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MOBILE SINK BASED ON DIFFERENTIAL SEARCH ALGORITHM AND PEGASIS PROTOCOL TO ENHANCE NETWORK LIFETIME IN WIRELESS SENSOR NETWORKS

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Abstract. *Wireless sensor networks (WSNs) have been deployed in many applications that require long-term observation and deployment in hard-to-reach environments. The sensor node energy limitation can cause data transmission failure. Thus, energy efficiency becomes important in WSN. Sink movement can be a strategy to improve energy efficiency. However, determining the optimal sojourn point is a non-deterministic polynomial-time hard (NP-hard) problem. This paper proposes a mobile sink based on the differential search algorithm (DS) and the PEGASIS protocol (MSDSP) to enhance energy efficiency and network lifetime. In MSDSP, estimates of the remaining energy and distance from the sensor node to the sojourn point are the basis for selecting the chain leader (CL). Next, the DS algorithm determines the optimal sojourn points. The experimental results show that MSDSP has better performance than the comparison protocol; mobile sinks increase energy efficiency based on PEGASIS routing protocol (MIEEPB) and Revised MIEEPB protocol in energy efficiency and network life. Also, MSDSP can extend the period of stability.*

Keywords: Wireless sensor networks, Mobile sink, Differential search algorithm, PEGASIS, Sojourn point

1. Introduction.

Wireless sensor networks (WSNs) are a collection of sensor nodes that are connected to each other and can interact independently through wireless media. This technology has been applied widely in various sectors, such as military, forest fire observation, volcano observation, and mining. In general, WSN is involved in monitoring environments that are difficult to reach by humans and require a long observation time [1,2]. However, the heavy duties WSN are carried out by sensor nodes which have limitations in terms of resources, such as energy, bandwidth, and computation [3-5].

Energy is a significant problem for sensor nodes because sensor nodes only use batteries as an energy source. Meanwhile, recharging or replacing the battery is difficult due to the harsh observation environment. The short operation period of the sensor nodes can interfere with the observation process. Thus, energy becomes the main research topic at WSN [6]. The massive energy consumption of sensor nodes is the data transmission process [7]. Data transmission may fail because the sensor node shuts down suddenly when the sensor node transmits data to the sink directly.

Multi-hop data transmission is a strategy that can be used to reduce energy consumption levels. Sensor nodes far from the sink can send data to the sink via the nearest neighboring node. However, the sensor nodes close to the sink have a large load because the sensor nodes forward the data received from the neighboring sensor nodes to the sink.

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Therefore, sensor nodes close to the sink die faster than sensor nodes far from the sink [8,9]. This condition is known as the energy hole problem.

Power-efficient data gathering in sensor information system (PEGASIS) is a chain-based protocol proposed by Lindsey and Raghavendra [10]. In PEGASIS, each node only communicates with its nearest neighbor node. Data transmission starts from the sensor node farthest from the sink and is forwarded to the nearest neighbor node by relay to the chain leader (CL). The CL is the node that is responsible for transmitting data to the sink. Even though the data traffic to the sink is not congested, the energy consumption increases as the distance between the nodes increases. In addition, this strategy can lead to high delay times.

The strategy with mobile sink can be exploited to reduce the level of energy consumption in PEGASIS. This strategy reduces the CL load because the transmission distance to the sink becomes closer than the static sink. Another approach to considering is the multi-chain. Mobile sinks and multi-chain are the main ideas in mobile sink improved energy-efficient PEGASIS-based routing protocol (MIEEPB) [11] and Revised MIEEPB [12]. These two protocols divide the network area into four sub-areas. Then, the sink moves to the sojourn point in each sub-area. These sojourn points are static. The residual energy and the node's distance to the sojourn point are the basis for choosing CL. However, the sensor node near the sojourn point will be selected as CL repeatly. Moreover, energy consumption increases when sensor nodes around the sojourn point die.

In this paper, a mobile sink based on a differential search algorithm and PEGASIS is proposed to extend the operating time of the WSN. To select CL, the proposed protocol determines the weight based on the distance from the node to the sojourn point of the mobile sink and the estimated remaining energy of the selected node. In addition, the proposed protocol finds the optimal sojourn point based on a differential search algorithm.

