Journal of Theoretical and Applied Information Technology
15th September 2024. Vol.102. No. 17

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

DATA REDUNDANCY ELIMINATION FOR ENERGY SAVING IN WIRELESS SENSOR NETWORKS USING CIRCLE INTERSECTION PROBLEM

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ABSTRACT

Wireless sensor networks play important roles in several monitoring and surveillance applications. These networks have important constraints, such as limited battery power in sensors. Hence, it is necessary to develop methods for saving battery power and enhance the network lifetime. The protocol low energy adaptive clustering hierarchy is an important clustering centered algorithm to improve the network lifetime. The algorithm reduces energy dissipation during inter-cluster data communication. Recently, evolutionary based energy efficient clustering methods, such as Flower Pollination Algorithm based Clustering method, Harmony Search based clustering algorithm, and Enhanced Flower Pollination based Fuzzy Inference System algorithm are proposed to enhance the lifetime of network. However, the methods do not consider data redundancy at the intra-cluster transmissions. In this paper, an energy saving mechanism is presented by considering the data redundancy at the sensor members within the cluster. The circle intersection problem is modelled for wireless sensor networks to decrease the energy expenditure during data transmission between sensor nodes and cluster heads. In addition, performance analysis of proposed method is presented. Simulations of the network are created, and the results are presented.

Keywords: *Sensors, Wireless Sensor Networks, Energy Efficient Communication, Clustering Algorithms, Circle Intersection Problem*

1. INTRODUCTION

A wireless sensor network (*WSN*) is defined as a wireless communication network with the capability of collecting the required data about an environment. In the last few decades, WSNs received intense attention because of their extensive range of applications and usage. In *WSN,* data is gathered by sensors from the environment and transferred to the local station. Examples of such environments are chemical plants, battlefields, agricultural fields, biological monitoring systems, and underwater communications. Due to the nature of the systems, *WSN*s have limited resources, particularly on battery power. Once the battery power is finished, the sensor device can no longer participate in the network. Hence, energy component in *WSN* is important [1]. In the literature, several methods were proposed to save energy and enhance the network's lifetime. The energy in the battery of a sensor is consumed during both computation and communication processes. However, in general, energy essential for data communication is much higher to energy needed for computation. In communication systems, energy expenditure is directly proportionate to the quantity of data to be transmitted [2].

$$E \propto D \tag{1}$$

where D is size of data for transmission and E is the energy consumption. In essence, less data to be transferred corresponds to reducing energy expenditure. To enhance the lifetime of network, a cluster-based approach, Low Energy Adaptive Clustering Hierarchy (*LEACH*) was proposed [15]. In *LEACH*, sensor nodes create clusters, and a Cluster Head (*CH*) manages the cluster. The required data from the environment are gathered by sensor nodes and sent to the respective *CH*. The aggregation of data occurs at *CH* and cluster transfers data to Base Station (*BS*), see Figure 1. A cluster-based energy efficient method using Flower Pollination Algorithm (*FPA*) is presented to increase network lifetime in *WSN* [43]. The method is a two-stage process, in which the first stage focusses on selecting the stable *CH* by using *FPA* optimization technique, whereas the second stage prepares the data transmission from sensor filed to the data center. Another method introduced by Mittal et al. with the motivation of selecting cluster heads for prolonging sensor network's lifetime [44]. Selection of *CH* depends on the Enhanced Flower Pollination Algorithm (*EFPA*) along with Fuzzy Inference Systems (*FIS*). An evolutionary algorithm-based Harmony Search is proposed to select a cluster head for *WSN* [39]. A Binary Discrete Harmony Search is used in fitness function during the setup phase of the model. A trust-based energy efficient clustering algorithm was presented for the secured applications in *WSN*, such as military and defense environments [45]. This method functions in rounds, setup phase and steady-state phase. During set phase, the protocol uses interval type-2 *FIS* and *Cockoo Search* Version 1.0 to calculate the fitness function value, whereas the steady-state phase reduces the energy dissipation. All the above algorithms presented focus on network stability by selecting the appropriate cluster heads. However, data redundancy is an important element in energy consumption, as it is significantly involved in communication energy consumption. The LEACH manages the data redundancy at only inter-cluster communications in the methodology. The coverage of a sensor on its sensing range is normally omnidirectional and can overlap with other sensors if the nodes are close by, see Figure 2. In the above cluster-based algorithms, nodes S1 and S2 transfer data to the *CH* without taking the intersection area into consideration. Thus, the cluster head obtains the same data twice from both sensors. Hence, there exists a data redundancy from overlapped sensing area of the two sensors that incurs an unnecessary energy consumption. If the amount of data to be transferred from a sensor to the *CH* is reduced, then the energy for communication is saved at the sensor level following the energy consumption at other levels of the *WSN* communication system, see Figure 3. If the data redundancy issue at the sensor node level is not sorted out, the same is propagated to higher levels. Even though LEACH sorts out the data redundancy problem at cluster head level, its computations are higher. In this paper, a localized methodology for reducing redundant data at the sensor node level is presented. The following shows the main contributions of the paper.

