Flower Pollination Optimization Algorithm for Wireless Sensor Network Lifetime Global Optimization

Marwa Sharawi, E. Emary, Imane Aly Saroit, Hesham El-Mahdy

Abstract*: As wireless sensor networks still struggling to extend its lifetime, nodes` clustering and nomination, or selection of cluster head node are proposed as solution. LEACH protocol is one of the oldest remarkable clustering approaches that aim to cluster the network`s nodes and randomly elects a cluster head for each cluster. It selects cluster heads but it is not responsible for proper clustering formation. In this paper we use the Flower Pollination Optimization Algorithm (FPOA) to propose a WSN energy aware clustering formation model based on the intra-cluster distances. The objective is to achieve the global optimization for WSN lifetime. Simulation results and performance analysis show that applying flower pollination optimization on WSNs clustering is more efficient. It is effectively balance power utilization of each sensor node and hence extends WSN lifetime comparatively with the classical LEACH approach.

***Index Terms*: Wireless Sensor Network; Energy-aware algorithm; Flower Pollination Optimization Algorithm; Hierarchical routing protocol.**

I. INTRODUCTION

Wireless Sensor Network (WSN) states as a complex homogenous telecommunication system consists of enormous number of tiny distributed battery constrained devices called sensors. Sensor nodes are efficiently collaborative with each other's to perform sensing and computing tasks form the surrounding application environment. They are communicating and interacting wirelessly. WSN`s lifetime are usually affected by the limitations of its sensors/nodes devices. Power scarcity is still the key challenge of research in the area of WSN telecommunication [1]. Clustering approaches and hierarchal routing protocols have been proposed to optimize the WSN`s lifetime. It transforms the WSN topological architecture from homogenous to heterogeneous deployment. Heterogeneous networks are more efficient than the homogeneous network in WSN. It assembles the sensor nodes into number of grouped called clusters, where each cluster has an only one associated node of centralization called cluster head.

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This greatly decreases the amount of the node`s consumed energy across the network and hence optimizes the power utilization and extends the network lifetime [2]. Low Energy Adaptive Clustering Hierarchy (LEACH) is a heterogeneous clustering based hierarchal routing protocol. It acts as; the randomly scattered nodes in homogenous WSN are grouped into clusters. Election process takes place to select cluster head based on the probability factor of the available energy in each node. The latter elected cluster head is in charge of the data aggregation from cluster nodes to base station. The communication functions between all the cluster members and cluster heads. Similarly cluster heads communicate to Base Station. LEACH relies on cluster formation and selection of a head for each cluster. WSN`s nodes are grouped into a number of clusters randomly and based on the available energy in each sensor node; nodes elect themselves to be chosen as a cluster head (CH). They are selected based on the highest residual energy in nodes. After clusters heads selection, the remaining nodes in the network can be assigned to join clusters based on their distances from the CH. Nodes in each cluster send data packets directly to the cluster head and hence each cluster head communicates with the base station (BS)/sink node [3]. LEACH algorithm operates a number of rounds and each round is divided to two phases. Setup phase, for CH selection, clusters formation, CSMA advertisement messages for the nominated CH and generating transmission schedule. Steady phase, for data packets aggregation, compression process and data packets transmission from CH to sink node. In each round a prior setting of the CH percentages P is used in the current round to select cluster head that neither its total energy is less than zero (dead node) nor it was a cluster head in the previous 1/P rounds. If the number of CHs <T(n), a sensor n becomes a CH for the current round, where T(n) is a threshold given by:

$$T(n) = \begin{cases} \dfrac{P}{1-P*(r \bmod \frac{1}{P})} & n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

Where;

P: is the percentage of the desired cluster heads.

r: is the current round.

G: is the set of nodes that have been cluster- heads (CHs) in the last *1/P* rounds.