We structure the remaining parts of this paper as follows. Section 2 provides a review of the protocol-based PEGASIS. Section 3 and Section 4 explain the energy model and network model that are used in this work. We present the proposed protocol and how the DS algorithm finds the sojourn points in Section 5. Section 6 discusses the simulation parameters and performance evaluation of the proposed protocol. Finally, some conclusions are given in Section 7.

2. **Related Works.**

Ramluckun and Bassoo proposed a new protocol combining PEGASIS and ant colony algorithms called PEG-ACO [13]. In this protocol, ACO is utilized to achieve an optimum chain. Meanwhile, the communication pattern between cluster head (CH) and cluster member (CM) uses the PEGASIS approach. The residual energy and the distance from the node to the sink are the parameters for selecting CH. Thus, the relatively close node to the sink has a high chance of becoming CH perennially. In addition, the CH that is located near the boundary of the network area has an enormous load.

Ali and Kumar offered a new approach that combined the firefly algorithm, PEGASIS, and neural networks [14]. At the start of the operation, the proposed approach establishes a grid topology of the same size in the network area. The firefly algorithm is used to select the CH in each grid. Before each CH sends data to the sink, CHs build a chain topology by adopting the PEGASIS protocol. Next, one CH is randomly selected as CL. This approach is good in terms of overhead, but the distribution load is unbalanced.

Wu et al. proposed an improved chain-based clustering hierarchical routing (ICCHR) in 2019 [15]. The ICCHR protocol combines the two concepts of the LEACH protocol and the PEGASIS protocol. ICCHR selects CH and forms a cluster based on LEACH. Residual energy, the distance of CH candidate to sink, and the distance of CH candidate to other nodes are parameters to select CH. Then, communication between CH is formed in a PEGASIS-based chain topology. In this approach, the CH, which is the closest to the sink, bears a considerable burden.

3. Energy Model.

The radio model proposed in [16,17] was used in this study. This radio model is commonly applied in many studies in WSN, including research in [10-15]. The selection of different radio models results in different assumptions regarding energy consumption in transmitting and receiving modes [16]. In this radio model, the data transmission process involves transmitter and amplifier components. We also consider two propagation models, namely the multipath fading and the free space propagation, to calculate the energy dissipation in the amplifier part. The transmission distance d and the threshold distance d_{th} affect the propagation model used. Suppose the data transmission distance d is less than the threshold distance d_{th}, and then free space propagation will be selected. Otherwise, multipath fading will be selected.

In the formula below, $E_{Tx\text{-}Elec}$ is the energy released by the transmitter component, E_{Elec} is the energy spent in the electronic circuit for 1-bit data, and b is the data length in bit. Furthermore, E_{Amp} is the energy output to the amplifier component, E_{Fs} is the energy consumed by free-space, E_{Mf} is the energy consumed by multipath fading. In this case, the energy consumed to transmit b-bit data over a transmission distance d can be formulated as follows:

$$E_{Tx}(b,d) = E_{Tx\text{-}Elec}(b) + E_{Amp}(b,d) \tag{1}$$

$$E_{Tx}(b,d) = \begin{cases} E_{Elec} * b + E_{Fs} * b * d^2, & \text{if } d < d_{th} \\ E_{Elec} * b + E_{Mf} * b * d^4, & \text{if } d \geq d_{th} \end{cases} \tag{2}$$

The following formula calculates the threshold distance d_{th}:

$$d_{th} = \sqrt{\frac{E_{Fs}}{E_{Mf}}} \tag{3}$$

On the receiving side, radio consumes energy to receive data:

$$E_{Rx}(b) = E_{Rx\text{-}Elec}(b) = E_{Elec} * b \tag{4}$$

Next, the radio performs data aggregation. If E_{da} is the energy used to aggregate 1 bit of data, then the total energy spent aggregating b-bits data is

$$E_{DA}(b) = E_{da} * b \tag{5}$$

4. Network Model.

In this research, the nodes are distributed over the network area in random positions. After all the nodes are spread out, the position of the nodes is fixed. Each sensor node also knows its location. All sensor nodes have the exact device specifications, so all sensor nodes have the same computing, communication, and sensing capabilities. Likewise, in terms of battery capacity, the initial energies of all nodes are the same. Since the communication in a WSN is symmetrical, the communication between the transmitter and receiver consumes the same energy.

