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LIFETIME OPTIMIZATION SCHEME FOR IOT SENSOR NETWORKS WITH DIFFERENT SENSING RANGE

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Abstract

Maximizing network lifetime and connectivity are challenging designs for IoT sensor networks. It has been used in many areas, especially for medical, agricultural, and environmental monitoring. Some monitoring applications require full coverage of sensing fields, such as security systems, while others require partial coverage of the sensing field, such as forest monitoring. The partial coverage of the sensing field can cause redundant sensor nodes to perform duplicate sensing. These nodes can be scheduled to sleep to increase network lifetime. Our protocol is called Lifetime Optimization Scheme for IoT Sensor Networks with Different Sensing Range (LODR). The proposed protocol eliminates redundant sensor nodes in order to avoid these sensor nodes performing unnecessary communication. It is a scheduling scheme for sensor nodes to determine the amount of overlapping sensing coverage between sensor nodes. It checks if the sensor node is entirely or partially covered by its neighbours. Our initiatives are focused on increasing network efficiency by minimizing energy consumption.

Keywords: Clustering, Energy efficiency, IoT sensor networks, Node scheduling.

1. Introduction

In recent years, wireless technology advances have allowed sensor nodes to evolve. Each sensor node has a sensing unit, a communication unit, and a processing unit [1-3]. Although usually, we use hundreds of these nodes to build IoT sensor networks, every sensor node needs to have a sensing unit that can detect events or changes in the environment [4-7], and the processing unit can process the data from the sensing unit. In addition, the transmission unit can transmit the sensed data to other nodes or a sink for further processing using radio communication [8, 9].

Sensor nodes report data to the sink. Due to the random deployment of nodes and most senor node applications requiring a very long battery lifetime, it is impossible to replace the batteries [10, 11]. In an IoT sensor network, energy is consumed by the three units in the sensor node, and the most energy-consuming operation is data sending and data receiving.

Designing an energy-efficient protocol is the primary concern in sensor networks which affects the network's lifetime significantly because sensor nodes' energy is limited and non-rechargeable [12-15].

This article proposes a Lifetime Optimization Scheme for IoT Sensor Networks with Different Sensing Range (LODR). This protocol considers the scheduling scheme problem for a given energy-constrained IoT sensor network where sensor nodes have different sensing ranges. It can eliminate redundant sensor nodes to avoid them performing unnecessary communication. It is a scheduling scheme for sensor nodes to determine the amount of overlapping sensing coverage between sensor nodes. LODR checks if its neighbours entirely or partially cover the sensor node, and also it avoids unnecessary, redundant sensing data, which saves energy and extends the network lifetime.

2. Related work

Singh et al. [16] suggest a heterogeneous network model improves the network life, consisting of 3 levels of wireless sensor networks. HetDEEC-3 uses three types of sensor nodes: supernodes, advanced, and normal nodes. HetDEEC-3 builds the network with clusters, and each cluster has cluster members. The cluster head was selected by using the threshold function and weighted probability. When comparing the performance of HetDEEC-3 with DEEC, we find that HetDEEC-3 is better than DEEC; it can save energy. However, this model has a large number of overhead controls.

Tang et al. [17] proposed a new data collection system based on the rate of overlapping sensor regions in wireless sensor networks. Since the data in a sensing area has a relatively high correlation, this scheme will collect data to eliminate redundancy and save energy. This scheme introduces three data collection rules: First, the top-level sensor nodes have priority over the lower-level sensor nodes. The top-level sensor gathers sensor nodes. Second, the free top-level sensor nodes select their gathering nodes from adjacent or parent sensor nodes. Third, data from each node is collected at most once. Therefore, the extra data is removed instantly, saving the sensor nodes' energy.

Diané et al. [18] propose the MR-LEACH protocol to improve energy consumption in sensor networks. This protocol uses measurement redundancy to save energy. The measurement redundancy is that a group of sensor nodes are in the same geographical region, sending the same sensor data. The protocol determines and collects the extra sensor nodes, and only a single sensor node transmits data in each redundant set. MR-LEACH can combine geographical proximity with measurement redundancy for energy saving and provides the best end-to-end delay.

Sarwesh et al. [19] proposed a structure with two types of nodes. The first type is normal nodes that can sense the field and collect data. The second type is that the relay node performs communication and calculation tasks. This structure provides a relay node to improve power consumption. It reduces data overload and the computational complexity of the sensor nodes. Based on the data traffic, the relay node is determined. If data traffic is low, the structure assigns a single relay node to three sensors, while in medium data traffic, a single relay node is allocated to two nodes. If the amount of data is high, the single relay node is assigned to one sensor node. The relay node selects the optimal path from the source to the final destination and finds the optimal path by looking at the remaining energy of the sensor node.