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The problem with LEACH is the unevenly distribution of cluster heads, as well as the restriction to dominate the selection of the next cluster head to only nodes that wasn`t selected as a cluster head in the previous 1/P rounds. This results and causes a loss of chances to potential nodes that may have a high energy although it could be previously selected as a cluster head. Moreover, a large number of nodes with the same energy level can be nominated as a cluster heads for the next round. The disadvantage of this approach is that the entire nodes can be elected as a potential cluster heads with an expected high energy; however it does not guarantee the highest energy node in the network. Such a large number of the nominated cluster heads leads to a large number of clusters in WSN even though some of these clusters may have a few number of nodes. In order to overcome the challenges of LEACH to optimally select the CH and efficiently distribute clusters` nodes, this paper propose a flower pollination based optimization clustering algorithm for WSN. It is exposed for homogenous wireless sensor environment. It enhances the wireless sensor network lifetime by associating the cluster nodes according to the distance to the proper cluster head. The objective; fitness function, employed to minimize the intra-cluster compactness with minimum distance between nodes in same cluster. The rest of the paper is organized as follows. Section II explains the flower pollination optimization algorithm (FPOA). Section III introduces the proposed model. Section IV presents the simulation environment and the used assumptions of this work. Further, the simulation results and performance analysis of the proposed model comparatively to the LEACH protocol are shown in section V. Finally section VI concludes the research and gives future insight.

II. FLOWER POLLINATION OPTIMIZATION ALGORITHM (FPOA)

Flower pollination optimization algorithm (FPOA) is a recently invented optimization algorithm. It is inherited from the natural inspiration of pollination process. It mimics the process of flowering planets reproduction via pollination. As pollinators are mainly responsible for transferring pollens among flowers, pollination may occur in either local or global flow [4]. Pollination process can fall into two form categorizes; biotic and abiotic based on the pollens transferring mechanism. For biotic pollinations, flowers always depend on insects and/or animals as pollinators to transfer the flowering pollens. However for abiotic, flowers do not need any pollinators for the pollens transferring process [5, 6]. Naturally most of flowers considered to follow the biotic pollination form. This indicates that pollination or crosspollination process can take place by pollinators' movements or travelling long distances causing a global pollination. Travelling pollinators are usually follows the L'evy's flight behavior. Their flying steps are also follows the L'evy's flight distribution [7]. For each kind of pollinators, there is a specific type of flowers that it is responsible for, this called flower consistency. Flower consistency helps to minimize the cost of investigation of each pollinator. Evolutionary wise, it increase the transferring time of pollens and hence optimize and maximize the reproduction process. With the limited available memory of pollinators, flower consistency eliminates the learning, investigation and switching [8]. Furthermore, it can be considered as an incremental step based on the similarity/difference of any two flowers. The biological objective of flower pollination is to optimally reproduce a new enormous generations of the flower kind with the fittest features that ensure the kind`s survival. In order to ideally formalize the flower pollination algorithm, characteristics of pollination process, flower constancy and pollinator behavior should be approximated based on the following essential rules:

i. Global pollination achieved by L'evy's flights` travelling pollinators for both biotic and cross-pollination.
ii. Local pollination achieved abiotic and self-pollination.
iii. The new generation reproduction probability depends on the flower consistency and proportional to flowers` similarities/differences.
iv. The switch probability $p \in [0, 1]$ controls the shift between local and global pollination.

The simple flower pollination model assume that each plant has only one flower, and each flower only produce one pollen gamete. Thus, there is no need to distinguish a pollen gamete, a flower, a plant or solution to a problem [9]. According to the rules above, the flower pollination optimization algorithm (FPOA) can be represented mathematically as follows:

For global pollination, pollinators such as insects are intend to travel long distances to achieve the global optimization of reproduction based on flower consistency, this can mathematically achieve by:

$$x_i^{t+1} = x_i^t + L(x_i^t - g_*) \tag{2}$$

Where;

x_i^t : is the pollen i or solution vector x_i at iteration t.

g_* :is the current best solution found among all solutions at the current generation/iteration.

L: is the strength of the pollination, which essentially is a step size.

In using L´evy`s flight model to mimic the characteristic of the flying insects efficiently [7, 11]. That is, L > 0 from a L´evy`s distribution.

$$L \sim \frac{\lambda \Gamma(\lambda) \sin\left(\frac{\pi\lambda}{2}\right)}{\pi} \frac{1}{s^{1+\lambda}} \ (s \gg s_0 > 0) \tag{3}$$

Where;

$\Gamma(\lambda)$: is the standard gamma function. This distribution is valid for large steps s > 0.