- Proposed Circle Intersection Problem (*CIS*) for identifying the overlapped sensing area.
- Proposed an energy efficient methodology for *WSN* based on intersection area.
- A mathematical modelling of two-point intersection area and its analysis.
- Simulation and presentation of results for the proposed energy efficient method.
- The complexity analysis on the proposed method.

The *CIS* is a mathematical model to identify the overlapped sensing area of any two sensor nodes. The accuracy of identifying the intersection is important to avoid data redundancy. The proposed method WSN Energy Efficient Mechanism based on Intersection Area (*WSN-EEMIA*) focuses on reducing the intra-cluster data redundancy. The method minimizes data redundancy at the lower level and stops propagating to higher levels.

The rest of article is structured as follows, Section II presents literature survey on various cluster-based energy efficient methods. In addition, the *LEACH* and variations on *LEACH* protocols are reviewed. Section III describes the main contributions of paper. These contributions include the modeling of Circle Intersection Problem for WSN, and the proposed energy efficient method *WSN*-Energy Efficient Mechanism based on Intersection Area (*WSN-EEMIA*). Section IV describes simulations and performance of the proposed method. Section V concludes the article.

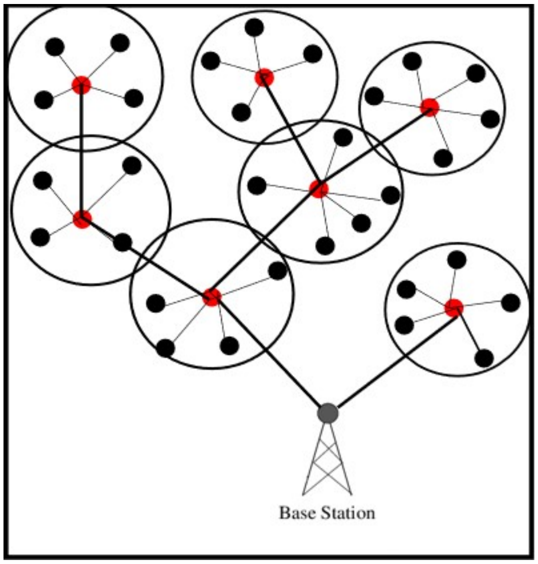

Figure 1. The Cluster Based WSN Model

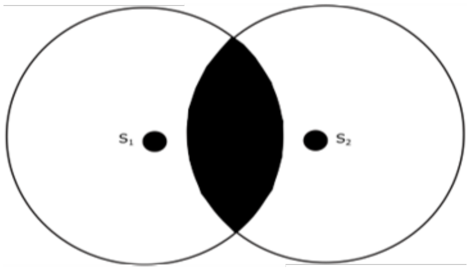

Figure 2. Overlap Area of Two Sensors

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2. RELATED WORK

For the last two decades, the research in WSN is received significant attention and has been carried out in a wide range of sectors [6], [30], [31]. The important component in WSN is the sensor device that senses the surrounding environment. The sensors have a short lifetime due to limited energy. Hence, the design of WSN needs to consider energy expenditure. Efficient power consumption in the network as less as to enhances the overall network's lifetime [7], [8]. Reducing energy consumption by two units can increase the lifetime network by a factor of two, which brings in a significant improvement in the whole lifetime of the system. Nevertheless, the method used for energy usage reduction must be robust to sensor device failures, scalable, and fault-tolerant to extend lifetime of network [9]. The majority of energy consumption in sensor networks occurs during communication rather than the sensing and computation processes. Hence, it is necessary to design protocols for energy efficient communication in sensor networks [3]. In literature, many methods are designed for energy efficiency [4], [5], [10], [11], [12], [13], [14], [32]. In WSN, the coverage and communication elements are two important factors while designing energy efficient protocols [27].

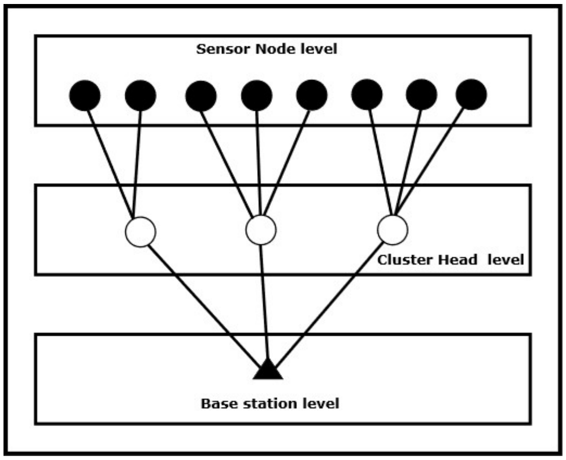

Figure 3. Communication Hierarchy in WSN

The authors in [15] proposed the first hierarchical routing-based method to expand the lifespan of sensor network. Nodes in a network form clusters, and each cluster assigns a *CH*. Sensor nodes transmit sensing data to *CH*. The *CH* aggregates the data and retransmits it to local station. Since cluster head performs more actions than the normal sensor nodes, it is energy intensive. If the cluster head dies, then all network links from nodes within cluster lose communication power [2,9,16]. The mechanism to choose the *CH* in *LEACH*, which depends on the threshold:

$$T(n) = \begin{cases} \dfrac{P}{1 - \mathrm{P} * \left(\mathrm{r} \bmod \dfrac{1}{\mathrm{P}}\right)} & \text{if } n \in G \\ 0 & \text{Otherwise} \end{cases} \quad (2)$$