Hasan et al. [20] proposed a self-tuning method to create an energy-efficient protocol for low-power nodes. This approach focuses on managing energy dynamically while providing services. The node set is inactive to save energy, while the remaining active sensor nodes provide continuous monitoring. This algorithm first identifies the most effective sensor node, then determines the best sensor node in conjunction with the predefined sensor nodes.

Ganguly et al. [21] aim to design a reliable structure that determines the best route location and number of routes. The cultural algorithm was chosen to develop a reliable path for data transmission by determining the number of routers required and their locations. Multiple data can be monitored simultaneously, and data collected from all sensor nodes. The cultural algorithm provided a fast approximation of the optimal results.

Dong et al. [22] propose the RMER protocol. RMER selects fewer sensors in hotspot areas within the base station's single hop range, while RMER selects more sensors in areas without hotspots. These areas are relatively far from the base station that has enough energy. RMER directs the sensed data to the base station after collecting the data. It can reduce power consumption in hotspot areas and increase network life.

Chen et al.[23] introduced a unique strategy for increasing the lifetime of range-adjustable wireless sensor networks. The study presents the notion of range-adjustable WSNs, in which each sensor's range may be modified to save energy. This enables the sensors to modify their range based on current network circumstances, such as the distance to nearby sensors, in order to maximize the network's lifetime. The proposed NEDA method operates by representing the sensor network as a probabilistic graphical model PGM, with each sensor acting as a node. The PGM denotes the probability distribution across all potential sensor combinations that optimize network longevity. The NEDA algorithm then explores the space of potential sensor setups using a neighbourhood-based search. This entails picking a random sensor and modifying its range based on the current arrangement of nearby sensors. The revised configuration is then tested to see if it increases the network's lifetime. If so, the new configuration is approved; if not, it is denied.

Wu and Cai [24] used the Fibonacci tree optimization method FTOA. The proposed technique uses the FTOA to determine the best sensing schedule for the network. First, the protocol explores the space of potential sensing schedules using a tree-based approach, where each node in the tree represents a sensing schedule, and the Fibonacci sequence is utilized to calculate the tree's branching factor. The protocol then employs a fitness function to assess the energy usage and data accuracy of each sensor schedule in the tree. The fitness function is intended to strike a compromise between energy usage and data accuracy, ensuring that the network runs efficiently while giving correct data.

Bravo et al. [25] propose designing and deploying a Hybrid Network with Low Power and Long Range. It details designing and constructing a hybrid wireless sensor network for urban areas that combines low-power and long-range technology. The proposed hybrid WSN is made up of two types of sensor nodes: long-range nodes and short-range nodes. Long-range nodes employ LoRa technology, which has low power consumption and long-range communication capabilities. Short-range nodes use Zigbee, which has faster data speeds and reduced latency for local communication. The document details the hardware and software components of the sensor nodes, as well as the communication infrastructure used to gather data from the sensor nodes.

Karimi-Bidhendi et al. [26] offer a node deployment strategy for heterogeneous two-tier wireless sensor networks with a restricted communication range. The study describes a two-tier WSN architecture with two kinds of sensor nodes: high-power nodes and low-power nodes. The high-power nodes gather data, while the low-power nodes operate as data sensors, sending data to the high-power nodes. The suggested node deployment method tries to consume as little energy as possible while maintaining network coverage and connection. The algorithm uses a mathematical model to find the ideal number and location of high-power and low-power nodes in the network. The model considers a variety of aspects, including communication range, network structure, and energy usage.

Mukherjee et al. [27] suggested a sleep scheduling technique for imbalanced energy harvesting in industrial wireless sensor networks. The research then addresses the difficulty of uneven energy harvesting, in which certain nodes may gather more energy than others due to placement, orientation, or environmental variances. The suggested sleep scheduling method intends to balance sensor node energy consumption and harvesting while maintaining network connectivity. Based on its energy harvesting and consumption rates, the protocol employs a mathematical model to establish the ideal sleep schedule for each node. The model considers several aspects, including the unpredictability of energy harvesting, network structure, and energy consumption patterns.

3. Problem Definition

This protocol considers the scheduling scheme problem for a given energy-constrained sensor network where nodes have different sensing ranges. Let us assume that the nodes are randomly distributed in the sensing area. Each node has initial energy. We assume a sink is located outside the sensing field. The formal problem definition is given below: The IoT sensor network contains a set of sensors deployed in the sensor field. This IoT network is energy-restricted; schedule sensor node activities so that there is an opportunity to extend the network's life.

