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Efficient Energy-Aware Clustering Approach Area Splitting-Based for Wireless Sensor Networks

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ABSTRACT

Modern wireless communications advancements and miniaturization components in the field of electronics have led to the development of lower-cost, multi-functional micro-sensors. A very new useful type of network, called Wireless Sensor Networks (WSNs), has emerged in recent decades, acting as generators and relay data by controlling interesting physical phenomenon. However, some problems need to be improved in their mastery, particularly that of energy conservation. This valuable energy has to be sufficiently available until a WSN reaches its mission. In order to increase WSN lifetime, numerous protocols have been designed to address this problem of power consumption. The pioneer of these protocols was Low Energy Adaptive Clustering Hierarchy (LEACH) protocol and other enhancement variants were subsequently created in this context. In this paper, a new protocol named Area Splitting for Clustering (ASC) that reduces energy consumption and increases network lifetime is proposed. The performance evaluation of ASC has been carried out and showed that it outperforms those of Leach and its variant protocols.

1. INTRODUCTION

The development of Wireless Sensor Netwroks (WSNs) has created a recent research community that is committed to addressing the unique challenges and opportunities presented by these networks in different domains. As technology advances, WSNs will likely continue to evolve and contribute to solving real-world problems, further motivating researchers to explore new avenues and innovations in the field. Despite the efforts and remarkable progress that have been made, there are still some obstacles that need to be overcome to reach full maturity. In order to ensure the proper functioning of a WSN until its successful final mission, the energy consumption of sensors remains a crucial factor to consider among these obstacles. Energy efficiency must be considered at every stage of WSN design and operation. From the hardware design of sensor nodes to the development of communication protocols and routing algorithms, energy awareness should be integrated to minimize unnecessary energy expenditure [1]. The question of energy conservation has been extensively studied through multiple protocols, but no definitive result has been achieved. Even if the problem is solved, it will still be a challenge to overcome the excessive miniaturization of sensors, such as nanosensors. The optimization of energy consumption may be believed to be relevant for a long time [2].

Studies aimed at optimizing this scarce resource focus on communication (via routing protocols) in WSNs, as energy dissipation is primarily caused by message transmission. Therefore, knowing that clustering is commonly accepted as a hierarchical approach to efficiently manage the control and regulation of communications of cluster members, the optimization of sensor energy consumption is often addressed through this context.

Depletion of a sensor node power not only puts that sensor out of service (no more ensuring data collection) but can also end its role as relaying data collected by its neighbouring nodes to the sink. If the number of these relay nodes exceeds a certain threshold, the data collected by a WSN would no longer arrive (Through the sink) to the end user, which would compromise the mission of this WSN. Node energy is regarded as the primary resource that a WSN is dependent on.

To select cluster heads based on the number of neighbour nodes, we suggest a new clustering approach that splits deployment areas. The proposed approach has an added value, as the CH, which is chosen according to proven equations, is always closest to most of the sensor nodes and has the highest energy. This reduces energy consumption by a large percentage and increases the network lifetime. This protocol performed better than well-known referenced protocols in simulation scenarios carried out.

The main contributions of our work are:

- formation of a virtual grid, or a split area into equal cells.
- An inclusion algorithm is proposed to perform the number of nodes included in the communication radius of the candidate's node to be a CH.
- Selection of CHs taking into account both residual energy and the density of neighboring nodes calculated from précédente step.

• Monitor the energy levels of CHs to detect CHs out of energy and replaces them by selecting new CHs.

The remainder of our research is organized as follows: The related research on the clustering approach is presented in Section 2. In section 3 we present our proposed protocol with its performance evaluation and comparison with protocols of reference. Our work is concluded, and we will provide a future perspective in the fourth section.

2. RELATED WORK

Cluster-based algorithms play a vital role in Wireless Sensor Networks (WSN), offering advantages such as scalability and energy efficiency. These algorithms group sensor nodes into clusters, and it is the responsibility of the cluster heads (CHs) to send data from the cluster nodes to the sink. The election of CHs is a critical aspect, impacting energy consumption and network lifespan [3]. Various CH election algorithms exist, each designed to address specific challenges and requirements of WSNs. These algorithms consider factors like node proximity, residual energy levels, and communication overhead.

To select CHs effectively. Common techniques include centralized approaches, where a central entity orchestrates CH selection, and distributed methods, where nodes collaboratively elect CHs based on local information [4].

LEACH [5] has served as the basis for many variations and improvements in cluster-based routing protocols for WSNs, addressing some of its limitations and tailoring the protocol to specific application requirements. It remains a fundamental protocol in the field of WSNs and energy-efficient routing [6]. Information is collected by nodes from their surroundings and transmitted to their corresponding CH. CH groups, compresses, and delivers the aggregated data from cluster participants to the sink. The lifespan of WSNs is enhanced in LEACH protocol by reducing the number of transmitted packets through cluster structuring.

One of the many drawbacks is that the cluster head was chosen without considering the node's current energy or distance. An additional limitation that renders LEACH meaningless for big networks is that the CH only needs to make one hop in order to communicate with the sink.

LEACH's two main phases are cluster setup and steady phase. In the initial phase, the node is in charge of choosing a CH at random from 0 to 1. In the following round, that sensor will become a CH if it is less than T (n), which is determined by Eq. (1).

The threshold is given as:

$$T(n) = \frac{P}{1 - p \times \left(r \bmod p^{-1} \right)}, \quad \forall n \in G. \qquad T(n) = 0, \forall n \in G \tag{1}$$

P: indicates the CH's percentage in the network.

r: represents the current round.

