DOI: 10.24996/ijs.2024.65.6.38

ISSN: 0067-2904

ESMCH: An Energy-Saving, Multi-Hop, Clustering, and Hierarchy Protocol for Homogeneous WSNs

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Received: 19/12/2022 Accepted: 4/6/2023 Published: 30/6/2024

Abstract

The wireless sensor network (WSN) is one of the most important achievements of the modern technological revolution and greatly affects human life. These networks suffer from some limitations that affect their performance, such as the limited power of their devices. Clustering technology is one of the effective power conservation techniques that improves the performance of WSNs, so this article focuses on developing aggregation technology by proposing an Energy Saving, Multi-hops, Clustering, and Hierarchy (ESMCH) protocol for homogeneous WSNs. The proposed protocol improves clustering technology in several directions. The first direction is by determining the ideal number of cluster head nodes (CHs) suitable for the network, and the second is through the perfect choice of nodes that will represent CHs. The third trend is the selection of secondary CHs. The last trend is the formation of clusters, which depends on an important parameter (distance to CHs). The proposed system uses the TDMA method to schedule the data transfer process to CHs (inside the cluster) and the CSMA method to organize the exchange of data packets between CHs (outside the clusters) for delivery to the base station. The results of simulation experiments in MATLAB R (2020 a) show that the proposed protocol extends network lifetime by 32% compared to the LEACH algorithm and by 26% compared to the SEP algorithm. The results also display that the ESMCH protocol increased the throughput of the WSN by 16.8% compared to its throughput when using the SEP algorithm and by 30% when using the LEACH algorithm.

Keywords: WSNs, Clustering, CHs, TDMA, CSMA, SEP, LEACH.

ESMCH: بروتوكول توفير الطاقة والقفزات المتعددة والتجميع والتسلسل الهرمي لشبكات الاستشعار اللاسلكية

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الخلاصة

تعد شبكات الاستشعار اللاسلكية أحد أهم إنجازات الثورة التكنولوجية الحديثة التي تؤثر بشكل كبير على

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حياة الإنسان. تعاني هذه الشبكات من بعض القيود التي تؤثر على أدائها، مثل محدودية طاقة أجهزتها. تعد تقنية التجميع واحدة من أكثر تقنيات حفظ الطاقة شيوعًا والتي تعمل على تحسين أداء شبكات المستشعرات، لذا تركز هذا البحث على تطوير تقنية التجميع من خلال اقتراح بروتوكول توفير الطاقة، والقفزات المتعددة، والتجميع، والتسلسل الهرمي (ESMCH) لشبكات المستشعرات اللاسلكية المتجانسة. يعمل البروتوكول المقترح على تحسين تقنية التجميع في عدة اتجاهات: أولاً، من خلال تحديد العدد المثالي لعقد رؤوس الكتلة (CHs) المناسبة للشبكة. ثانيًا، من خلال الاختيار المثالي للعقد التي سوف تمثل رؤوس الكتل. الاتجاه الثالث هو اختيار رؤوس الكتل الثانوية. الاتجاه الأخير هو تشكيل الكتل اعتمادًا على معامل مهم وهو المسافة الى رأس الكتلة. استعمل النظام المقترح طريقة (TDMA) لجدولة عملية نقل البيانات إلى CHs (داخل الكتلة)، واستعمل طريقة (CSMA) لتنظيم تبادل رزم البيانات بين رؤوس الكتل (خارج المجموعات) لتسليمها إلى المحطة الأساسية. أظهرت نتائج تجارب المحاكاة في برنامج MATLAB R (2020 a) أن البروتوكول المقترح يطيل عمر الشبكة بنسبة 32٪ مقارنة ببروتوكول LEACH وبنسبة 26٪ مقارنة مع بروتوكولSEP. أظهرت نتائج المحاكاة أيضًا أن البروتوكول المقترح زاد من إنتاجية شبكة الاستشعار اللاسلكية بنسبة 16.8٪ مقارنة بإنتاجيته عند استعمال بروتوكولSEP، وبنسبة 30٪ عند استعمال بروتوكول LEACH .

1. Introduction

Recently, significant advances in microprocessors and the widespread growth of wireless communications have resulted in the production of small-scale smart sensors that have the ability to constantly track physical changes in environments and have the ability to communicate with each other wirelessly to create a network known as a Wireless Sensor Network (WSN). WSNs consist of a base station that collects and processes data transmitted from a group of wirelessly connected sensors deployed in a given environment for the purposes of independent long-range monitoring. WSNs have many civil and military applications, such as remote health monitoring, smart home automation, tracking of people or vehicles, monitoring of chemically polluted environments, monitoring of volcanic activity, earthquakes, natural disasters, and others [1]. Wireless network sensors are usually designed with a small size and limited resources (computational capacity, power supply, and storage capacity), so they must reduce resource consumption to increase network efficiency and lifetime.