The sink has extensive resources, including energy. In addition, the sink is mobile and knows all sensor nodes in the network area. The network area is divided into four sub-areas by sink. The sink moves from one sub-area to another to collect data from each CL at a constant speed. The sink visits all sub-areas in one round.

5. The Proposed Protocol.

The optimal sojourn point is a significant factor affecting energy efficiency and network lifetime. Finding the optimal sojourn point is an NP-hard problem [18]. The proposed protocol utilizes a differential search (DS) algorithm to control mobile sink stops at optimal sojourn points. The DS algorithm introduced by [19] was inspired by the herd migration patterns of organisms. The proposed protocols are named mobile sink based on DS algorithm and PEGASIS (MSDSP).

The operating times in the MSDSP are expressed in the round. Each round consists of four phases: the phase to determine the optimal sojourn point, the topology chain formation phase, the CL selection phase, and the data-gathering phase. At the start of the operation, the sink divides the network area into SA sub-areas of the same size. N sensor nodes are distributed randomly to the network area. After that, the sink sends a request message to all sensor nodes to obtain information on each sensor node living in the network area.

5.1. **Search for optimal sojourn point.** The information obtained from the sensor nodes becomes the basis for the sink to find the optimal sojourn point in the sa sub-area ($sa = 1, 2, \ldots, SA$). Furthermore, the information is sink-processed with the help of DS so that the sojourn point can be determined. The details of how the DS determines the optimal sojourn point in each sub-area are as follows.

1) Initialize population

Before the sink forms the initial population, it constructs a set of sensor nodes that are still alive and have the energy to operate in the sub-area. The set of sensor nodes in sa sub-area can be expressed as $SN_{sa} = \{sn_i | \forall i \in [1\ N_{\textit{allive-sa}}] \wedge E_{\textit{Res-sn}_i} > 0\}$, where sn_i is the sensor node i, $N_{\textit{allive-sa}}$ is the number of sensor nodes that are still alive in the sa and $E_{\textit{Res-sn}_i}$ is the residual energy of the sensor node.

Furthermore, sink builds up the initial population. In DS, the population is termed a superorganism, which is symbolized by $\textit{superorganism}_{sg}$ where sg shows the maximum number of generations. sg can be expressed as $sg = 1, 2, \ldots, \max SG$. Superorganism consists of $nPop$ artificial-organisms, namely X_o, $o = 1, 2, \ldots, nPop$. Here, $nPop$ is a number of population. Artificial-organism is an individual organism that references the best candidate solution as a sink sojourn point. In addition, the artificial-organism has as many elements as ($x_{o,d}$, $d = 1, 2, \ldots, D$) the problem dimensions D. The initial position of each artificial-organism is generated in the lower boundary range bb and upper limit ba with the following formula:

$$x_{o,d} = rand() * (ba_d - bb_d) + bb_d, \tag{6}$$

where $rand()$ is a random number in the range $[0, 1]$.

2) Evaluation

The purpose of this evaluation is to find the artificial organism that can give the best result. In this context, artificial-organism is the best at sojourn point that minimizes energy consumption. The evaluation of each artificial organism is carried out by considering the distance from the sink sojourn point to all sensor nodes in the chain topology. This consideration is essential so that data transmission from the farthest sensor node to the sink does not consume much energy. In addition, the data transmission time is fast. If D_{ms,sn_i} indicates the distance between the candidate sink sojourn point to the i sensor node and $D_{sn_i,sn_{i+1}}$ is the distance between sensor nodes, then the objective function R for evaluating the candidate sink sojourn points can be formulated as follows:

$$R = \min \left\{ D_{ms,sn_i} + \sum_{i=1}^{N_{\textit{allive-sa}}} D_{sn_i,sn_{i+1}} \right\} \tag{7}$$