G: represents the sensor nodes group that have not been CH in the previous 1/p rounds.

T(n): the threshold calculated for a node n and it is calculated in every round.

LEACH protocol architecture is shown in Figure 1. Normal nodes in such type of protocol consume less energy than the CH node because the last one gathers and merges collected information before sending it to the SINK. Leach protocol is based on one hop process between CHs and the SINK whatever the distance between them and the energy level of these CHs [7]. When a node is selected as CH, it must inform other sensor nodes of its new ranking in this round. To prevent conflicts between CHs, an 'ADV' alert with the CH identifier is sent to all other nodes using the CSMA/CA-MAC protocol.

The message is ensured to be received by all nodes through dissemination. Furthermore, it ensures that the nodes belonging to the CH require a minimum amount of energy to communicate. The decision of a node to join a CH is therefore based on the amplitude of the signal received by that node. So, the CH with the most robust signal, or the nearest, will be chosen. In the case of signal amplitude equality, ordinary nodes randomly select their CH. Each node member communicates its choice to its CH. Upon receipt of a request, the CH responds with a message "Join-REQ".

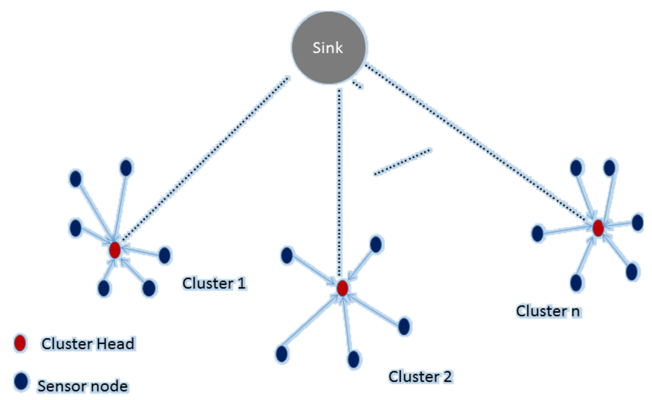

Figure 1. LEACH protocol clusters formation

Each CH serves as a local manager to oversee data communication inside its cluster after cluster formation. Each member node is given a time slot to transmit data during the creation of a TDMA scheduler. A frame is the collection of slots allowed to cluster nodes. The time of each frame varies with the number of sensor nodes in the cluster. In order to less interference between broadcasts in neighbouring groups, each CH also chooses a random code from a set of CDMA propagation codes. In order, for its subscribers, to use it for communication, it is then sent to them.

During the steady-state phase, data will be transferred to the sink. Using the TDMA scheduler, members transmit their sensed data during their own slots. This enables them to conserve energy by turning off their communication connections outside of their slots. The CHs aggregate these data after which they combine, compress, and transfer the complete message to the sink.

The network will advance to the next round after a certain amount of time. Up until all network nodes have elected the CH once through the preceding rounds, this process is repeated. The round is restarted at zero in this instance.

Although LEACH has the merit of being the first to apply the clustering approach in WSNs to organize communications according to the sensor cluster heads and sink hierarchy to optimize energy consumption in a WSN, it suffers from several weaknesses:

(1). After the protocol is executed, some clusters may have more member nodes and others fewer; some CHs may be located at the centre and others at the edge of the cluster, which implies an increase of energy consumption.

(2). The ideal number and distribution of CHs cannot be guaranteed because CHs are selected randomly.

(3). Sensors with minimal residual energy have the same chance of being elected CHs as nodes with high residual energy, which poses the problem of premature energy failure for the former. In such a case, if energy failure recovery capabilities have not been planned for, the WSN mission may be compromised due to the loss of data collected by members of a CH with a depleted battery.

(4). CHs communicate directly in single hops with the Sink, which means that the Sink is within their range. In large WSNs, the communication must be multi-hop through CHs to the Sink and even multi-hop within the same cluster.

(5). The random selection algorithm of CHs causes an imbalance problem in the energy load. The distance factor is not taken into consideration when forming clusters, due to which sometimes very large clusters and very small ones exist at the same time in the network [5].

3. LEACH BASED ROUTING PROTOCOLS

Due to LEACH protocol limitations, much research was done to overcome these limitations, and many protocols were developed to decrease energy consumption and increase the network lifetime. In this section, we will introduce some of the new protocols derived from LEACH.

3.1 VLEACH

In the LEACH protocol, if the Cluster Head lacks sufficient energy to transmit the data collected from its members to the Base Station, the data from that cluster will be lost [8].

The VLEACH protocol consists of clusters, each comprising a Cluster Head (CH) responsible for transmitting data collected from the cluster nodes to the sink. Additionally, there is a vice-CH that assumes the task of the CH in the event of its failure. The cluster nodes are responsible for gathering data from their surroundings and transmitting it to the CH. The CH in the original LEACH dies early as a result of its continuous data collecting from cluster nodes, aggregation, and transmission to a hypothetical distant Sink [9].

In VLEACH protocol, we have CH and vice-CH that take on the responsibilities of CH when CH dies. It is not necessary to vote for a new CH every time and the current CH dies if the above work is completed. This will increase the lifespan of the network as a whole and network-wide communication.

3.2 MOD-LEACH

Compared to LEACH, the MODLEACH protocol represents advancement. It featured two unique approaches to cut down on energy consumption: a reliable cluster head replacement mechanism, and dual transmission power levels [10].

According to the simulation findings, MODLEACH is superior to LEACH when factors like throughput, cluster head formation, and network longevity are taken into account [11].