For the local pollination, that achieved by abiotic and self-pollination based on flower constancy, the mathematical representation is as follows:

$$x_i^{t+1} = x_i^t + \epsilon(x_j^t - x_k^t) \quad (4)$$

Where;

x_j^t and x_k^t : are the pollens from the different flowers of the same plant species.

ϵ : is local random walk drawn from the uniform [0, 1].

For the fourth rule, the switch probability p ∈ [0, 1] is used to control the exchange of the pollination process from local to global and vice versa. The following figure 1 presents the pseudo code for the flower optimization algorithm using L´evy`s flight model [10].

```
Objective function min or max f(x), x = (x_1, x_2, x_3, ..., x_d)
Initialize a population of (n) flowers/pollen gametes with random solutions
Find the best solution g_* in the initial population
Define a switch probability p ∈ [0, 1]
Define stopping criteria (either a fixed number of generations/ iterations or accuracy)
While (t <MaxGeneration)
        For i = 1: n (all n flowers in the population)
      If rand < p,
raw a (d-dimensional) step vector L which obeys L'evy's distribution
obal pollination via x_i^{t+1} = x_i^t + L(x_i^t - g_*)
          Draw ϵ from a uniform distribution in [0, 1]
          Randomly choose j and k among all the solutions
          Do local pollination via x_i^{t+1} = x_i^t + ϵ(x_j^t - x_k^t)
      End if
          Evaluate new solutions
f new solutions are better, update them in the population
    End For
    Find the current best solution g_*
End While
Output the best solution found
End
```

Figure 1. Flower Pollination Optimization Algorithm (FPOA) pseudo code [10].

III. PROPOSED MODEL

The main challenge of WSN is to optimize the performance of the sensor nodes to save energy and hence extending the network lifetime. In order to achieve the objective of lifetime extension, we propose WSN clustering algorithm based on flower pollination optimization algorithm. It further enhances the wireless sensor network lifetime by associating the cluster nodes according to the distance to the proper cluster head. Objective to the intra- cluster distances, flower pollination algorithm optimizes the formation of clusters. It optimally associates the cluster`s nodes to each cluster based on the intra cluster distances optimization (fitness) function. Therefore, it selects the best CHs distribution that guarantees a routing optimization with the minimum communication links` cost between nodes within each cluster. The proposed model procedures are introduces as follows:

Start

Network Model

1. Deploy a WSN environment with a sized area *(M x N).*
2. Randomly scatter the energy constrained stationary sensor devices in the WSN deployed field *(static deployment).*
3. Assume that sensors are regularly sending data to destination node.
4. Assume that nodes located close to each other, and have correlated data.

Energy Model

5. Initialize all the nodes with their properties and set their initial energies based on the first order radio energy model [12].
6. Node are transmitting message with *k* bits through a distance *d* in symmetrical communication channels, and hence consume energy $E_{Tx}(k,d)$. Based on the distance *d* between the sender and receiver, the energy can be calculated as follows [12]:

$$E_{Tx}(k,d) = E_{Tx_{elec}}(k) + E_{Tx_{amp}}(k,d) \quad (5)$$

$$E_{Tx}(k,d) = \begin{cases} E_{elec} * k + E_{amp\_fs} * k * d^2 & d < d_0 \\ E_{elec} * k + E_{amp\_mp} * k * d^4 & d > d_0 \end{cases} \quad (6)$$

$$d_0 = \sqrt{\frac{E_{amp\_fs}}{E_{amp\_mp}}} \quad (7)$$

Where;

$E_{Tx}(k,d)$: is the transmission energy consumption k bits data to a node.

d: is the distance between sender and receiver nodes.

E_{elec}: is the energy dissipations per bit used to run the transmitter or receiver circuitry.

E_{amp_fs}: is the amplifier parameter of transmission corresponding to the free-space.

E_{amp_mp}: is the amplifier parameter of transmission corresponding to the two-ray models.

d_0 : is the transmission distance threshold.

On other hand, the reception dissipation energy for message of k bits for any node is expressed by $E_{Rx}(k)$. It can be calculated by the equation below due to running the receiver circuitry $E_{Rx\_elec}(k)$:

$$E_{Rx}(k) = E_{Rx\_elec}(k) = E_{elec} * k \quad (8)$$

Where;

$E_{Rx}(k)$: is the energy consumption in receiving k bits of data.