Many researchers have tried to solve the problem of limited power for sensors (sensors run on a battery with limited power and cannot be backed up or replaced, especially in environments that humans don't have access to). Therefore, some researchers have developed sensors with electronic circuits that consume very little power, and others support the limited power of the sensors by designing protocols based on modern energy-saving technologies [2]. Clustering is an efficient power conservation and scalability technique frequently used in the design of routing protocols. Clustering is a very useful technology in WSNs because it brings several benefits, like balancing power consumption between nodes, extending network life, improving network throughput, reducing the number of devices directly connected to the sink, and thus reducing packet loss due to collisions [3]. The optimal formation of clusters and the appropriate election of CHs are urgent necessities to increase the effectiveness of cluster techniques towards achieving their goals. The clustering technique involves distributing network devices into several clusters and then electing one of the cluster nodes to represent CH, which is accountable for collecting data from other members and transmitting it directly or indirectly to the sink.

The process of electing CHs is carried out in several ways, such as the probability method, randomness, centralized control, etc. Therefore, the correct election of the CH node increases the efficiency of the clustering technique [4], [5]. From this point of view, this work focuses on proposing an energy-saving, multi-hop, clustering, and hierarchy algorithm for homogeneous WSNs. The proposed protocol aims to increase the effectiveness of WSNs by balancing power consumption and growing network lifetime while increasing throughput. The proposed algorithm involves two stages: set-up and steady-state. The set-up stage includes the process of determining the ideal number of CHs suitable for the network (per cycle), the process of selecting CHs (and secondary CHs), and the process of creating clusters.

In the proposed algorithm, the traditional clustering method is improved in several directions: first, by determining the ideal number of CHs suitable for the network. The second is electing appropriate nodes that will represent nodes of CHs, depending on four important parameters (node density, node centrality, node energy, and distance to the base station). The third trend is to select secondary CHs (if necessary) according to two parameters: residual power of the primary CH and distance to sink. The last trend is to form clusters depending on an important parameter (distance to CHs nodes). At the steady-state stage, CHs start collecting data from sensors (cluster members) based on the Time Division Multiple Access (TDMA) approach [6]. Then, the cluster heads transmit data directly to the sink if they are close to it or send data to the sink in a multi-hop manner via other intermediate cluster heads (to reduce the transmission distance, which decreases power exhaustion for the devices).

Data packets exchanged between CHs nodes (multi-hop transmission) implemented outside clusters are based on the Carrier-Sense Multiple Access (CSMA) scheme [7] in order to reduce data packet collisions. This paper is arranged as follows: Section 1 presents an introduction to WSNs. Section 2 outlines some of the related works. Section 3 provides an overview of the suggested approach. Section 4 provides details of the radio propagation model. Section 5 provides details of the suggested approach. Section 6 describes the simulation and evaluation of experiments. Section 7 sets out the conclusions of the results and future work.

2. Literature Survey

Heinzelman et al., in 2000 [8], defined a Low-Energy Adaptive Clustering Hierarchical (LEACH) approach for WSN. LEACH is a cluster-based protocol that uses a mechanism to distribute devices to several local clusters, each cluster consisting of members and a CH node (which is the node that collects data from cluster members and sends it to the sink). The CHs are elected periodically and randomly, distributing the power consumption evenly among the cluster devices. The CH selection process is done by the probabilistic method; each device creates a random number ranging between 0 & 1 (in each cycle), and then this number is tested. If the number generated by a given sensor is less than a certain threshold value, then that sensor is elected as a CH (for this cycle only); otherwise, it is considered a member of the cluster. The threshold value (*Thr (no.d)*) is calculated according to the following formula:

$$Thr\ (no.d) = \begin{cases} \frac{Pre}{1-Pre \times \left(CC\ mod \frac{1}{Pre}\right)} & no.d < S.D \\ 0 & others \end{cases} \quad (1)$$

Here, (*no.d*) indicates the total number of devices. (*Pre*) indicates the ratio among the expected numbers of elected CHs to the number of devices in the network. (*CC*) refers to the current cycle. (*S.D*) represents the set of devices that did not act as CH in the last (*1/pre*) cycle. The LEACH algorithm still has some weaknesses, such as adopting randomness to choose CHs without caring about the remaining power in the devices. In addition, LEACH adopts a one-hop scheme to transmit packets from the CHs to the sink without considering the distance between them, which leads to fast energy dissipation of the nodes.