3.3 LEACH-C

LEACH-C (Centralized LEACH) is indeed a centralized protocol designed to improve the efficiency of cluster formation and CH selection in Wireless Sensor Networks (WSNs). In LEACH-C, the sink node, which typically serves as the central coordinating entity in WSNs, takes on the responsibility of making all decisions related to CH selection and cluster formation [12].

In LEACH-C, there is a guarantee or discussion about the placement of cluster head nodes. Since the cluster is adaptive, obtaining bad clustering while using the central control system to form a cluster may produce better clusters.

At begin of each iteration, the position and residual energy of sensor nodes will be transmitted to the Sink. After acknowledging this information, all nodes must be given an equal part of the energy burden, according to the Sink. For this, the Sink calculates the average energy value of all nodes and determines that the residual energy of the nodes is more than the average. Once it forms the clusters with their CHs, it sends out a message containing the CH identifiers (IDs). For each node, if the node ID matches the same ID that it received, that node will be elected as the CH; otherwise, the node will make contact with the relative CH and transfer data to the latter at its slot.

However, it dramatically increases network overhead since all sensors will have to transmit their position to the Sink at the moment during each CH election phase.

As the author discussed, the steady-state phase of LEACH-C is the same as the steady-state phase of LEACH [12].

3.4 I-LEACH

The rounds of this protocol are split between set-up and steady-state durations, similar to classic LEACH. If a node's energy level is higher than the average energy value during setup, the sink elects that node as the cluster head. The data signals sent to the cluster heads and then relayed to the sink during the steady-state period are scheduled using the TDMA protocol [13].

I-LEACH's combination of energy-aware CH selection and TDMA-based scheduling contributes to improved energy efficiency and network performance, extending the operational lifespan of WSNs. This protocol is particularly suitable for applications where energy conservation and prolonged network operation are critical, such as environmental monitoring and surveillance systems [14].

3.5 SLEACH

Sectored or S-Leach is a technique that reduces the transmission distance between nodes by segmenting the communication space into sectors that are centred around the sink. Reduced distance causes the node energy to live longer because the energy needed for transmission is inversely correlated with distance [15].

3.6 RED-LEACH

This is an advanced leach protocol that operates in rounds, with setup and steady state phases between each round. Each node's leftover energy and distance from the Sink are taken into account by RED-LEACH, which are important for energy efficiency [16].

3.7 E-LEACH

An approach for choosing a CH to save energy has been introduced by earlier research on E-LEACH. The remaining energy is a factor that E-LEACH takes into account while choosing the following CH. According to simulations, E-LEACH has a longer network lifetime compared to LEACH. Data transfer from a CH to the Sink has been altered by the suggested method. If a CH has a lower distance to the Sink, it will look for another CH as a next hop rather than delivering data directly to the Sink [17].

3.8 AE-LEACH

There are four significant parts in AE-LEACH. The sensor nodes' mobility is calculated in the first part. The second one uses the AE-LEACH protocol to conduct clustering based on descriptors. The goal trajectory is calculated using the Particle Filter (PF) algorithm in the third part, and energy efficiency is calculated using the Gini index in the fourth part [18].

4. PROPOSED PROTOCOL

In the clustering approach, clusters have some characteristics, like the number of nodes included and the position of the cluster head inside the cluster, and this may impact the amount of energy consumed by the whole network. Similarly, choosing a cluster member node to replace the current CH that is running out of energy and forwarding the captured data to the sink in a single-hop or multi-hop path also plays an important role in dissipating the energy of nodes. All of this can impact, positively or negatively, the network lifetime and inevitably, the success or failure of the WSN mission [19, 20].

To this end, the new Area Splitting Clustering protocol (ASC) was designed to mitigate or remedy the drawbacks encountered in previous LEACH-based protocols. The ASC protocol provides the following advantages:

(1) Divide the clusters that have more nodes (more than the average) into two equal groups with one CH each. The problem of the position of the CHs is solved by choosing as CH the node closest to the majority of the cluster members.

(2) The distribution is close to the optimum because we do not choose CH randomly, and each zone will have its CH close to the majority of the nodes in its cluster.

(3) In the proposed protocol, residual energy is considered as a very important factor, so a node with insufficient energy is not chosen as a CH to avoid its rapid death.

(4) Inter-cluster multi-hop communication is used to send packets of isolated nodes.

(5) The formation of clusters takes into account the distance factor. The clusters will have the same width depending on the transmission range of the CH of each cluster, which is considered the same in our protocol.

(6) There is a fixed number of CHs in the network for every round.

Due to the limited number of LEACH advantages compared to our ASC, this new protocol decreases energy consumption significantly compared to the other LEACH-based clustering protocols.

4.1 Network model

At sensor deployment and after area splitting, the following assumptions hold:

- All nodes have the same length of communication range CR and reception range RR.
- All nodes have fully charged batteries, static and are equipped with a GPS system.
- The sink is stationary with no resource limitations. It has the location information of all nodes in the network.

The total energy consumed by a sensor is divided in three types according to the Eq. (2):

$$E_{cons} = E_{tr} + E_{rec} + E_{agg} \tag{2}$$

where, E_{cons}, E_{tr}, E_{rec}, and E_{agg} are consumed, transmission, reception, and aggregation energies for a sensor node in the general case.

(1) GPS Location using satellite

There are two types of sensor locations in a wireless sensor network. Distributed localisation is done for each sensor node in a local way, i.e., each node evaluates its location using inter-sensor measurements, and the information is collected from its neighbors, whereas in our protocol all sensor nodes are thought to be GPS located, in a centralized way, i.e., their locations are transmitted straight to the SINK. The SINK gets the nodes' latitude and longitude also from satellite.