The amount of total energy consumption of wireless sensor network can be calculated as follows:

$$E_{total} = E_{node\ to\ CH} + E_{receive\ CH} + E_{CH\ to\ BS} + E_{CH\ fussion} \quad (9)$$

Where;

$E_{node\ to\ CH}$: is the total consumed energy of all the ordinary nodes to send data to their cluster head nodes.

$E_{receive\ CH}$: is the total consumed energy of all cluster

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head nodes to receive the data from ordinary nodes.

$E_{CH\ to\ BS}$: is the total consumed energy of all cluster head nodes to send the data to the base station.

$E_{CH\ fussion}$: is the total consumed energy of data fusion for all cluster head nodes.

Cluster Head Selection

7. For every obtained cluster from the flower pollination clustering a candidate CH is to be selected. The CH_i is selected as the node inside the cluster i with the most remaining energy; see equation (10).

$$CH_i = max_{nodes \in Ci}\ Remaing\ energy \quad (10)$$

Cluster Formation

8. Cluster formation is based on flower pollination optimization algorithm. In here, flower algorithm searches for optimal distribution of nodes on clusters.

9. The objective; fitness function, employed to minimize the intra-cluster compactness with minimum distance between nodes in same cluster.

$$J = \sum_{j=1}^{x} \sum_{i=1}^{k} \left\| x_i^j - c_j \right\|^2 \quad (11)$$

Where;

x_i^j: is the senor node i that belongs to the sensor j.

c_j: is the cluster head node for the cluster j.

$x_i^j - c_j$: is the distance between station position and cluster center.

So the goal of flower pollination optimization is to find the number of cluster centers *(N)* that minimize the above equation.

Data Transmission

10. Each cluster head is directly connects to the sink node (*base station*) which is a high-energy node, located far away from the sensor nodes in the point (X_{sink}, Y_{sink}).
11. Sensor nodes transmit their data packets directly to cluster head.
12. Each CH receives data from all of its cluster nodes and performs some necessary iteration for compression. It is directly connected to the sink node (*base station*) to forward the aggregated data packets.
13. Nodes die only when they are out of energy.

End.

IV. SIMULATION

The proposed model has been simulated and examined using MATLAB environment. We implement a homogenous WSN deployment squared range area *(100 x 100 m²). 100* stationary sensor nodes are scattered and distributed uniformly in the deployed region. The base station is fixed, motionless and stationary central device that is located far outside the WSN deployment sensing region in the point *(50,150)*. Referring to the LEACH structured model; in each cluster; nodes are responsible for sensing and collecting data from the surrounding environment and they are always have data to send. They have a fixed rate of sensation and directly connected to the corresponding cluster head. Cluster heads are responsible for data aggregation. In each cluster the length of data packets that sent from these sensor nodes to cluster head is 200 bits in our model. While the Length of packet that sent from each cluster head to base station is 6400 bits. They are communicating directly in one single hop with the base station. The simple first order energy consumption model is applied to all the WSN nodes. The experiment and energy parameters in this paper are listed in Table 1.

TABLE I. FPOA PARAMETERS

PARAMETER	VALUE
The standard gamma function λ	1.5
The local random walk $\epsilon \in [0, 1]$	$\in [0, 1]$
The switch probability $p \in [0, 1]$	0.8

TABLE II. LEACH PARAMETERS

PARAMETER	VALUE
Maximum number of rounds	9999
Desired percentage of cluster heads *P*	0.1

TABLE III. SIMULATION PARAMETERS

PARAMETER	VALUE
Network Size	100 x 100 m²
Number of nodes	100
Packet size from node to CH	4000 bits
Packet size from CH to BS	200 bits
Initial Energy *(E0)*	0.5 J/node
Minimum Energy	0.0001 J
Transmitter Electronics *(Eelec)*	50 nJ/bit
Receiver Electronics *(Eelec)*	50 nJ/bit
Data Aggregation Energy	50 nJ/bit
TransmitterAmplifier $(\sum fs)$ *if* $d \le d0$	10 pJ/bit/m²
Transmitter Amplifier $(\sum mp)$ *if* $d \ge d0$	0.0013 pJ/bit/m⁴

V. RESULTS AND PERFORMANCE ANALYSIS

In our simulation, metrics below are the examined performance metrics:

A.Stability vs. Instability period

Stability is the period from the start of the network operation and the first dead node. We also refer to this period as “stable region.” The instability is the period between the first dead node and last dead node.