4. LODR Protocol

The proposed protocol eliminates redundant sensor nodes in order to avoid these sensor nodes performing unnecessary communication. It is a scheduling scheme for sensor nodes to determine the amount of overlapping sensing coverage between sensor nodes. LODR checks if its neighbours entirely or partially cover the sensor node. There are many different situations for locating the sensor nodes and their neighbours. For example, sensor nodes can have different sensing ranges. Consider the scenario illustrated in Figs. 1(a), (b), and (c): two cases come out from this scenario. In the first case, a sensor node is considered to be completely redundant if fifty percent or more of its entire sensing range is covered by its neighbours. In the second case, a sensor node is considered to be partially redundant if less than fifty percent of its entire sensing range is covered by its neighbours. We generalize this result suppose that node s_i is entirely covered by its neighbours, then each point on s_i must be covered by its neighbours.

Definition 1: In IoT sensor networks, a set of n nodes is randomly deployed in the M sensor region.

Definition 2: The sensor nodes in a sensor network are categorized into different types T_i based on their sensing range R_i.

Definition 3: Any two sensors s_i and s_j are in position (x_i, y_i) and (x_j, y_j), respectively.

Definition 4: Any two sensor nodes s_i and s_j have different sensing ranges. The node sensing region is centred around this node with a radius r_i.

Definition 5: The area covered by a node s_i is the area of sensing given by

$$A_i = \pi r_i^2 \tag{1}$$

Definition 6: s_i and s_j are neighbours if they can communicate with each other. The distance between s_i and s_j denote by

$$d(i,j) = \sqrt{|x_i - x_j|^2 + |y_i - y_j|^2} \tag{2}$$

Definition 7: All sensor nodes in M are aware of their location.

Table 1 list all the notations used in this paper.

Table 1. The notation used in this paper.

Notation	Definition
$\boldsymbol{s_i}$, $\boldsymbol{s_j}$	Sensor nodes
$\boldsymbol{N(i)}$	Neighbours of sensor node i
$\boldsymbol{r_i}$	Sensing radius of sensor node i
$\boldsymbol{d(i,j)}$	Distance between i and j
$\boldsymbol{T_i}$	Type of sensor nodes
$\boldsymbol{A_i}$	Area of sensing
$\boldsymbol{R_i}$	Sensing Range
$\boldsymbol{C_i}$	Communication range
$\boldsymbol{Z_{ij}}$	Area of intersection
$\boldsymbol{M}$	Sensing field

Our protocol requires a sensor network running in rounds. It includes three phases executed sequentially: construction, overlapping, and processing. The processing phase should be much longer than other phases.

Each sensor node chooses its role during the construction phase. The protocol then calculates the amount of overlapping sensing coverage between sensor nodes during the overlap phase. The processing phase's final goal is to lengthen the network's lifetime by lowering the number of control messages needed to connect with other sensor nodes. The processing phase can increase the number of sleeping nodes, which lowers the number of control messages.

4.1. Construction phase

In this phase, basic information is collected, as it is used in the following phase. Basic information consists of the sensor nodes' location and the sensor node's initial energy. At each round, modes are assigned to the sensor nodes. During network lifetime, a sensor node can be in one of these modes: Fully Inactive, Partially Inactive, Fully Active, and Partially Active. At the start of each round, each sensor node begins with Fully Active mode.

In Fully Inactive mode, the sensor node is put to sleep to save energy. A sensor node goes into Partially Active and Partially Inactive modes if our protocol determines that other neighbours partially cover the sensor node.

Information is communicated to the sink by LODR using update messages. The node turns Fully Active at the beginning of a round and sends an update message to the sink with its ID, remaining energy, current mode, and sensing range. The cluster head is chosen in this stage. While other sensor nodes with less energy are chosen as non-cluster heads, the LODR protocol chooses the sensor nodes with high residual energy as cluster heads.

For the current round, these nodes determine which cluster it belongs to. The signal strength obtained will determine this choice. As a result, the sensor nodes will determine which cluster head is closest and transmit the joining message.

In each round, the cluster heads should be engaged. The cluster administration and data collecting are the responsibilities of the cluster heads. They develop and send a schedule to decide when the sensor nodes should transfer data. A single cluster head and several sensor nodes are present in each cluster.

4.2. Overlapping phase

The LODR protocol verifies if the sensor nodes are redundant in the overlapping phase. If it is the case, the LODR protocol can execute the overlapping phase for partial coverage optimization. The following gives an example from Fig. 1 to illustrate the concept of the overlapping phase.