(2) Radius calculation

The problem is: does the radius used to split the area will be the sensation range or the communication range?

Because the sensation range is the smallest and the connection between the sensors to be effective, or the sensors are said to be fully connected, the communication range, will be considered as The Radius R to base all the calculations.

Figure 2 shows an example of an area split based on R.

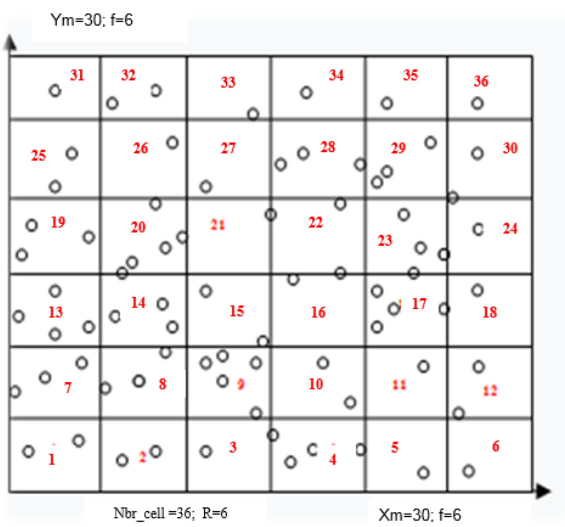

Figure 2. Division area

4.2 Splitting algorithm and cell naming

Our work aims to implement a protocol that is based primarily on the formation of a virtual grid, or a split area into equal cells covered by sensor nodes deployed by a flying device. Each sensor node uses its GPS-indicating position to associate with a point on a given cell. Nodes located geographically in one cell in the area are considered equivalent in terms of cell number and will also have the same Cluster Head (CH) that will be chosen in each round, as will be shown in the following phases of the protocol. This equivalence is based on keeping nodes located in a particular cell of the area.

The division of the zone N*M on equal cells of size L*L such that L=2*R, where R is the communication range as explained before (It is assumed that all sensors have an equal radius because they are of the same type.).

In each cell, a sensor leader is chosen to collect the data from the different sensors and transmit the aggregated information to the Sink, which has a database that contains the coordinates of each sensor. This sensor, called the Cluster Head, will be replaced by another one as its energy will be reduced at the end of the round. At each round, another sensor will be chosen as a CH. The variables are calculated as shown in Figure 2 where the area is divided into 36 cells containing 75 nodes randomly deployed.

Let the following variables be true:

Nbr_cell: number of cells in the total area.

Z_n: number of the cell to search for the sensor n.

R: the diameter or half the cell length. (R is assumed to be the same for all sensors).

F: number of cells in the x and y axis.

c1, c2: order of the cell where the node i is located for the X and Y axis respectively.

xm, ym: length and width of the total area respectively.

The formula to localize nodes is as follows:

$$Z_n = c2 \times F + c1 + 1 \tag{3}$$

The cell, where a sensor node is located, is calculated by Eq. (3); c1 and c2 are the locations of the sensor node in x and y axis respectively. They are calculated in the following Localization algorithm.

4.2.1 Node localization

Let x and y be the coordinates of the concerned node; xm and ym are the length and width of the total area, respectively, and F is the number of cells in the width. The number of the cell where the sensor node belongs will be named zn in the structure of node i, which will be calculated in the algorithm below:

<u>*Localization algorithm :*</u>

```
For   x=0 to (xm/2*r) -1 do
  if S(i).xd >2*r* x then
   if S(i).xd<2*r*(x+1) then
      s1=x
For y= 0 to (ym/2*r)-1 do
   if S(i).yd>2*r*y   then
   if   S(i).yd<2*r*(y+1)  then
            s2=y
    S (i).zn=s2*f+s1+1
```

4.2.2 Inclusion method

Each sensor node has in its memory a table that contains the number of its cell, the total number of nodes in its cell, and the total number of nodes in its Radius.

Let a node n0 that we would calculate its neighbours with the coordinates (x0, y0) and let n (x, y) be the coordinates of a sensor node n included in the communication radius of the node n0. So for testing the inclusion of any node in the circle, substitute its coordinates in x and y, respectively, in the following inequality:

$$(x - x_0)^2 + (y - y_0)^2 \leq R^2 \tag{4}$$

To determine if the sensor is included, we must substitute its coordinates x and y in Eq. (4). The points to be solved will be removed from the resolution of this equation. The following inclusion algorithm calculates the number of nodes included in the communication radius of the candidate's node to be a CH.

Let

(x, y), (x0, y0): are the coordinates of the included node and the coordinates of the node having the radius R, respectively, in the map.

***z*:** total number of cells in the area.

Nbn: number of nodes in a cell j.

<u>*Inclusion algorithm:*</u>

```
For j=1 to z do
   For   i = 1 to cell (j).nbn   do
      For k =1 to cell(j).nbn   do
        if   k<>i  then
         if(sqrt((S(i).xd-S(k).xd)^2+(S(i).yd-S(i).yd)^2))<R
then
              S (i).ic=S(i).ic+1
```

Although the coordinates of the nodes of each cell are known by the GPS system, the calculation is done by each sensor node and information resulted will be stored as shown in the Table 1, that contains node's cell number; the total number of nodes in that cell and the number of neighbours or nodes included in its communication range.

After detecting the death of a node by a CH at a given round, an update message will be transmitted to all nodes in its cell.

Table 1. Node parameters

Cell Number	Number of Nodes	Nodes Included

4.3 Cluster head selection

The choice of the CH will be based on a single criterion called Inclusion Number (IN), which must be the maximum in its cell. The calculation of this number will be shown after from the second round until the end of network's life, the residual energy amount is the second-used factor.