Toor, A. S., and Jain, A. K., in 2019 [9], presented a Mobile Energy Aware Cluster Based Multi-Hops (MEACBM) method for hierarchy heterogeneity in wireless sensor networks. The MEACBM algorithm elects suitable nodes to represent the CHs through a model in which the residual power factor is a prerequisite for electing the CHs nodes. The suggested approach adopts the principle of dividing the heterogeneous network into three layers: the first and second layers, where nodes exchange data within one cluster (single-hop). The third layer involves exchanging data outside of clusters (multi-hops). The proposed algorithm is based on dividing the network space into segments, after which a suitable sensor is chosen to represent a mobile packet collector (responsible for collecting packets from cluster head nodes). The results of simulations showed that the MEACBM approach achieves the highest performance in terms of extending the network life, increasing throughput, and improving its stability period compared to other approved clustering algorithms.

Ayoub et al., in 2017 [10], suggested a Multi-Hop Advance Heterogeneous Energy Effective (MAHEE) protocol for WSNs. The suggested approach is based on the idea of proper selection of cluster head sensors and advanced cluster head sensors (taking into account node power). It relies on the mechanism of multi-hops out of clusters to raise the stability period of the network. Simulation experiments showed that the suggested algorithm increases the reliability of WSN compared to the results of the protocols (LEACH, SEP, DEEC, MAHEE, and M-LEACH), as it reduces power exhaustion, which increases the network balance and life.

Nasr and Quwaider, in 2020 [11], proposed an efficient clustering algorithm to decrease power exhaustion and increase the lifetime of wireless sensor networks, which is an evolution of the LEACH approach. The suggested approach is based on the election of CHs sensors according to the remaining energy in the nodes as well as the adoption of multi-hop mechanisms between clusters. The suggested approach uses the secondary CHs selection method to reduce power consumption and ensure no data packet loss. The simulation results showed that the suggested approach improves the network lifetime by 128.80% compared to the performance achieved by the LEACH algorithm.

3. Overview of the Proposed Protocol

The suggested protocol is designed to prolong the lifetime of WSNs by increasing the balance of energy consumption between sensors and to increase network throughput by reducing lost data packets. These goals were achieved by developing the clustering mechanism and making it more efficient, reducing the consumption of network nodes. The proposed algorithm develops the traditional clustering method (at the set-up phase) in different directions: firstly, by determining the ideal number of CHs suitable for the network, and secondly, by electing nodes that will ideally represent CHs nodes, depending on four important parameters (node density, node centrality, node energy, and distance to the sink). The third trend is the election of secondary CHs (to minimize power exhaustion of primary CHs), according to two parameters (residual power in the primary CH and distance to the sink).

The last trend is to form clusters depending on an important parameter (the distance to the nodes of the CHs). Figure 1 illustrates a model of the network topology used in this work, which shows the random deployment of a large number of devices with a single base station (sink) in a given environment. We hypothesize that the hierarchical structure of the homogeneous network consists of four levels of sensors, all of which communicate with each other and with the sink. The first level of nodes (sensors) refers to the members of the clusters (nodes in blue). The second level represents the sensors of the secondary CHs (nodes in black), which are the sensors responsible for collecting data from other sensors and transmitting it directly to the primary CHs.

The third level represents the sensors of primary CHs (nodes in red), which are the sensors responsible for collecting data from other sensors (or from secondary CHs) and sending it to the sink directly or via other intermediate CH nodes. The fourth level in the network represents the advance cluster heads (ACHs) nodes (the sensors near the sink that have the gray color). ACHs are the nodes accountable for passing the packets of the remote CHs nodes directly to the sink. The proposed approach adopts the method of electing new cluster head nodes in each data transmission cycle so as to distribute the power consumption among the cluster sensors, which increases the network balance. In addition, the proposed protocol uses the TDMA method to forward packets from sensors to CH in order to schedule the data transfer process and avoid data packet collisions. Regarding the exchange of data packets between CHs in a multi-hop method, the proposed protocol uses the CSMA method to avoid data packet loss, which increases network reliability and throughput.