In the minimum global search process, artificial-organisms move from one stopover site to another stopover site. These artificial organism individuals are randomly selected to move towards the target $donor$ $\left(donor = X_{\textit{random-shuffling}(o)}\right)$ to find a suitable stopover site as a migration site. The function $X_{\textit{random-shuffling}(o)}$ is used to change the order of the artificial-organism and the rate of change in this order is controlled by $scale$ value. $Scale$ value is obtained based on the results of gamma-random number generation [20]. If an artificial-organism finds a stopover site that is richer in resources than the stopover site found previously, it will move to that stopover site. In DS, the pattern of search for stopover sites by artificial-organisms adopts the Brownian-like random walk model [20]. The formula for determining the stopover site is as follows [19]:

$$StopoverSite = Superorganism + Scale(donor - Superorganism) \tag{8}$$

5.2. **Chain topology construction.** In MSDSP, the network area is divided into four network sub-areas. Each sub-area has one chain. The sink's information obtained from the sensor nodes is also used to form the chain topology in each sub-area visited by the sink. Based on this information, the sink calculates the distance from itself to each sensor node. The sensor node, which has the farthest distance from the sink sojourn point, is designated as the end node. The topology chain construction starts from the end node. Then, this end node looks for the nearest sensor node to establish a connection with it. Nodes that are already connected to the end node also look for the closest unconnected node in the chain topology to join them. This process is the same until all sensor nodes in the sub-area are connected in one topology chain.

5.3. **Chain leader selection.** To ensure the successful transmission of data to the sink, the CL should not shut down unexpectedly while performing its tasks. Therefore, each sensor node as a CL candidate in the topology chain must calculate the estimated residual energy after being selected as CL. Suppose $E_{Res\text{-}sn_i}$ is the residual energy of the sensor node i and E_{CL} is the energy required to perform the task as CL. In this case, if the sensor node i is selected as CL, the sensor node will have a residual energy $E_{Est\text{-}res\text{-}sn_i}$ of

$$E_{Est\text{-}res\text{-}sn_i} = E_{Res\text{-}sn_i} - E_{CL} \tag{9}$$

$$E_{CL} = E_{Tx}(b, d) + E_{Rx}(b) + E_{DA}(b) \tag{10}$$

After the sensor nodes have succeeded in calculating the estimated residual energy, the sensor nodes calculate the distance to the d_{ms} sink sojourn point. Furthermore, the sensor nodes calculate the weight of B_i with the following formula:

$$B_i = \frac{E_{Est\text{-}res\text{-}sn_i}}{d_m s} \tag{11}$$

Weights of sensor nodes in the sub-area are compared to determine which node is entitled to be CL. The node with the highest weight value has a great chance to become CL. Finally, the sensor nodes compute the distance from it to the parent node (d_{toPN}) and compare it to the distance from it to the sink sojourn point (d_{ms}). If ($d_{toPN} > d_{ms}$), the sensor node will be the secondary head and transmit data to the sink.

5.4. **Data-gathering.** Data collection by sink starts from transmitting token by CL to the end node. After the end node receives the token from the CL, the end node transmits the data and the token to the neighboring node. The exact process applies to all sensor nodes in the chain, so each sensor node aggregates data. Each sensor node compresses the aggregated data in a factor of 0.6 [21]. Next, the sensor node transmits data and token to the neighboring node up to the CL. Then, the CL performs data aggregation and sends it to the sink. This data-gathering phase follows the MIEEPB protocol data transmission scheme.

6. Simulation and Performance Evaluation.

6.1. **Simulation.** MSDSP performance evaluation is carried out by simulation in the MATLAB environment. MSDSP performance is compared to MIEEBP protocol [11] and Revised MIEEPB protocol [12] to assess MSDSP capabilities for energy efficiency and network lifetime. In this simulation, the network area size was 100 m × 100 m which was divided into four sub-areas. The maximum duration was 5000 rounds. In detail, all simulation parameters and their values are presented in Table 1.

Table 1. The detail simulation parameters

Parameter	Value
Size of area network	100 m × 100 m
Number of nodes	100
Initial node energy (E_o)	0.5 J
E_{Elec}	50 nJ/bit
E_{Fs}	10 pJ/bit/m^2
E_{Mf}	0.0013 pJ/bit/m^4
E_{da}	5 nJ/bit
Packet size	2000 bits

This experiment used the parameters of network lifetime, total energy consumption per round, and average residual energy per round to evaluate MSDSP performance. Network lifetime parameter is defined as the time span when sensor nodes start operating until all sensor nodes die [22]. Network lifetime is measured by three parameters, namely first node dies (FND), half of the nodes die (HND), and the last node dies (LND). These three parameters can be defined as follows.