P=The value of probability to become *CH*
G= List of nodes, which were not *CH*
r= the present node

A node *n* identifies a value between 0 and 1, which is a random and it has a value smaller to threshold T(n). For present round, the node will be *CH*. Some enhancements were provided on *LEACH* to improve performance and network lifetime. In the paper [17], the authors provided a thorough state-of-the-art survey of *LEACH* and its successors. The *E-LEACH* method was presented to improve the mechanism of *LEACH* by considering remaining energy in node during cluster head choice [20]. The *S-LEACH* protocol was presented and bases the network with the defined number of *CH*s in each round [21]. The protocol *K-LEACH* was presented by Bakaraniya et al. to use the K-medoid algorithm for choosing cluster heads [22]. This approach also takes load balancing as a factor, in addition to increasing lifetime of network. A *D-LEACH* protocol is presented to use probability parameters for each data frame [23]. The *CS-LEACH* mechanism minimizes energy spending of nodes by providing an intelligent sleeping mechanism [24]. In this method, some set of nodes go into sleep mode with the ISM approach. *Vor-LEACH* [25] presented an architecture to optimize the energy efficiency in the system. This method uses Voronoi regions instead of clusters and depends on the distance relationship of the nodes [19]. The *VLEACH* was proposed for improvement of *LEACH* to introduce vice cluster head in case *CH* of wireless sensor network dies [9]. The *VLEACH* increases the robustness of the cluster.

There are few efficient clustering mechanisms proposed in the literature for enhancing energy expenditure and improving lifetime of network. A method based on Flower Pollination Algorithm was presented to improve network stability in *WSN*s [43]. The presented method FPA-based Stable Threshold Sensitive Energy Efficient cluster-based Routing Protocol (*FPSTERP*) involves two steps: setup phase and steady-state phase. First step is responsible for the choice of CH, whereas second step is for optimal route establishment. However, this method emphasizes *CH* selection and optimal route to enhance lifetime of *WSN*. The information aggregation activity takes place at the cluster head and did not focus on the data redundancy at the lower-level communications.

An energy efficient clustering algorithm was presented to select *CH* by considering parameters residual energy, the distance, and node centrality [44]. The method uses Enhanced Flower Pollination Algorithm together with the Fuzzy Inference System as fitness function. The method *EFPA*-based stable Threshold Energy Efficient cluster-based Routing Protocol (*FESTERP*) contains two steps. The first step is the setup phase, which performs the selection of *CH* using *FIS* based *EFPA* approach. The steady-state process is responsible on the environmental states from sensor field.

An energy aware method for *WSN* to prolong the network lifetime was proposed [39]. This method uses Harmony Search, which is based on fitness function in selection of *CH*s. The method uses parameters of total energy dissipation, node's residual energy, cluster cohesion, and cluster separation for forming the high-quality clusters. In this method, the operations are carried in iterations, where each iteration contains a setup step and communication step. In the setup step, the Discrete Binary Harmony Search (*DBHS*) is used to find the best CH and its members. Communication step solves the problem of load balancing.

A non-cryptographic secure aware clustering algorithm for *WSN* is proposed to the trust-based environments, such as in military and defense departments [45]. This method uses interval type-2 FIS and *Cuckoo* search version 1 (CV 1.0) to compute the fitness value during the *CH* opting process. The fuzzy model uses the factors trust value, residual energy, node density, and distance to BS which provide opportunity for selecting secure *CH*. The defined protocol Trust-aware Energy-efficient Fuzzy type-2 CV1.0 based Routing Protocol (*TEFCSRP*) operates in iterations that consists of setup and steady-state stages. In setup stage, the CH is chosen by FIS based CV 1.0, whereas steady-state phase takes care of data transmission from sensing area to BS. The steady-state stage contains two types of data transmissions, inter-cluster and intra-cluster transmissions. There is a good scope of reducing energy dissipation during transmission phase than the setup phase as the interval for the steady-state stage is much higher than setup stage.

A few algorithms inspired by biological evaluations are used for cluster head selection named Evolutionary Algorithms (*EA*). Some of these algorithms include Genetic Algorithm (*GA*) [25-32], Artificial Bee Colony (*ABC*) algorithm [38], spider monkey optimization [41], Differential Evaluation (*DE*) [36-37], Harmony Search Algorithm (*HSA*) [39-40], Particle Swam Optimization (*PMO*) [42] and others. These EA algorithms are ambitious; however, they suffer from either early convergence or slow convergence.