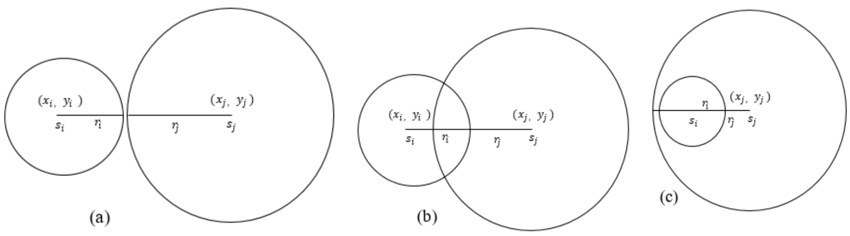

Fig. 1. Illustration of the coverage areas in different types of sensor nodes based on their sensing ranges.

As shown in Fig. 1, consider two neighboring sensor nodes s_i and s_j . Let notation (x_i , y_i) and (x_j , y_j) denote the locations of sensor nodes s_i and s_j. Let r_i and r_j denote the desired sensing radii and R_i and R_j denote the sensing range of sensor nodes s_i and s_j. z_{ij} denote the area size of the intersection region of the sensor $s_i's$ and $s_j's$ sensing ranges.

$$z_{ij} = |R_i \cap R_j| \tag{3}$$

The area covered by s_i is the area of the sensing disc given by (1). Based on sensing ranges, the sensor nodes are categorized into T_i different types. The sensing range of a s_i sensor node denoted by R_i . As shown in Fig. 1(a), the sensor nodes s_i and s_j are different types based on their sensing ranges. The distance between s_i and s_j is greater than $r_i + r_j$, they can communicate with each other but without any redundant area. In Fig. 1(b), the distance between s_i and s_j is lesser than $r_i + r_j$ and greater than max (r_i, r_j). There is a redundant area with existing sensor nodes s_i and s_j. In Fig. 1(c), the distance between nodes s_i and s_j is lesser than or equal to $(\max(r_i, r_j) - \min(r_i, r_j))$. The sensing area is redundantly covered by the sensor node, which has max (r_i, r_j). Let d indicate the distance between sensor nodes s_i and s_j. The possible values of d are $0 \leq d \leq (\max(r_i, r_j) - \min(r_i, r_j))$ and sensor node s_i is covered by the neighbor s_j. d should not be greater than $(\max(r_i, r_j) - \min(r_i, r_j))$.

It can be seen in Fig. 1(c) that if the sensor node s_i lies in the sensor $s_j's$ sensing range, then it is a redundant node. Therefore, the sensing range of the sensor s_i is covered by the sensor s_j. The node s_i is covered by a different type of sensor node s_j, then the sensor node s_j can present 100% of the sensing range of the sensor s_i . It depends on the position of the sensor node s_i and $0 \leq d \leq (\max(r_i, r_j) - \min(r_i, r_j))$. For a given pair of sensor nodes s_i and s_j , the redundancy level could be estimated as follow:

- $d > r_i + r_j$: Fig. 1(a) illustrates that the sensing range of s_i is not covered by the sensor node s_j.
- $d < r_i + r_j$: This case is illustrated in Fig. 1(b). Part of the sensing range of s_i is covered by s_j.
- $0 \leq d \leq (\max(r_i, r_j) - \min(r_i, r_j))$: This case is illustrated in Fig. 1(c). The sensing range of s_i is covered by the sensor node s_j.

If $0 \leq d \leq (\max(r_i, r_j) - \min(r_i, r_j))$ then the sensor node is potentially redundant; it switches to Fully Inactive mode until the next round.

If $d < r_i + r_j$ then the sensor node is already covered partially by other sensor nodes; it switches between two different modes until the next round. These modes are Partially Active mode and Partially Inactive mode.

If $d > r_i + r_j$ then the sensor node is not covered by neighbours; it switches to Fully Active mode until the next round.

4.3. Processing phase

The sensor life is the bottleneck of a lifetime of a sensor network. This phase extends the life of the sensor nodes by reducing the overlapping coverage region. Sensor node s_i can change its status to Fully Inactive mode or Partially Inactive mode only if there is some neighboring node that can cover its sensing range. The following introduces the concept of this phase.

The operation time of the IoT sensor network is divided into rounds. During the round, a sensor node can be in one of these modes: Fully Active mode, Partially Active mode, Fully Inactive mode, and Partially Inactive mode, as shown in Fig. 2.