As shown in Figure 3, 22 nodes are included inside the communication range of the node situated in the center of the shown circle. That number allowed the node to be a cluster head for the current round.

According to our proposed protocol, selecting cluster heads among several nodes has been made by an inclusion method, and we choose the node that has the maximum degree. That is, the node that has the most sensors in its circle.

4.3.1 Selection criteria for CH in the first round

Any CH elected in the first round, as described in the membership criterion, is a node with the largest number of sensors in its communication radius. No other factors will be taken into consideration. As it is supposed that all batteries of the sensors are fully charged, then the residual energy factor is not taken into account as a parameter for the CH choice in this first round.

4.3.2 Selection criteria for CH from the second round

After network operation for the first round, a CH is chosen in each cluster. Since all nodes have the same amount of energy, the inclusion number that ranks the nodes in each cluster and the node with the largest number of inclusions referenced by ***ic*** is chosen as CH. After which, a rotation mechanism based on this number and also on the residual energy, is applied to select the next CH. The appropriate CH receives the cluster members' gathered data and transmits the aggregated data to the distant sink directly [2].

The batteries charge rate for all sensor nodes will not be the same, and this will generate a preference between nodes that have already used less energy compared to those that have used up more. Therefore, the residual energy factor should be a second interesting parameter for selecting CH in the second round.

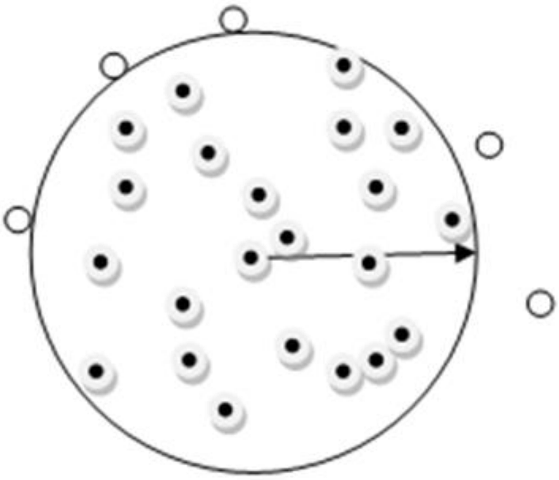

Figure 3. Nodes inclusion

4.4 Energy consumption model

Before going into further detail, it is necessary to remember the commonly accepted energy model for routing protocols in WSNs. Clustering approaches also use this valued model because of its assumptions inherent to radio characteristics, notably energy dissipation. The latter is essential because of its direct impact on routing protocol performance. The radio model in the study by Yick et al. [1] will be used to compare all contemporary protocol adjustments. The system model for transmitting data between two nodes is shown in Figure 4.

E_{elec}: is an electronic circuit energy.

do$=\sqrt{\frac{efs}{eamp}}$: is the threshold distance.

$Eamp$: is the energy consumed in the amplifier.

Efs: is transmit amplifier constant for free space and multipath fading modes.

E_{Rx}, E_{Tx}: are the energy amount received and sent respectively.

To send a k-bit message to a receiver far from it by a distance d, the ETx radio transmitter consumes:

$ET_x(k,d)=Eelec*k+Eamp*k* \quad d^p$

So the system has two cases for transmission energy:

$ET_x(k,d)$=k*Eelec+E_{fs}*k*d2, if d<d0

Or

$ET_x(k,d)$=k*Eelec+k*Eamp*d^4 m, if d>=d0

To receive a k-bit message, the ERx radio receiver consumes:

d: the distance to the SINK

$ER_x(k)=ER_{xelec}(k)$

$ER_x(k)=E_{elec}*k$

E$_{elec}$ and E$_{amp}$ present the energy dissipated in the electronic circuit and the amplifier, respectively.

When a cluster head CH receives data from other sensor nodes, the CH proceeds to aggregate the received data to produce a single signal to be sent to the sink. During this operation, the amount of energy consumed is equivalent to Eagg (aggregation energy).

The energy consumed by CH is computed as follows:

if distance_to_SINK < do

E_{CH}(i,k,d)=k*Eelec*mi+k*E_{agg}*(mi+1)+k*Eelec+E_{fs}*k*(d)^2.

if distance_to_SINK >= do

E_{CH}(i,k,d)=k*Eelec*mi+k*EDA*(mi+1)+k*Eelec+k*Eelec+Eamp*k*(d)^4.

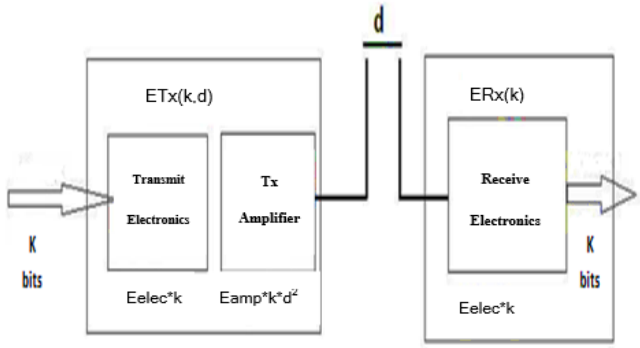

Figure 4. Wireless sensor radio model [1]

4.5 Residual energy calculation

The energy of each sensor node counts as an important parameter along with the number of its neighbouring sensors. The residual energy factor affects the choice of CHs in each round, starting with the second round. Thus, the probability of choosing a cluster head will depend on two factors:

(1) Residual energy ***E.***

(2) Number of included nodes ***ic***.