Researchers presented a method *NoV-LEACH*, which reduces the data redundancy at the sensor level of *WSN* communication system [18]. However, the *NoV-LEACH* uses global information, which is costly for wireless sensor networks. The method did not explain the details of the mathematical models for calculating the intersection area of sensor nodes.

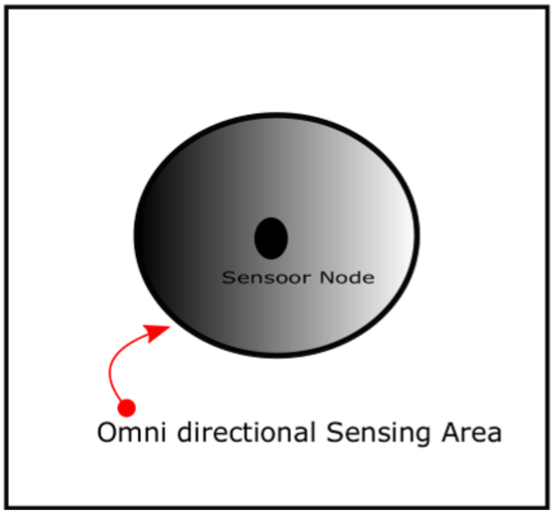

Figure 4. Omni Directional Sensing Area

Circle intersections have become familiar in sensor networks due to their homogeneous characteristics. The authors in [28] use the circle intersection approach to find location information of nodes. On other hand, researchers proposed a method for WSN to cover the entire sensing area with a subset of n sensor nodes [29]. This method saves the resources of the sensor nodes that do not participate in network formation.

3. CONTRIBUTIONS

In WSN, a sensor node contains a transceiver for communication and a sensing device for monitoring the surveillance area. In WSN, an important constraint is the limited battery power of a sensor node. The node is considered dead if its battery is exhausted. Hence, the mechanisms for reducing the energy consumption in WSN have received significant attention. *LEACH* uses an efficient energy consumption mechanism that has the main objective of increasing the network's lifetime [15]. In *LEACH*, sensors gather data from the area of sensing range, transmit it to *CH* followed by information aggregation at the *CH* and forwarding of data to base station. The process of information aggregation is carried out to avoid the duplication of data to be transmitted from *CH* to base station. However, the process of avoiding duplication of data from sensors to *CH* is lacked in *LEACH*. Similarly, few energy efficient clustering-based optimization approaches were presented recently for *WSN* [39,43-45]. These methods use various evolutionary algorithms in identifying the stable cluster heads. The operations of these methods run in stages, setup stage and steady-state stage. During the first stage, stable clusters are formed so that it increases the network lifetime. The second stage is responsible for communication of data from sensor field to base station. During steady-state stage, energy dissipation is reduced by aggregating data at *CH* and retransmit data to *BS*. However, it is important in reducing data redundancy during the intra-cluster communication process. In this section, a localized algorithm for achieving this task is presented. The overlapped area of sensor nodes in *WSN* is modelled as a circle intersection problem.

3.1 Circle Intersection Problem for WSN

The sensing area of a sensor is worthy of attention because the surveillance area to be monitored is important for the application. In general, sensor nodes for an application are homogenous and every node senses the surveillance area in an omnidirectional pattern, see Figure 4. In cluster-based WSN, a sensor node connects to a sink node, and the data collected during the sensing process is transferred to *CH*, which in turn forwards to base station. Transmission from *CH* to base station may occur in several hops.

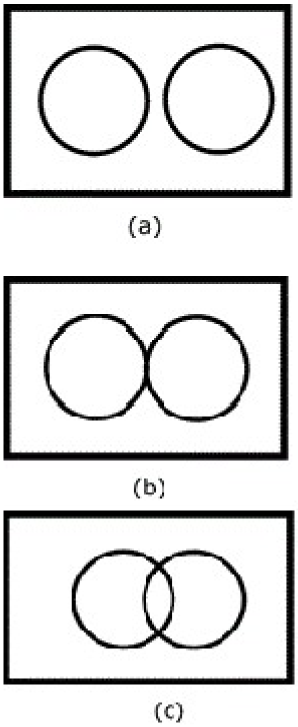

Figure 5. Overlap Area of Two Sensors: (a) Disjoint Overlap. (b) Single Point Overlap. (c) Two-Point Overlap.

The overlap of sensing areas in sensor networks is quite common due to the randomized deployment of sensors. For a pair of sensor nodes, several patterns of overlap areas are possible, see Figure 5. In the case of disjoint overlap and single point overlap, sensor nodes transfer the information without any data redundancy. On the other hand, for the two-point overlap, sensing data is transmitted by both sensors to cluster head, leading to several problems such as data redundancy and traffic congestion at *CH*s. Another significant point is that sensor nodes use extra power for transmitting data of intersection area during the communication process. However, sensors have limited battery power, and energy consumption needs to be minimized.