- FND is the number of rounds when the node dies for the first time.
- HND is the number of rounds at which half of the nodes on the network die.
- LND is the number of rounds as the last node on the network dies.

6.2. **Performance evaluation.** Table 2 shows that MSDSP can produce higher FND, HND, and LND values than MIEEPB. In terms of FND, the MSDSP was able to score 1754 rounds. Meanwhile, MIEEPB and Revised MIEEPB produced FND at 1413th and 1446th rounds, respectively. A high FND value on MSDSP indicates that MSDSP has a more extended period of stability than MIEEPB and Revised MIEEPB. Likewise, for the LND parameter, MSDSP produced the LND value at the 4772nd round. Compared to MSDSP, the sensor nodes using MIEEPB and Revised MIEEPB are only able to work up to 4488th and 4474th rounds. Thus, the utilization of MSDSP on sensor nodes can increase the network lifetime by 284 rounds and 298 rounds compared to MIEEPB and Revised MIEEPB, respectively.

Table 2. The simulation results for network lifetime measurement

Protocols	Network lifetime parameters		
	FND	HND	LND
MSDSP	**1754**	**1891**	**4772**
Revisied MIEEPB	1446	1877	4474
MIEEPB	1413	1877	4488

Figure 1 and Figure 2 show the change in the number of nodes operating in each round. These two graphs also reinforce the information presented in Table 2 that MSDSP can extend network lifetime. Even in MSDSP, sensor nodes experienced a significant reduction in the number of operating nodes on the network compared to the Revised MIEEPB and MIEEPB. The increase in the number of dead nodes in MSDSP occurred from the 1972nd round to the 2628th round. At the same time, the sensor nodes using MSDSP consume much energy, as shown in Figure 3. Thus, the average residual energy in each round is lower than the Revised MIEEPB and MIEEPB, as shown in Figure 4.

This increase in energy consumption is due to the DS algorithm being stuck at the local minimum. Thus, the CL requires extra energy to transmit data to the sink because the sojourn point is not optimal. Modification of the DS algorithm is required to achieve a global minimum. In addition, nodes along the chain except for the end node expend