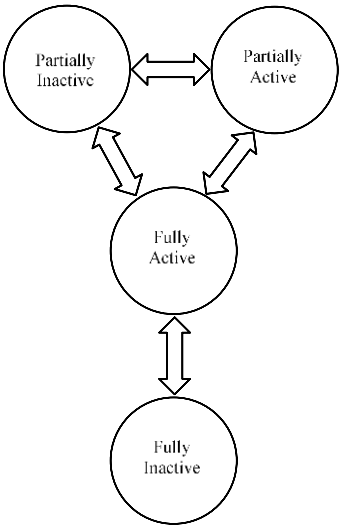

Fig. 2. State transition diagram of the sensor node.

The nodes are Fully Active at the beginning of each round. In every round, the chosen cluster heads must be engaged. Each Fully Active sensor node is in charge of maintaining its sensor region and interacting with the cluster's head. Data must first be delivered from the sensor nodes to the header because it is their responsibility to collect data from the monitoring region and provide the observed data directly to their header. The cluster's head gathers information from its participants and sends it to the sink. Each round should start with the chosen cluster heads in the Fully Active position. Due to the neighbours' sensor ranges being covered, if the node identifies itself as redundant, it will transition to Fully Inactive mode until the next round.

5. Simulation Results and Analysis

This section validates and assesses the effectiveness of the LODR that we built in OMNET. We simulate a network with sensor nodes spread randomly over an area of 100M X 100M, with a maximum of 100 sensor nodes. We take into account the following parameters in the simulation.

- The number of sensor nodes. We vary the number of sensor nodes from 50 to 100 to examine the impact of sensor node density on performance.
- The sensing range. The sensing range is changed from 5M to 10M.

5.1. Radio model

We employ a radio model comparable to the one shown in [28]. The power consumption and transmission calculations for n-bit data over distance d are shown in the following equations. The power dissipation for transmitting circuits is denoted by E_{Tx} in the equations, whereas the power dissipation for receiving circuits is denoted by E_{Rx}.

E_{DA} is the amount of energy used to gather data. Each sensor node has primary energy of 0.2 Joules. According to Eq. (4), each sensor node requires a certain amount of energy to send n-bit data over a distance of d.

$$E_{Tx}(n,d) = n * E_{elec} + n * \varepsilon_{fs} * d^2 \quad (4)$$

The amount of energy required to receive n-bit data across a distance of d per sensor node is

$$E_{Rx}(n) = nE_{elec} \quad (5)$$

The amount of energy required for data aggregation is

$$E_{DA} = 5nJ/bit/signal \quad (6)$$

E_{elec} stands for electronics energy, and ε_{fs} stands for free space power loss.

The parameters utilized in the simulation are listed in Table 2. Every simulation result is calculated using the average of ten separate simulations.

Table 2. Simulation parameters.

Parameter	Value
Size of sensing field	100M × 100M
Number of sensor nodes	50 ~ 100 nodes
Initial energy of each node	0.2 ~ 0.9 Joule
Sensing range	5~10 M
Base station location	50×175
E_{elec}	50 nJ/bit
ε_{fs}	10 pJ/bit/m^2
Size of a data packet	500 bytes
Size of info packet	25 bytes

We discuss simulation results where we use different types of sensor nodes, the different values of T_i that determine the type of sensor nodes in the network. For T_i = 2, 3, 4, 5, and 6, the sensor nodes can be divided into 2, 3, 4, 5, or 6 types based on their sensing ranges. For T_i = 2, the model describes two types of sensor nodes; each type has 50 sensor nodes. The radiuses of the sensing range of type1 and type2 nodes are 5 M and 6 M, respectively. For T_i = 3, the model describes three types of sensor nodes; the number of sensor nodes in each type is 33 sensor nodes. The radiuses of the sensing range of type1, type2, and type3 nodes are 5M, 6M, and 7M, respectively. For T_i = 4, the model describes four types of sensor nodes; each type has 25 sensor nodes. The radiuses of the sensing range of type1, type2, type3, and type4 nodes are 5M, 6M, 7M, and 8M, respectively. For T_i = 5, the model describes five types of sensor nodes; each type has 20 sensor nodes. The radiuses of the sensing range of type1, type2, type3, type4, and type5 nodes are 5M, 6M, 7M, 8M, and 9M, respectively. For T_i = 6, the model describes six types of sensor nodes; each type has 16 sensor nodes. The radiuses of the sensing range of type1, type2, type3, type4, type5, and type6 nodes are 5M, 6M, 7M, 8M, 9M, and 10M, respectively.

5.2. Evaluation of energy consumption

The capacity of LODR to save energy is assessed in this section using initial energy of 0.9 Joule. As a result, the network lifetime, average energy consumption per round, and sensor node stability period are chosen as the performance measurements. The energy consumption of the LODR and LEACH protocols is compared in Fig. 3. The number of rounds is shown on the x-axis, while the y-axis shows how many joules of energy were used by the sensor nodes. LODR outperforms LEACH. As a result, energy usage is substantially lower than it is for LEACH.