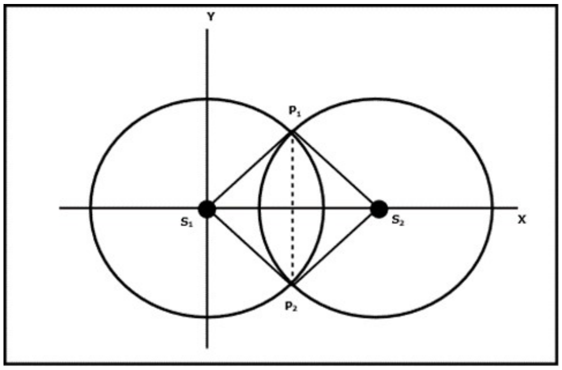

Figure 6. Circle Intersection

The sensing coverage calculation is modeled as a circle intersection problem. The circle-circle intersection is familiar in many mathematical contexts [26]. However, a careful design is required for the sensor network as it has limited sensing and communication coverage ranges. The procedure for calculating the overlap area of two sensor nodes is as follows: subtract the triangle areas of $\lhd S_1P_1P_2$ and $\rhd S_2P_1P_2$ from the sum of areas of the two sectors $\nabla S_1P_1P_2$ and $\nabla S_2P_1P_2$ see Figure 6. Here, we denote $\lhd S_1P_1P_2$ as the left triangle, $\rhd S_2P_1P_2$ as the right triangle of the two-point intersection, and $\nabla S_1P_1P_2$ denotes the sector area of sensor S_1 with the intersection points P_1 and P_2.

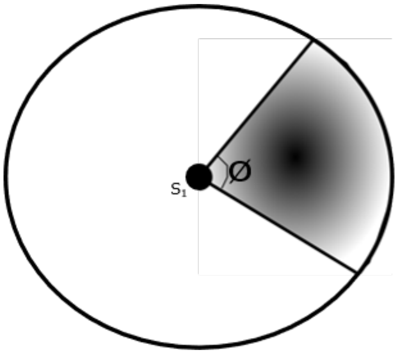

Figure 7. Circle Sector

Let the intersection area of sensors S_1 and S_2 is denoted as $\diamond S_1S_2$, then

$$\diamond S_1S_2 = \nabla P_1S_1P_2 + \nabla P_1S_2P_2 - \lhd S1P1P2 - \rhd S2P1 \quad (3)$$

Here, the radius of circle indicates sensing range of the sensors. It is assumed that all sensors in network have same sensing range, and denote it as *SR*. Let the location of sensors S_1 and S_2 be (x_1,y_1) and (x_2,y_2), respectively.

Distance between two sensors is given by

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (4)$$

The value of y for the point P_1 or P_2 is

$$y = \pm\sqrt{SR^2 - \frac{d^2}{4}} \quad (5)$$

The sector area, see Figure 7, can be obtained as

$$\nabla S_1 \emptyset = \frac{\emptyset}{360} \prod SR^2 \quad (6)$$

where

$$\emptyset = 2\sin^{-1}\frac{y}{SR} \tag{7}$$

Therefore, the sector angles for the two sensors S_1 and S_2 are

$$\emptyset_{S_1} = 2\sin^{-1}\frac{y}{SR} \tag{8}$$

$$\emptyset_{S_2} = 2\sin^{-1}\frac{y}{SR} \tag{9}$$

Here, we denote $\emptyset_{S_1}$ as the angle of sector for sensor S_1. The two sector areas are given by

$$\nabla S_1P_1P_2 = SR\sin^{-1}\frac{y}{SR} \tag{10}$$

$$\nabla S_2P_1P_2 = SR\sin^{-1}\frac{y}{SR} \tag{11}$$

The areas of the triangles from sensors S_1 and S_2 are

$$\lhd S_1P_1P_2 = \frac{1}{2}SR^2\sin^{-1}(\emptyset_{S1}) \tag{12}$$

$$\rhd S_2P_1P_2 = \frac{1}{2}SR^2\sin^{-1}(\emptyset_{S2}) \tag{13}$$

Another way of calculating the areas of the triangles is

$$\lhd S_1P_1P_2 = (\sqrt{SR^2-\frac{d^2}{4}})(\frac{d}{2}) \tag{14}$$

$$\rhd S_2P_1P_2 = (\sqrt{SR^2-\frac{d^2}{4}})(\frac{d}{2}) \tag{15}$$

The intersection area of the two sensors is

$$\diamond S_1S_2 = 2SR\sin^{-1}\left(\frac{y}{SR}\right) - \frac{1}{2}SR^2\sin^{-1}(\emptyset_{S1}) \tag{16}$$

$$\diamond S_1S_2 = 2(SR\sin^{-1}\left(\frac{y}{SR}\right) - (\sqrt{SR^2-\frac{d^2}{4}})(\frac{d}{2})) \tag{17}$$

The algorithm for calculating the intersection area is as follows.