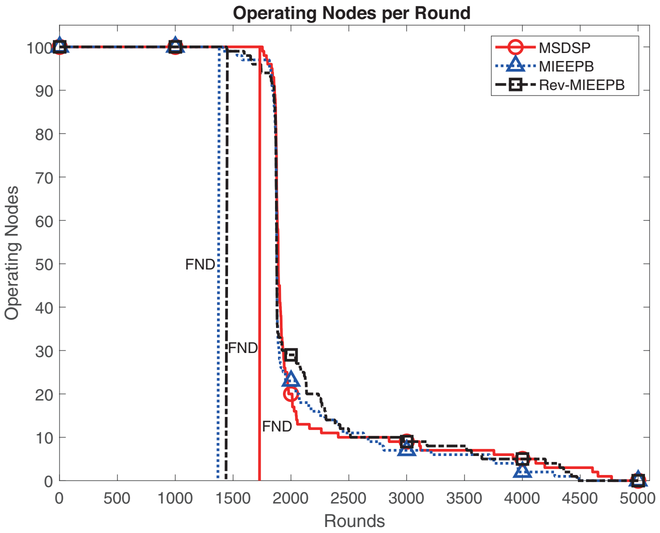

Figure 1. Operating nodes per round

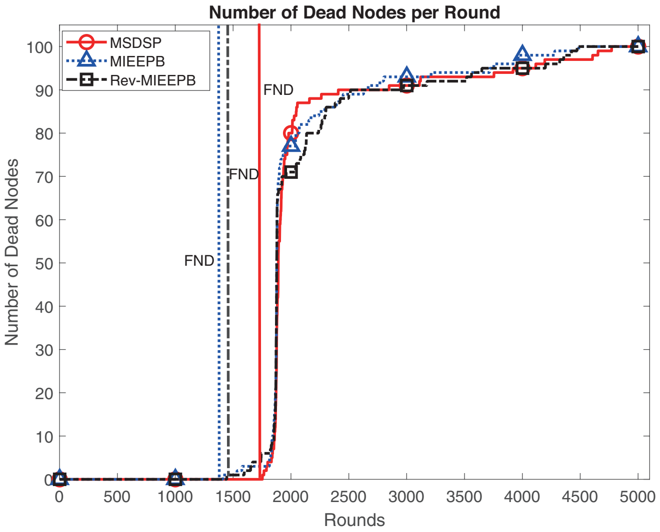

Figure 2. Number of dead nodes per round

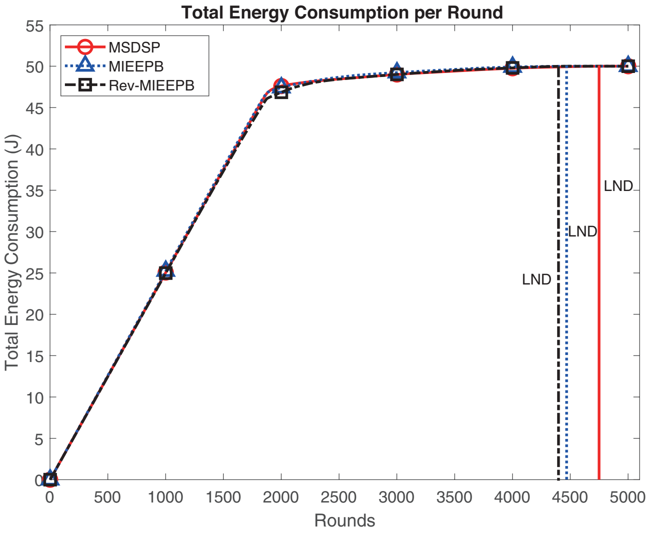

Figure 3. Total energy consumption per round

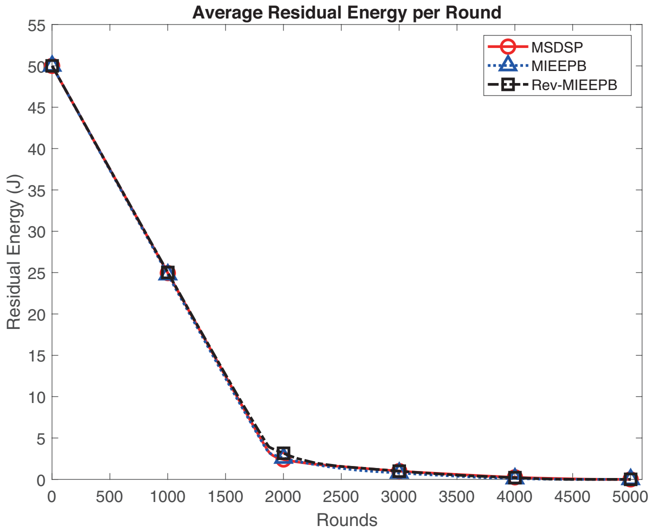

FIGURE 4. Average residual energy per round

energy to receive and aggregate data from neighboring nodes. The optimal number of nodes in the chain needs to be considered to reduce excessive energy consumption and delay time. However, when the operating time passes 2628 rounds, MSDSP can reduce the level of energy consumption.

The determination of dynamic sojourn points in the MSDSP contributes to energy efficiency. In MIEEPB and Revised MIEEPB, sojourn points are static. Thus, when the nodes around the sojourn point die, the CL distance to the sink becomes further away, and extra energy is required for data transmission to the sink. The decrease in the number of alive nodes on the network is accelerating.

7. **Conclusions.** In this paper, a mobile sink based on differential search algorithm (DS) and PEGASIS protocol (MSDSP) is proposed to improve energy efficiency and extend network lifetime. MSDSP searches the optimal sojourn points by utilizing the DS algorithm. Furthermore, the MSDSP selects CL based on the estimated residual energy of the CL candidate and the distance to the sojourn point. The simulation results show that MSDSP can improve energy efficiency, stability period, and extend network lifetime. The FND value is increased by 341 rounds and 308 compared to MIEEPB and Revised MIEEPB. Also, the LND value is increased by 284 rounds and 298 rounds compared to MIEEPB and Revised MIEEPB. For future work, we will consider determining the optimal number of nodes in a chain and improving the DS algorithm.

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