Furthermore, it is evident that as the number of rounds increases, the energy consumption of LODR increases slowly while the energy consumption of LEACH increases rapidly. This is because all the sensor nodes stay in active mode in LEACH. As a result, as shown in Fig. 4, LODR achieves reduced average energy consumption compared to other protocols.

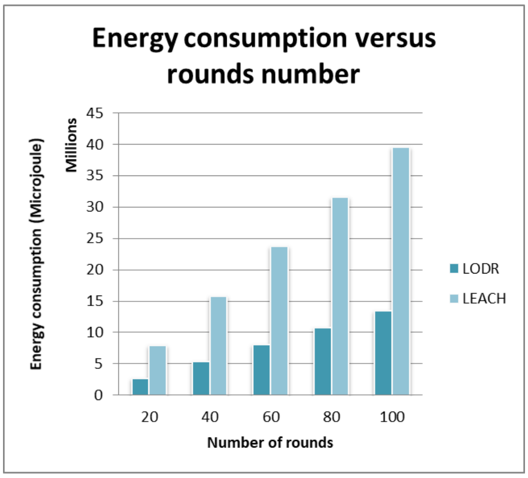

Fig. 3. Energy consumption of sensor nodes.

5.3. Evaluation of stability period

In this section, we use the stability period as a performance measure to evaluate protocols. The stability period represents the number of rounds from network initialization to the death of the first node. We vary the sensing range between 5 M and 10 M. For example, when T_i = 2, the model describes two types of sensor nodes; each type has 50 sensor nodes. The radiuses of the sensing range of type1 and type2 nodes are 5 M and 6 M, respectively. As seen in Fig. 5, LODR performs better than the other protocol regarding the stability period. This is because LEACH considers the residual energy of sensor nodes, which has a negligible impact on the stability period. On the other hand, LODR dynamically adjusts the mode of sensor nodes. Due to the reasons mentioned above, the stability period in the LODR protocol is long as it consumes relatively less energy. From the figure, we can see the LODR has the possibility of collecting data from the entire network up to round 98 with the sensor nodes alive in the sensor network, while in the LEACH protocol, the first node death occurred in round 39.

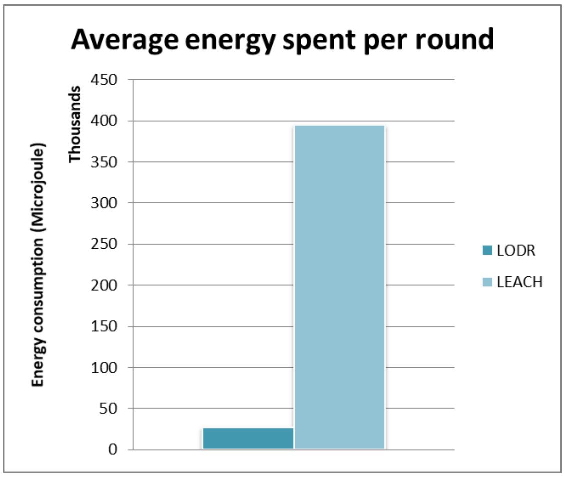

Fig. 4. Average energy spent per round.

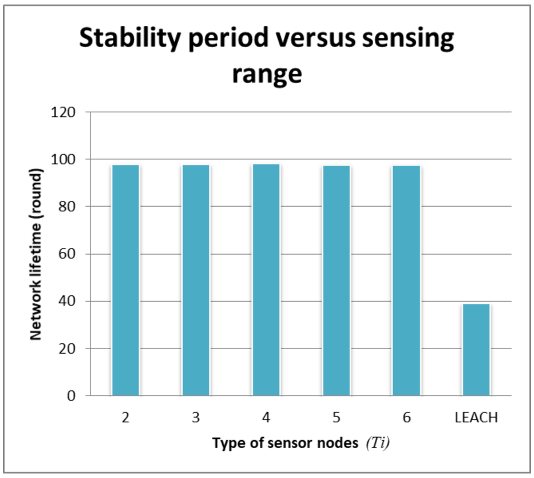

Fig. 5. Stability period.

5.4. Evaluation of network lifetime

The performance metric used in this section to evaluate protocols is the network lifetime, where network lifetime is represented by the number of rounds from network initialization until the death of 80% of the sensing nodes. Figures 6 and 7 show dead sensor nodes during the network lifetime. The half-dead sensor nodes for T_i =2, 3, 4, 5, or 6 die at 123, 136, 151, 172, and 186 rounds, respectively, and

80% of sensor nodes die at 128, 141, 156, 178, and 196 rounds, respectively, while the half dead sensor nodes for LEACH protocol die at 52 rounds and 80% dead sensor nodes for LEACH protocol die at 55 rounds.