The value of the production of the two factors for every sensor node is calculated as in the Equation below:

$$V(i) = S(i).E \times S(i).ic \quad (5)$$

where,

S(i).E **and** ***S(i).ic*** are the residual energy and number of neighbouring nodes, respectively for the sensor node i.

V(i) is the value of the production of E and *ic*.

So for each cluster, the value of each sensor node will be calculated as in Eq. (5), and the sensor that has the greatest value will be elected as a cluster head.

4.6 Network stability

When a CH becomes out of energy, it is essential to select a suitable replacement node to take over its responsibilities to maintain connectivity and ensuring the availability of CHs in the cluster. The replacement process for dead Cluster Heads (CHs) plays a crucial role in mitigating the impact on the overall network performance and ensuring network stability. By promptly replacing dead CHs with suitable nodes, we can maintain connectivity, preserve the desired network structure, and sustain the functionality of the protocol.

By promptly replacing dead CHs, we ensure that the network remains operational and that data can be efficiently routed to the sink. As shown in Figure 5, every dead CH inside a round will be directly replaced by a node that has the succeeding value of V(i) illustrated in the Eq. (5).

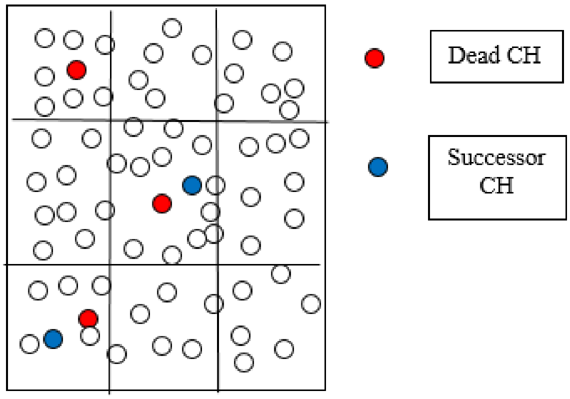

Figure 5. Successor CH inside the round

4.7 Distance between nodes

As our protocol deals with separated clusters with one CH for each, the important distance is between nodes in the same cluster where the distance factor is more important.

If some cells are very dense with sensor nodes and others are not. The densely cells will be divided into two separated ones and they will be considered as two different cells.

5. SIMULATION AND RESULTS

5.1 Simulation parameters

We have chosen a Matlab development environment in which the nodes are homogeneous and randomly deployed in the operational environment. We considered a network with a density of 100 nodes deployed on a square surface of 200×200m^2.

The simulation starts with an initial energy for every node equal to E0=0.1 J and no limited data amount to be sent to the sink. In addition, that sink has no resource limitations (energy, memory, calculation, etc.).

We specify all the parameters used for the scenario simulation, such as energy thresholds, communication ranges, and update intervals, in the Table 2.

To evaluate the performance of LEACH, Mod-LEACH, V-LEACH, S-Leach, and ASC protocols, we are mainly interested in the energy consumption of nodes since it constitutes a paramount parameter for the determination of the WSN lifetime duration. We therefore carry out our simulation according to two metrics: the energy consumption and the lifespan of the sensor nodes.

The comparison of the energy consumption of LEACH, Mod-LEACH, V-leach, S-Leach, and our ASC is the first part of our simulations. The next diagram shows the amount of energy used:

All nodes in the wireless sensor network die in rounds 494,437, 334, 279, and 65 for the ASC, SLeach, Leach, Mod-Leach, and V-Leach protocols, respectively. Compared to reference protocols, this favours our ASC protocol in terms of minimizing energy consumption and thus maximizing the lifetime of the WSN. The energy consumption in our protocol is reduced significantly compared to SLeach and Leach protocols. This is especially important for WSNs, where sensor nodes are put in wide areas where energy is consumed more than small ones.

Table 2. Simulation parameters

Parameters	Values
Network surface	200*200m²
Position of the sink	X=0.5xm, Y=0.5ym
Number of nodes	100
Initial energy of node	0.1 J
Energy threshold	0.00001 J
ET_x (Energy Transmission)	0.00000050 J/bit
ER_x (EnergyReception)	0.00000050 J/bit
Efs (Signal amplification coefficient in free space)	10*0.000000000001
Eamp (Amplification Energy when d> d_0)	0.0013*0.000000000001
E_{agg} (Aggregation energy)	5*0.000000001
P (Probability of being a CH)	0.1
Rmax (Number of rounds)	1000
Communication range	5m

5.2 Network lifetime

In order to assess the WSN lifetime, 1000 iterations (rounds) are performed. The results obtained are illustrated by the graph in Figure 6.

Exploring different network densities, deployment areas, and communication range patterns, various simulations have been done to provide deeper insights into the ASC protocol's performance under various conditions. Table 3 presents detailed simulation results, that compare the performance of the ASC protocol with other protocols under similar conditions.

The network using MOD-LEACH, LEACH, VLEACH, SLeach, and ASC protocols is exhausted after 276, 327, 66, 411, and 484 rounds of the simulation on average, respectively.

The ASC proposed protocol exhibits the highest lifetime compared to the LEACH, Mod-Leach, and SLeach protocols because the first has a better distribution of CHs and fewer energy consumptions compared to other protocols. The increase of network lifetime is about 20% compares to S-Leach and around 30% compared to Leach and 80% compared to ModLeach.

The performance provided by the ASC protocol is achieved through overhead elimination caused by the formation of dynamic clusters in LEACH, V-leach, and Mod-leach.