Algorithm 1: Areas for two-point intersection

```
Step1: Obtain the locations of sensors $S_1$ and $S_2$. Let them be as $(x_1,y_1)$ and $(x_2, y_2)$.
Step2: Calculate distance $d$ between two sensors using equation 4.
Step3: Find the area of the sectors for sensors $S_1$ and $S_2$ as $\nabla S_1P_1P_2$ and $\nabla S_2P_1P_2$, respectively.
Step4: Find the area of triangles $\lhd S_1P_1P_2$ and $\rhd S_2P_1P_2$.
Step5: Calculate the intersection area $\diamond S_1S_2 = \nabla S_1P_1P_2 + \nabla S_2P_1P_2 - \lhd S_1P_1P_2 - \rhd S_2P_1P_2$.
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The following are some of the properties related to the intersection area of sensor nodes.

Lemma 1: The area of a single point intersection for a pair of sensors is zero.

Proof: Let the two sensors be S_1 and S_2, and their sensing range is SR. The distance between the sensors is d. An intersection occurs when $d < 2SR$. From Figure 5(b), $d=2SR$. Thus, there is no overlap between the sensors and the area is zero. Hence, the lemma is proved.

Lemma 2: The intersection area of disjoint sensors is zero.

Proof: Let the sensing range of two sensors S_1 and S_2 be SR. The distance between the sensors is d. Since $d > 2SR$, see Figure 5(a), there is no overlap between the sensors and the intersection area is zero. Hence, the lemma is proved.

Theorem 1: For evenly distributed n sensor nodes in a square grid, total number of intersections is $2n-2\sqrt{n}$

Proof. Let m be the number of sensors in a row

$$m = \sqrt{n} \tag{18}$$

From Figure 8, geographically, there are two types of sensors. The outer layer sensor contains either two or three intersections. The inner layer sensors contain exactly four intersections.

The total number of intersections at the outer layer is

$$O_{in} - 4(m-1) \\ = 4(\sqrt{n} - 1) \tag{19}$$

The total number of intersections at the inner layer is

$$I_{in} = 2(m-1)(m-2) \\ = 2(\sqrt{n} - 1)(\sqrt{n} - 2) \tag{20}$$

The total number of intersections in the grid

$$T_{in} = 4(\sqrt{n} - 1) + 2(\sqrt{n} - 1)(\sqrt{n} - 2) \\ = 2n - 2\sqrt{n} \tag{21}$$

Hence, theorem proved.

Theorem 1 is useful in many contexts, such as residual energy calculations and excessive energy spent in an evenly distributed scenario. An example of such networks are grid sensor network.

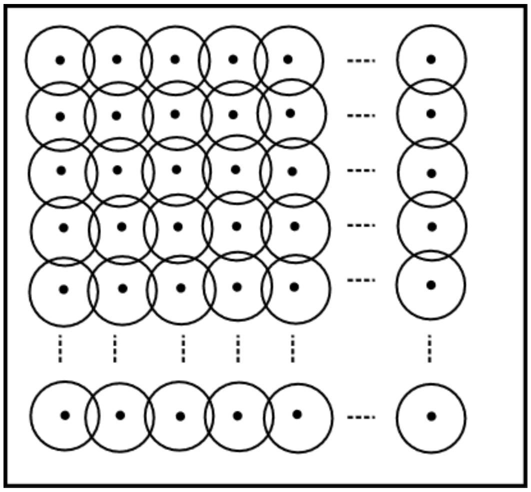

Figure 8. Evenly Distributed Sensors in Square Grid

3.2 The Energy Efficient Communication

The proposed energy efficient methodology named as WSN Energy Efficient Mechanism based on Intersection Area (*WSN-EEMIA*), which is a localized nature of algorithm. The following algorithm describes the *WSN-EEMIA* method.

Algorithm 2: *WSN-EEMIA*

Step1: Every sensor broadcasts *a hello-packet* with *ID* and location data.
Step2: Follow the procedure of *LEACH* for forming the clusters and select the *CH*s. We denote all sensors that belong to the cluster as *brotherhood*
Step3: Each *CH* broadcasts the *ID*s of all sensors of its *brotherhood*, and sensors maintain its *brotherhood* information.
Step4: Every sensor node computes the overlap area with its *brotherhood* using the Algorithm 1 and stores in *overlap-vector*. Keep zero value if there is no overlap area with the respective neighborhood sensors.
Step5: Every sensor node, which has the lowest ID than all of the sensors in its *overlap-vector*, sends complete circle data to *CH*. Otherwise, sensor sends only data of non-overlap area to the cluster head.
Step6: A sensor node that has a positive value in the *overlap-vector* and has the lowest *ID* sends the complete circle data, and other sensors transmit only the data of the non-overlap area.
Step7: The non-redundant data from the sensors is received by *CH* followed by transmission of data to local station.

Theorem 2: The energy saving of a network with evenly distributed *n* sensor nodes in a square grid is $2 * (2n - 2\sqrt{n}) * x * (SR \sin^{-1}(\frac{y}{SR}) - (\sqrt{SR^2 - \frac{d^2}{4}})(\frac{d}{2})$ joules, where *x* is energy required for communication of an unit area.

Proof: Let the intersections exist in evenly distributed sensor nodes of a regular grid, as shown in Figure 9. The energy spending for a single intersection is