Figures 6 and 7 demonstrate that compared to sensor nodes in the LEACH, those equipped with the LODR protocol operate more continuously. It is evident from Figs. 5, 6, and 7 that LODR becomes more effective as the network lifetime and stability period lengthen. The data transferred to the sink is shown in Fig. 8. The x-axis shows the different types of sensor nodes, while the y-axis shows the quantity of data transferred to the sink. The graph demonstrates that when compared to the LEACH protocol, the LODR protocol transmits more data to the sink.

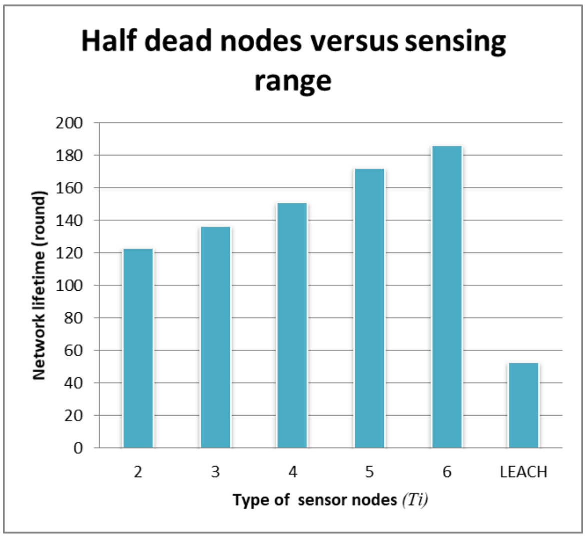

Fig. 6. Network lifetime – half dead sensor nodes.

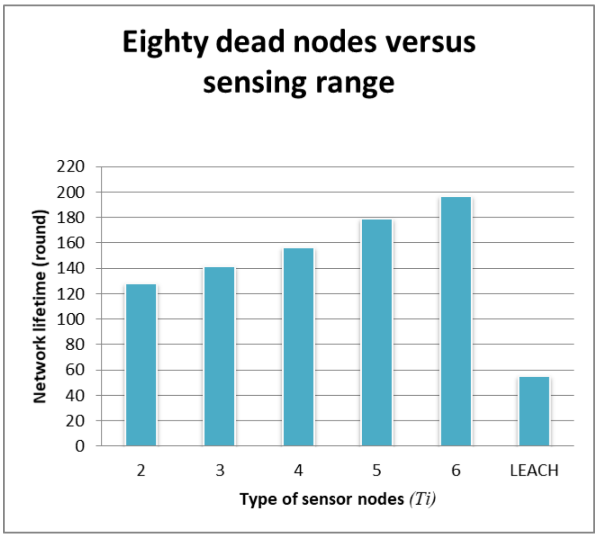

Fig. 7. Network lifetime – eighty dead sensor nodes.

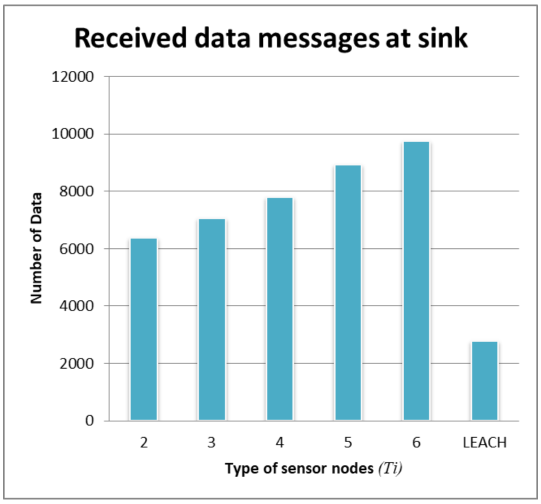

Fig. 8. Number of data messages received by the sink.

5.5. Evaluation of active and inactive sensor nodes

In this section, the active and inactive sensor nodes are evaluated by changing the number of sensor nodes between 25 and 100, with an increase of 25, when the sensing range varies between 5M to 10M. Figure 9 shows several Fully Active, Partially Active, Fully Inactive, and Partially Inactive sensor nodes.

According to this chart, when the number of sensor nodes rises, the proportion of Fully Inactive, Partially Inactive, and Partially Active sensor nodes will rise. In contrast, the proportion of Fully Active sensor nodes will drop. This is because when more deployed sensor nodes are used, there are more redundant sensor nodes. These nodes will be classified as redundant sensor nodes by the LODR protocol. Therefore, they will be fully or partially inactive for the current round since that of their neighbours entirely or partially covers their sensing range.