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TABLE IV. WSN STABILITY AND LIFETIME COMPARISON

PROTOCOL	*LEACH*	*FPOA*
Stable region	291 rounds	1094 rounds
Unstable region	896 rounds	204 rounds
Network Lifetime	1187 rounds	1298 rounds

B.Number of packets sent to BS vs. round

Number of packets sent to BS that measure the performance of data gathering in WSN and ensures the success of data packets transmission across the network. This metric is practically measure the throughput of the network. It traces the number of received packets to the sink/Base Station node. Increasing number of these packets over the rounds shows the efficiency of the proposed technique. Optimization of throughput is mainly the WSN data aggregation efficiency.

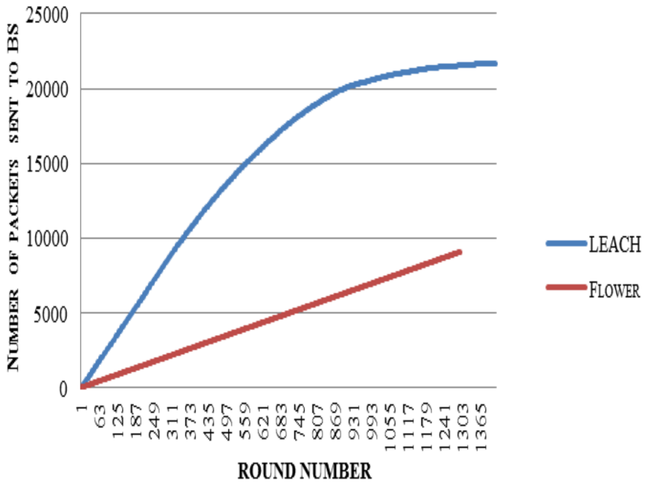

Figure 2. Number of packets sent to BS vs. round using LEACH vs. FPOA.

C.Number of alive and dead nodes per round

Number of dead nodes that mainly measure the lifetime of WSN as well as the optimization of consumed energy, this includes:

1. The death of first node: this measure the time period since the WSN deployment of nodes to the death of the first node. This time interval measures the start of the WSN coverage reliability degradation.
2. The death of 50% of the nodes: this measure the time period since the WSN deployment of nodes to the 50% node deaths. The metric indicates the consumed amount of the initial energy.
3. The death of all the nodes: this measure the time period since the WSN deployment of nodes to the death of the last node. It measure the WSN lifetime.

Simulated results represent network life time by showing number of dead nodes respected to number of rounds. Results show that nodes die out in LEACH quickly and in early rounds most of nodes die while the first node of the proposed technique dies in latter rounds. The proposed shows very promising results as the after a number rounds the network reach a stability period with a defined number of live nodes. The death of first node: this measure the start of the WSN coverage reliability degradation. The death of 50% of the nodes indicates the consumed amount of the initial energy. The death of all the nodes measure the WSN lifetime.

TABLE V. THE COMPARISON OF LIFETIME OF WSN NODES

LIFETIME OF WSN NODES	*ROUND NUMBER OF (LEACH)*	*ROUND NUMBER OF (FPOA)*
Area: 100 × 100, Nodes: 100, BSL: (50, 150)		
Round first node dies	292	1095
Round 50% node dies	744	1126
Round last node dies	1187	1298

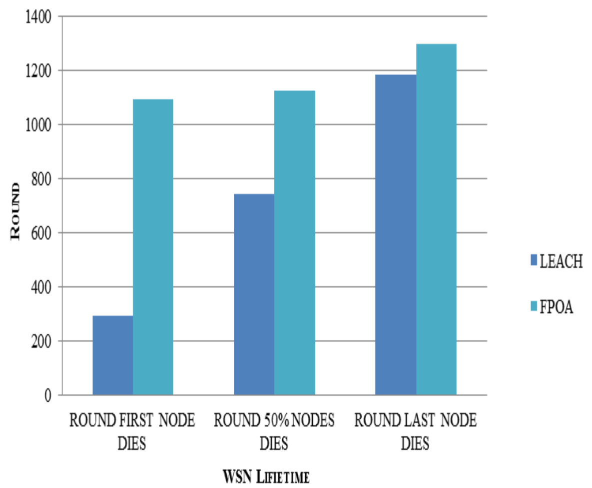

Figure 3. The comparison of lifetime of WSN nodes using LEACH vs. FPOA.