Table 3. Protocols simulations

Simulations	ASC	Mod-Leach	Leach	VLeach	SLeach
Simulation1	473	278	353	64	437
Simulation2	486	268	338	67	350
Simulation3	481	280	337	66	436
Simulation4	494	278	278	66	420
Average	483.5	276	326.5	65.75	410.75

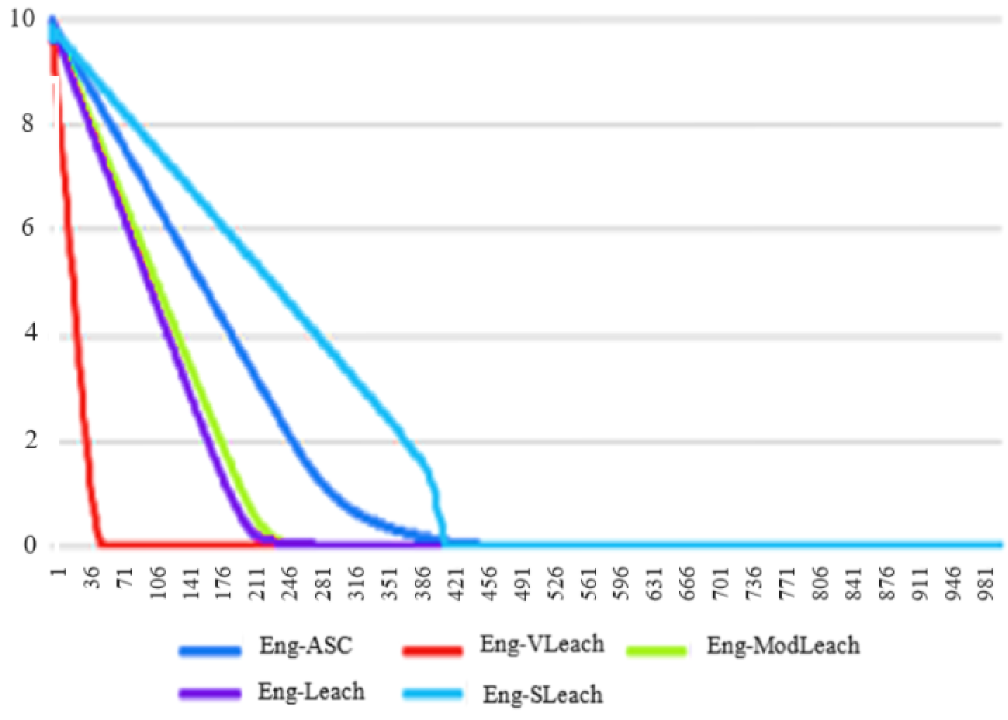

Figure 6. Energy consumption in the 5 protocols

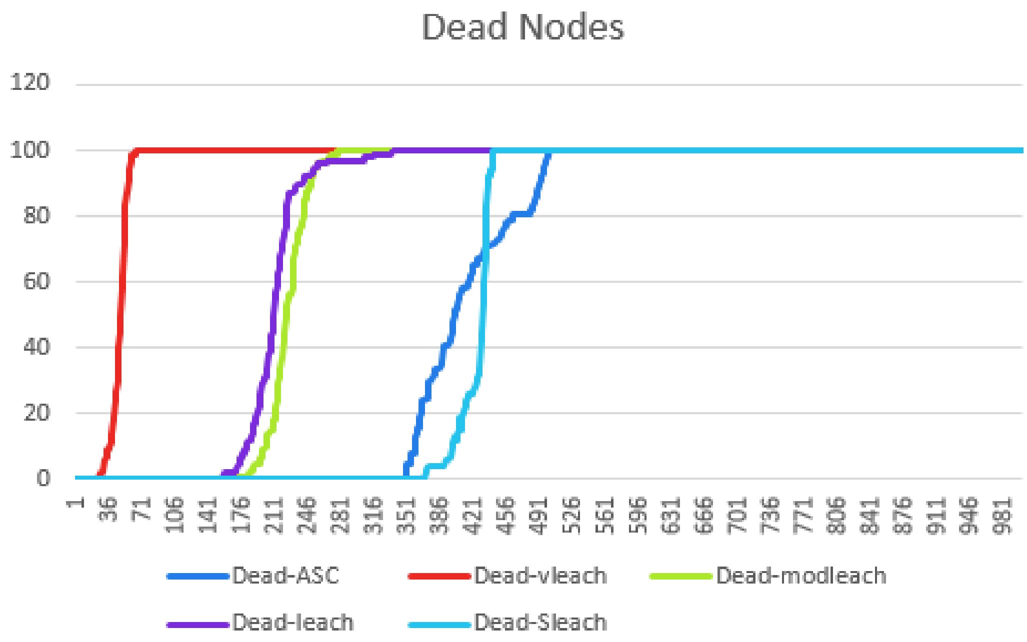

Figure 7. Last dead nodes

5.3 Dead nodes in all protocols

Table 4. Last dead node in the 5 protocols

Protocol	Round
LEACH	334
MOD-LEACH	279
V-LEACH	65
S-LEACH	437
ASC PROTOCOL	494

After 1000 iterations for all precedent protocols, it is clear that our proposed protocol overcomes others and it has the last dead nodes as given in the Table 4:

The next diagram shows the curve of the protocols until the last dead node. Figure 7 shows that our proposed protocol has the last dead node compared to Leach, VLeach, Mod-Leach, and S-Leach protocols.

5.4 Statistics of dead nodes

In the critical round of 450 in the life of the network, a histogram in Figure 8 illustrates the advantage of our protocol because most of networks were dead except ASC where our protocol that takes a big advantage over all others.