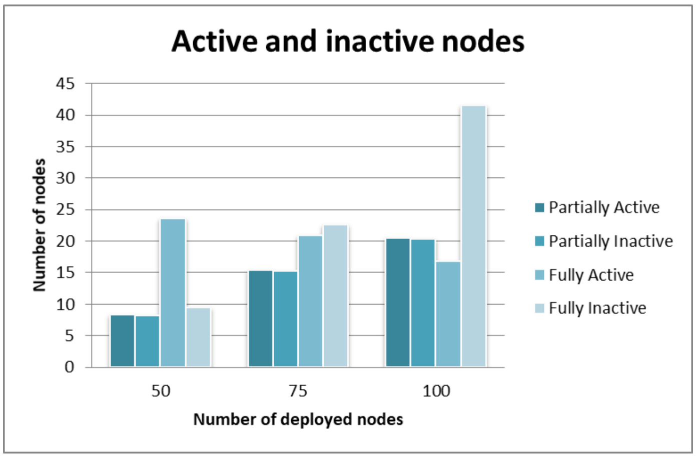

Fig. 9. Active and inactive nodes versus a number of deployed nodes.

We change the sensing range between 5M and 10M to examine the impact of the sensing range on the active and inactive nodes. Figure 10 depicts the impact of changing the sensing range on the quantity of active and inactive nodes.

As illustrated in this chart, the number of Fully Inactive sensor nodes will increase when the detecting range widens. In contrast, the number of Partially Active, Partially Inactive, and Fully Active sensor nodes will drop.

The redundant nodes' probability is considerably increased by the deployed nodes' expanded sensing range. Therefore, these nodes will be referred to as redundant sensor nodes by the LODR protocol. However, they will be fully or partially inactive for the current round because their neighbours entirely or partially cover their sensing ranges.

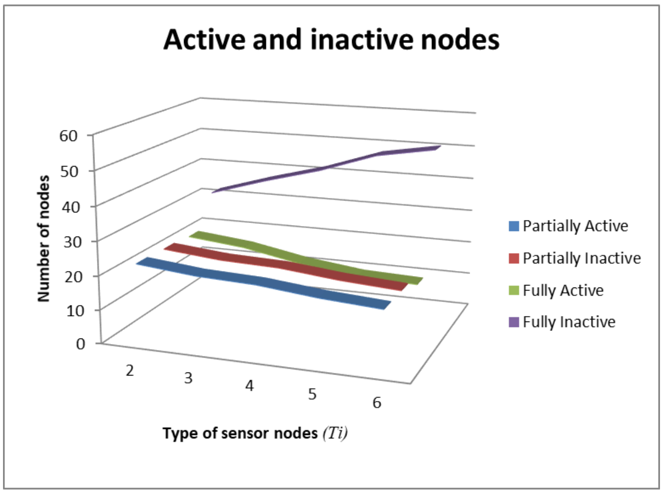

Fig. 10. Active and inactive sensor nodes versus the type of sensor nodes.

6. Conclusion

Since nodes of wireless sensors are low-power, designing IoT sensor network protocols requires protocols that reduce energy consumption, as this issue is essential when designing protocols. Therefore, we proposed Lifetime Optimization Scheme for IoT Sensor Networks with Different Sensing Range (LODR), an energy-efficient protocol for IoT sensor networks. This protocol aims to maximize the lifetime of the sensor network by reducing energy consumption.

The proposed protocol eliminates redundant sensor nodes in order to avoid these sensor nodes performing unnecessary communication. It is a scheduling scheme for sensor nodes to determine the amount of overlapping sensing coverage between sensor nodes. LODR checks if its neighbours entirely or partially cover the sensor node. We used a simulation model for the wireless sensor network. This model contains several randomly distributed sensor nodes. When comparing the LODR with the LEACH protocol, we used four measures of comparison: network lifetime, power consumption, stability period, and active and inactive sensor nodes. Simulation results showed that LODR outperformed LEACH in all metrics. Simulation results confirm that LODR can provide energy efficiency that meets the limitations of IoT sensor networks.

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Nomenclatures

A_i	Area of sensing
C_i	Communication range
$d(i,j)$	Distance between i and j
E_{elec}	Electronics energy
M	Sensing field
$N(i)$	Neighbours of sensor node i
R_i	Sensing Range
r_i	Sensing radius of sensor node i
T_i	Type of sensor nodes
s_i , s_j	Sensor nodes
Z_{ij}	Area of intersection

Greek Symbols

ε_{fs}	Free space power loss

Abbreviations

IoT	Internet of Things

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