Feb. 2012, doi: 10.1002/dac.2315.

[20] M. S. Abdulridha, G. H. Adday, and I. S. Alshawi, “Fast simple flooding strategy in wireless sensor networks,” *Journal of Southwest Jiaotong University*, vol. 54, no. 6, 2019, doi: 10.35741/issn.0258-2724.54.6.12.

[21] K. M. Passino, “Biomimicry of bacterial foraging for distributed optimization and control,” *IEEE Control Systems*, vol. 22, no. 3, pp. 52–67, 2002, doi: 10.1109/MCS.2002.1004010.

[22] H. Chen, B. Niu, L. Ma, W. Su, and Y. Zhu, “Bacterial colony foraging optimization,” *Neurocomputing*, vol. 137, pp. 268–284, Aug. 2014, doi: 10.1016/j.neucom.2013.04.054.

[23] H. Chen, Y. Zhu, and K. Hu, "Adaptive bacterial foraging optimization," *Abstract and Applied Analysis*, vol. 2011, pp. 1–27, 2011, doi: 10.1155/2011/108269.

[24] H. Chen, Y. Zhu, and K. Hu, "Cooperative bacterial foraging algorithm for global optimization," in *2009 Chinese Control and Decision Conference*, Jun. 2009, pp. 3896–3901, doi: 10.1109/CCDC.2009.5191509.

[25] S. Lindsey, C. Raghavendra, and K. M. Sivalingam, "Data gathering algorithms in sensor networks using energy metrics," *IEEE Transactions on Parallel and Distributed Systems*, vol. 13, no. 9, pp. 924–935, Sep. 2002, doi: 10.1109/TPDS.2002.1036066.

[26] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*, 2000, vol. vol.1, p. 10, doi: 10.1109/HICSS.2000.926982.

BIOGRAPHIES OF AUTHORS

Abdulmalik Adil Abdulzahra received a B.Sc. degree in communication engineering from Iraq University College and an M.Sc. in Information Technology from South Ural State University, Russia. He is a member of staff at Al-Kunooze University College. He can be contacted at email: abdulmalik@kunoozu.edu.iq.

Baida'a Abdul Qader Khudor received a B.Sc. and M.SC. degree in computer science from the College of Science, University of Basrah, Basrah, Iraq. Mrs. Baida'a is a staff member of the College of Computer Science and Information Technology. She can be contacted at email: baidaa.khudur@uobasrah.edu.iq.

Imad S. Alshawi received a B.Sc. and M.Sc. degrees in computer science from the College of Science, University of Basrah, Basrah, IRAQ. He received a Ph.D. degree in wireless sensor networks at the School of Information Science and Technology, Information and Communication System Department, Southwest Jiao tong University, Chengdu, China. Mr. Alshawi has been a Prof. of Computer Science and Information Technology at the University of Basrah, for 20 years. He serves as a frequent Referee for more than fifteen journals. He is the author and co-author of more than 40 papers published in prestigious journals and conference proceedings. He is a member of the IEEE, the IEEE Cloud Computing Community, and the IEEE Computer Society Technical Committee on Computer Communications. He can be contacted at email: emad.alshawi@uobasrah.edu.iq.