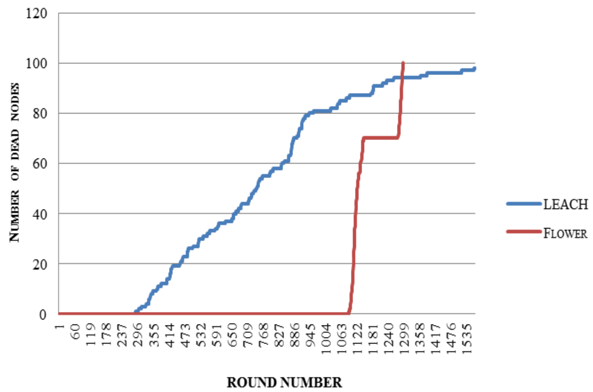

Figure 4. Number of dead nodes vs. round using LEACH vs. FPOA.

D.Sum of energy of nodes vs. round

Sum of energy of nodes vs. round: this measures the amount consumed energy across the WSN lifetime. The comparative analysis of the proposed technique as well as LEACH algorithm shows that LEACH

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has lower sum of total energy across all the rounds. WSN total energy has drastically drained. This implies that the proposed technique increased the total amount of energy of the WSN and hence provides more power to extend the network lifetime.

Moreover, in applying LEACH algorithm, WSN never reach a stability intervals with a fixed number of nodes that preserve an energy level across the network, while based on proposed technique, the network could preserve stable state with a little fluctuation. The proposed technique reached global maximization of WSN lifetime based on applying optimal selection of CH nodes which effectively preserve the global energy.

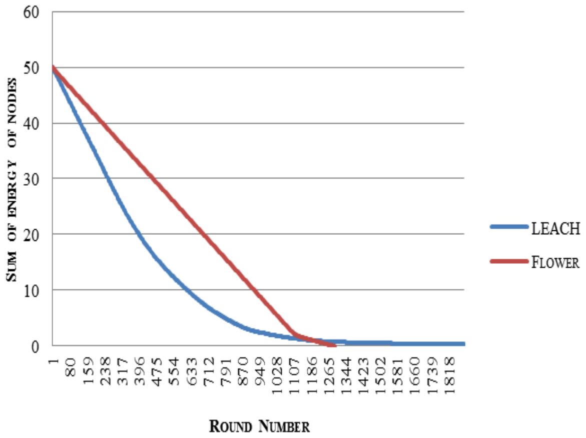

Figure 5. Sum of energy of nodes vs. round using LEACH vs. FPOA.

VI. CONCLUSION AND FUTURE WORKS

This paper introduces the evolutionary characteristics of flower pollination to solve unconstrained global optimization problem. We propose a flower pollination based optimization clustering algorithm for WSN. It is exposed for homogenous wireless sensor environment. It further enhances the wireless sensor network lifetime by associating the cluster nodes according to the distance to the proper cluster head. Objective to the intra- cluster distances, flower pollination algorithm optimizes the formation of clusters. It optimally associates the cluster`s nodes to each cluster based on the intra cluster distances optimization (fitness) function. Therefore, it selects the best CHs distribution that guarantees a routing optimization with the minimum communication links` cost between nodes within each cluster. This also optimize the sum of nodes energy (WSN total energy) based on the fixed number of cluster heads that minimize the overhead of data aggregation and the management and control signals for each cluster head. Numerical analysis and performance metrics as the throughput, network stability, energy consumption, number of dead nodes and WSN lifetime proved a better performance of the proposed model comparatively to the classical LEACH algorithm.

Results show an optimization in periods of network stability and network lifetime. This efficiently extends the WSN lifetime and noticeably reduces the energy consumption. The future work will focus on expanding the optimization of WSN based on multi-objectives approaches.

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