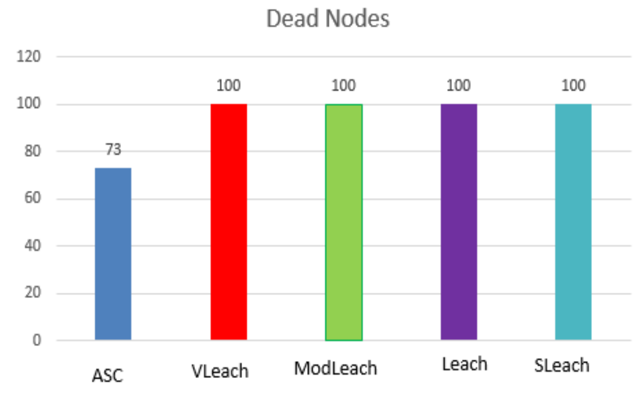

Figure 8. Critical round 450 for dead nodes

5.5 Energy consumption

The energy consumption in the 5 protocols shows that our protocol has drastically decreased the energy consumption.

Because of best choice of CH for each round, using simple processing that minimizes energy consumption and the CH chosen is always the closer to other sensor nodes. Figure 9 shows all networks are out of energy except the network that uses our protocol where energy still enough for more than 50 rounds.

Table 5. Throughput Average

	ASC	MODLeach	LEACH	VLEACH	SLEACH
Simulation 1	16373	23121	21851	2048	90
Simulation 2	15583	22702	21994	2046	2000
Simulation 3	17573	22478	21152	2048	3700
Simulation 4	15215	22791	22791	2050	2300
average	16186	22773	21947	2048	2000

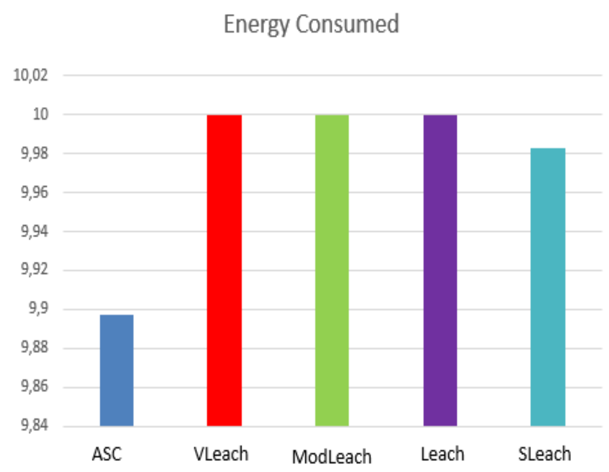

Figure 9. Energy consumed in the round 440

5.6 Throughput

After simulations for Leach, Mod-Leach, V-Leach, S-Leach, and ASC protocols, we obtained the following graph, illustrated in Figure 10. Where the throughput in our protocol is decreased because of less packets sent to the Sink compared to Leach and its derivative.

From Table 5, we can see that the ASC protocol has significantly decreased the number of messages sent to Sink and CHs and has 16186 packets sent on average compared to Leach which has an average of 21947 messages and over 22773 for the Mod-LEACH protocol.

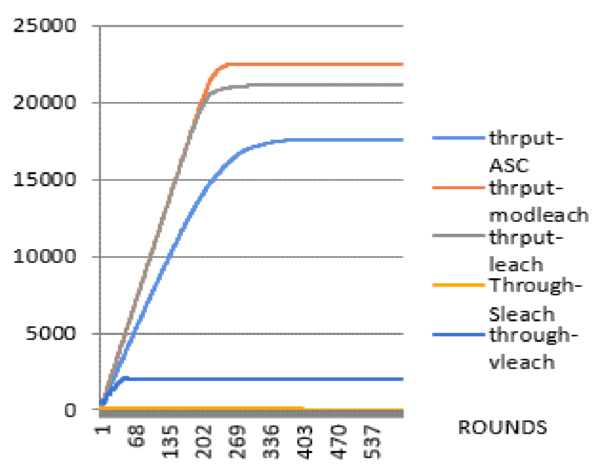

Figure 10. Throughput

For V-Leach and S-Leach, we have a very low throughput that doesn't reach 4000 for both, and S-Leach is slightly under 2000. This is due to the fact that our protocol has the best method for choosing the cluster head for every cluster of nodes, which has decreased the redundancy of the messages sent compared with the two left protocols.

The throughput of our protocol is lower than that of Leach and Mod-Leach because our protocol has significantly and positively reduced the number of messages sent to Sink and CHs, since sending and receiving messages is the most costly activity in terms of node energy dissipation. This also contributes favourably to reducing node energy consumption, which enhances the ability of a WSN to successfully reach its mission.

The proposed ASC protocol adopts a new method for cluster formation and cluster head designation. The performance of our proposed ASC and reference protocols (LEACH, VLEACH, and ModLEACH) has been evaluated according to different relevant metrics, and the results obtained showed that ASC performs better than these well-known competitors, particularly for long-lived WSN applications.

6. CONCLUSION

This paper proposes an Area Splitting for Clustering (ASC) to optimize energy consumption and increase network lifetime. The ASC protocol proposes an innovative approach using geometric equations for selecting Cluster Heads (CH), thus differing from classical probabilistic methods. This helps identify the optimal nodes to act as Cluster Heads (CHs) based on their positions relative to other nodes. Minimizing communication distances between nodes and CHs leads to lower power usage, thereby extending the battery life of sensor nodes. The ASC protocol ensures a more uniform and efficient distribution of CHs compared to probabilistic methods. This results in better resource management and enhanced overall network performance.

In future work, we aim to investigate the protocol's resilience and dependability by evaluating its robustness under various failure scenarios (such as node failures and disruptions in the communication link).

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