$$2 * x * (SR \sin^{-1}(\frac{y}{SR}) - (\sqrt{SR^2 - \frac{d^2}{4}})(\frac{d}{2}) \tag{22}$$

For evenly distributed *n* sensor nodes, the number of intersections from *Theorem1* is *2n-2*$\sqrt{n}$.

The total energy consumption is

$$4 * (2n - 2\sqrt{n}) * x * (SR \sin^{-1}(\frac{y}{SR}) - (\sqrt{SR^2} \tag{23}$$

Since the proposed protocol, WSN-EEMIA transmits the overlap area only once, the energy consumption is

$$2*(2n-2\sqrt{n})*x*(SR\sin^{-1}(\frac{y}{SR})-(\sqrt{SR^2} \quad (24)$$

The energy savings are the difference between equations 23 and 24.

$$2*(2n-2\sqrt{n})*x*(SR\sin^{-1}(\frac{y}{SR})-(\sqrt{SR^2} \quad (25)$$

Hence, the theorem is proved.

3.3 Complexity Analysis

Calculating areas of triangles and sectors of any two sensor nodes S_1 and S_2 requires constant time, hence time complexity of *Algorithm 1* is *O(1)*. Thus, time complexity of new method *WSN-EEMIA* becomes O(1). Let p be number of bits needed to transfer a unit of surveillance area, then total number of bits needed to transfer a sensor's full surveillance area is $\pi r^2 p$, where r is sensing range of a sensor. Here, it is assumed that sensing coverage of a sensor is Omni-directional. Table 1 shows the communication complexity of various energy efficient methodologies. The communication complexity mentioned is for the sensor members of a cluster.

Table 1: The Communication Complexity

The Method Name	Communication Complexity
LEACH [15]	$O(r^2p)$
FPSTERP [43]	$O(r^2p)$
FESTERP [44]	$O(r^2p)$
TECP [39]	$O(r^2p)$
TEFCSRP[45]	$O(r^2p)$
WSN-EEMIA	$O(r^2p-2\rho p)$

In the above table, the ρ is the intersection area of two sensor nodes. The communication complexity of the proposed method *WSN-EEMIA* is lesser compared to other methods, as the method *WSN-EEMIA* reduces the data redundancy before transfer of data from sensor field.

The Table 2 shows the symbols or notations used in paper.

Table 2: The Symbols/Notations Used

Symbol/Notation	Description
$\diamond$	Intersection area
SR	Sensing Range
d	Distance between sensors
∇	Sector Area
$\emptyset$	Angle of sector
$\emptyset_{S_1}$	Sector angle of sensor S_1
$\nabla S_1\emptyset$	The sector area of the sensor S_1 with the angle covered $\emptyset$
$\nabla S_1P_1P_2$	The sector area in sensor S_1 with the two intersection points P_1 and P_2.
$\triangleleft S_1P_1P_2$	The area of the triangle in the sensor S_1 with the three points P_1, P_2, and centre of the sensing area of the sensor S_1 and the triangle is a left facing triangle.
$\triangleright S_2P_1P_2$	The area of the triangle in the sensor S_2 with the three points P_1, P_2, and center of the sensing area of the sensor S_2 and the triangle is a right facing triangle.
$\diamond S_1S_2$	The intersection of two sensors S_1 and S_2
ρ	Intersection area

The proposed mathematical model can reduce all the data redundancy for the evenly distributed nodes. However, theoretically it may not reduce all data redundancy in some scenarios of sensor nodes. For example, if all the nodes are close to each other and there is a sensing overlap for every sensor node. In the current work, there is a scope to minimize the data redundancy within the cluster itself. In practice, at the random deployment of sensors lead to sensing overlap area from many sensor nodes, which cause to increase the redundant data.

Computation of *CH* from given sensors depends on the heuristic described in *LEACH* [15]. Here, we assume that all sensors are homogenous characteristics with respect to communication and sensing range. Following election of *CH*, data transfer is carried out from sensor to *CH*. The Steps 5, 6, and 7 collectively reduce data redundancy. List of overlaps is noted in the *overlap-vector* of a sensor node. The *overlap-vector* is computed from the neighborhood of a sensor node within cluster. The vector is one dimensional. A nonzero value in the *overlap-vector* indicates the overlap area between the two sensor nodes.

For an exclusive transmission of the overlapped area by the sensors, the least *ID* heuristic is chosen. In other words, the sensor node having the least *ID* are chosen to send the complete circle data, whereas other sensors transmit only the data from the non-overlapping area.

4. SIMULATIONS

The simulation is performed with the methods proposed. The *LEACH* and *WSN-EEMIA* methods consider the necessary network parameters. In simulation, three experiments are involved to analyze the proposed method. The initial experiment checks correlation between number of nodes and their intersections. The total grid area of 1000x1000 m^2 is considered with varying quantities 10, 15, 20, 25, 30, 35, and 40 of randomly distributed sensor nodes. The sensing range of each node is 100 meters. It is calculated the number of intersections with variable number of nodes, see Figure 10. According to the graph in Figure 9, the number of intersections increases with increasing number of nodes. This happens because density of sensor nodes raises with increase of number of nodes in same grid area and with the same sensing range of nodes. Hence, increasing density of nodes leads to increased number of intersections in the same grid area.

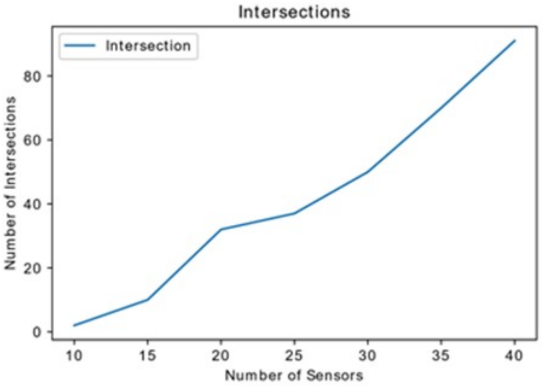

Figure 9. The Number of Intersect

Next experiment to compute the network energy consumption when transferring data from sensors to relevant cluster heads in protocols *LEACH* and *WSN-EEMIA*. In this task, 10, 15, 20, 25, 30, 35, and 40 randomly distributed sensors are placed in a 1000x1000 m^2 grid area. Each sensor node communication range is 100 *m*. The simulation is run for 600 seconds, and each sensor transfers sensed data to *CH* every second. However, during the entire simulation, the transmission of data from the sensors is limited to 400 seconds. Energy spent by sensor node during sensing process, transmission process, and receiving process. After the simulation, the amount of energy consumption of nodes in network is calculated, see Figure 10. It is observed from Figure 9 that the total energy consumed with *WSN-EEMIA* is lower than *LEACH* protocol. This is because of nodes in *WSN-EEMIA* consider data redundancy, whereas *LEACH* suffers from data duplication. In other words, The *WSN-EEMIA* methodology identifies the overlapped sensing areas and transmits the data within this area at only once, whereas *LEACH* transmits more than once the same data, which belongs to the overlapped sensing area.

The third experiment is to compute the sum of the overlap areas in sensor networks. For this experiment, the number of sensor nodes varied 10 to 40 with an interval of 5, and the grid area size is 1000×1000 m^2. The sensing range of each node is 100 *m*. It is found from Figure 11 that the total overlap area is increased with increasing number of sensors in network. This happens because the number of intersections rose with an increase in density of sensors with the same sensing range and grid size. Since the number of intersections increases, the intersection area is also increased, which leads to an increase in the total overlapped area.

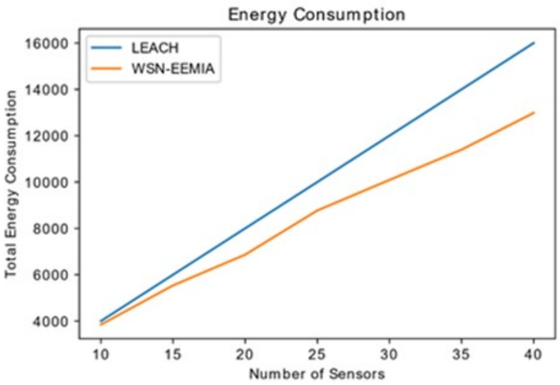

Figure 10. Total Energy Consumption

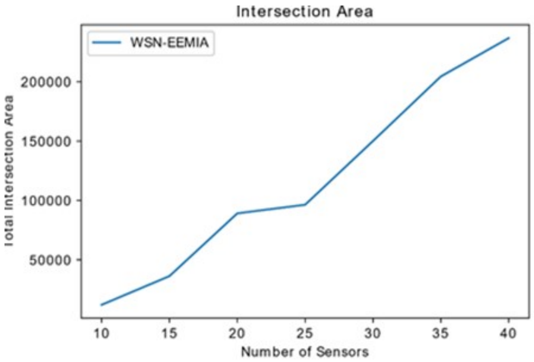

Figure 11. Total Intersection Area

5. CONCLUSIONS

In *WSN*, the sensors have limited energy in their battery and a sensor is in-active if its battery power is exhausted. Hence, the researchers of *WSN* give high priority for energy saving mechanisms in network. In the literature, several energy efficient clustering mechanisms were presented for *WSN* to provide stability in the network. However, they were not focused on reducing the lower-level data redundancy. In the article, a new energy efficient method *WSN-EEMIA* is proposed. The method focuses on avoiding data redundancy during intra-cluster data transmission. The Circle Intersection Problem for *WSN* has been introduced to identify the data redundancy at the sensor level of WSN. The mathematical model for *CIP* is presented. The In addition, the time and communication complexity analysis of the proposed method is presented. The simulation is carried out for the proposed method to analyze its performance.

The *CIS* model in the proposed method considers a two-pint intersection to identify the overlapped area. As for future research work, CIS needs to be extended for multiple sensor nodes at the same time.

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