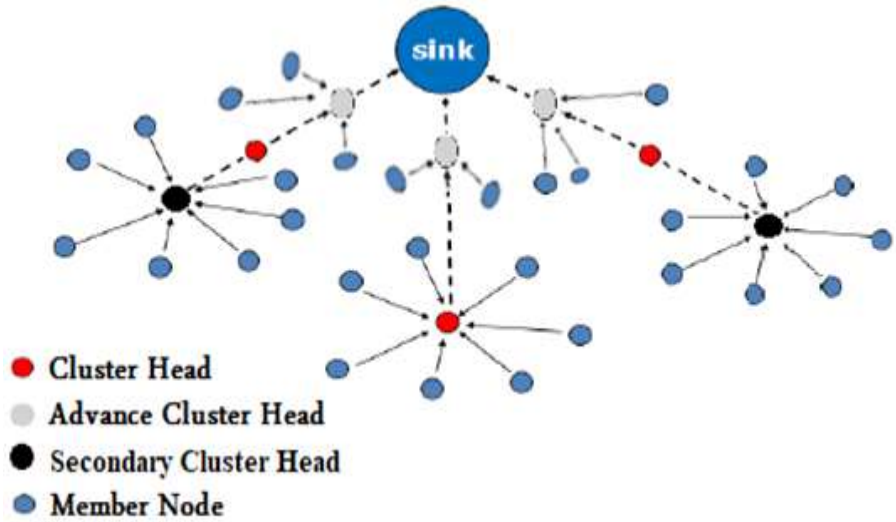

Figure 1: Network structure.

In the proposed network model, the sensor nodes are randomly deployed in the respective environment in order to get a greater degree of relaxation from some of the network constraints. Some assumptions that will facilitate this work will be defined as follows:

- All sensors remain fixed in their positions after they are installed in the working environment.
- Network sensors do not have any external battery support. That is, their batteries cannot be recharged or replaced once they are installed in their positions.
- All sensor nodes in the network are homogeneous in terms of initial battery power, storage resources, and processing capabilities.
- Sensors in the network are connected to a single static sink (BS) located at one end of the network, and there are no restrictions on base station power, processing resources, or memory.

- The base station is responsible for determining the ideal number of clusters, clustering nodes, defining the roles of all nodes in the network, and controlling data transfers across the network.
- Cluster master nodes are responsible for collecting the data of cluster members, performing data pre-processing such as discarding redundant data, and aggregating and sending the data in the form of a single packet.
- The distance between one sensor and another can be estimated according to the received signal strength indicator.
- The proposed algorithm assumes that all nodes are equal in terms of the extreme radio range (the radio range represents the maximum possible distance for a node to send data in the form of electromagnetic waves).
- Sensor nodes turn off the transmitter's radio antenna until the exact time to transmit its data, thus conserving more power.
- The wireless radio links are symmetric, which means that the energy consumed in sending packets from sensor *S* to sensor *N* is the same as the energy expended in sending data from sensor *N* to sensor *S*.

The following algorithm outlines the basic steps of the proposed protocol:

Step 1: Establishing a wireless sensor network by distributing (100) sensors randomly and installing a fixed base station (sink) on an area of (100 * 100 m^2). (Set-up phase)

Step 2: The sink sends information packets to the sensors (containing their coordinates). Sensors respond to the sink by sending packets of information (including location coordinates, amount of energy, and distance to the base station). (Set-up phase)

Step 3: Determine the ideal number of clusters to form according to the number of sensors in the network, the distance to the base station, and the dimensions of the network. (Set-up phase)

Step 4: The base station calculates the chance of each sensor representing a CH node based on the values of the chance function that is calculated using four parameters (sensor energy, sensor density, sensor centrality, and distance to the base station). (Set-up phase)

Step 5: The formation of network clusters is done by connecting nodes to the nearest CH (the distance between nodes and CHs depends on the RSSI). (Set-up phase)

Step 6: The CHs assign (TDMA) to each child node, and then the child nodes begin forwarding their data to the CH (if the distance between the child nodes and the sink is greater than the distance between the node and the CH; otherwise, the child nodes will send their data directly to the sink). (Steady-state phase)

Step 7: For each CH, if the distance between CH and ACH (CH near the sink) is closer than the distance between CH and the sink, the data will be sent to the ACH; otherwise, the data will be sent directly to the sink. (Steady-state phase)

Step 8: For each CH, if the residual energy of the CH is less than the average energy of the cluster nodes, a secondary CH node (the one with the highest energy) will be selected to reduce the energy consumption of the primary CH node. (Steady-state phase)

The following pseudo-algorithm gives a general description of the proposed protocol:

The pseudo ESMCH algorithm

*1. **START***
n =Total no. of sensors, Sink =Base Station;
A= Length of the square area of the network;
*3. **Sensor-information***
sensor[n]. Location = Current location of the sensor;
sensor [n]. Energy = Current energy of the sensor;

sensor [n]. Type = 'S';
(Initially all sensors are normal sensors (S), CH = Cluster head sensor, S-CH = Secondary Cluster head sensor, ACH = Advance Cluster head sensor)
4. For each sensor [n],
*Send sensor-information to the Sink (**set-up phase**)*
Input variables for calculating the chance function (CF)
sensor [n].SE = Energy of Sensor;
sensor [n].SDe = Sensor Density;
sensor [n].SCe = Sensor Centrality;
sensor [n].D.BS = Distance to the Base Station;
Determining the optimal number of CHs (Opt-CHs $_{NO}$)

$$\text{Opt-CHs}_{NO} = \sqrt{\left(\frac{n}{2\pi}\right) * \left(\frac{A}{sensor[n].D.BS}\right)}$$

Calculate the chance of each sensor to represent the CH using the chance function (CF)
For each sensor [n],
Sensor [n]. CF = (sensor [n].SE + sensor [n].SCe + sensor [n].SDe) / sensor [n].D.BS
End.
5. Selection of cluster heads with maximum (CF), (sensor [n]. type = 'CH')
6. Clusters formation based on the distance to (sensor [n].'CH'), (Distance estimated based on RSSI)
*7. Each (sensor [n].'CH') allocate TDMA to each (sensor [n]. S) in their cluster (**Steady-state phase**)*
8. For each (sensor [n].'CH'), If (distance $_{(CH\ to\ Sink)}$ > distance $_{(CH\ to\ ACH)}$) Then use multi-hop scheme (sent data to the ACH nodes, based on CSMA method)
Else
Use single-hop scheme (sent data from CHs to the sink directly)
9. For each (sensor [n].'CH'), If (sensor [n].SE $_{(CH)}$ < average sensor [n].SE) Then select (sensor [n].type ='S-CH')
Each (sensor [n].'S-CH') allocate TDMA to each (sensor [n]. S) in their cluster
Each (sensor [n].'S-CH') send data directly to (sensor [n]. 'CH')
Else
Use normal transmission (send directly to (sensor [n].'CH'))
*10. **END***

4. Radio Propagation Model

The radio wave propagation model directly influences the calculations of the quantities of dissipated energy needed to power the electronic circuits of sensors, energy amplifiers, and radio equipment that transmits and receives data. In this work, we use the wireless power consumption model listed in [12] because it is most commonly used in WSNs, is easy to handle, and accurately simulates the amount of power consumed to complete sensor operations. The distance between the receiving and transmitting sensors is the main factor in power attenuation. In this model, the distance is indicated by the symbol (d). The amount of attenuation of the signal transmitted over the transmission channel is denoted by (d^2) for short distances and (d^4) for long distances. The following formulas show the details of the power consumption model [12], [13], and [14]:

$$E_{Tx}(l;\ d) = \begin{cases} E_{elec} \times l + E_{fs} \times l \times d_2 & d < d_{th} \\ E_{elec} \times l + E_{mp} \times l \times d_4 & d \geq d_{th} \end{cases} \tag{2}$$

$$E_{Rx}(l) = E_{elec} \times l \tag{3}$$

Here, E_{Tx} *(l; d)* indicates the amount of power dispersed to send a (*l*-bit) message through a radio channel at distance (*d*). $E_{Rx}(l)$ represents the power consumed to receive (*l*-bit). (E_{elec}) refers to the amount of energy dispersed in the electronic circuits of the receiver and transmitter. (E_{mp}, E_{fs}) indicates the energy dissipation factor of the amplification circuits of the transmitted signal in the multi-path and free-space models, respectively. (d_{th}) represents the distance threshold, which is calculated according to the following formulas [15], [16]:

$$d_{th} = \sqrt[2]{\frac{E_{fs}}{E_{mp}}} \quad (4)$$

Model (2) is designed to calculate the amount of energy dissipated for the transmitted nodes only. Therefore, to raise the precision of the calculations, a new model for calculating the dissipated energy of the CHs nodes is built based on the previous models, as follows:

$$E_{CH}\,(l,d) = \begin{cases} (\frac{n}{nc} - 1)(E_{RX} \times l + \frac{n}{nc} \times l \times E_{ADa} + E_{TX} \times l + E_{fs} \times d^2_{to\ sink}) & d < d_{th} \\ (\frac{n}{nc} - 1)(E_{RX} \times l + \frac{n}{nc} \times l \times E_{ADa} + E_{TX} \times l + E_{mp} \times d^4_{to\ sink}) & d \geq d_{th} \end{cases} \quad (5)$$

where, (*n*) refers to WSN nodes. (*nc*) represents the number of clusters in the network. $(\frac{n}{nc} - 1)$ indicates the number of nodes in one cluster. (E_{ADa}) represents the amount of energy consumed to aggregate the data.
Figure 2 shows the power consumption model used in the proposed algorithm [17].

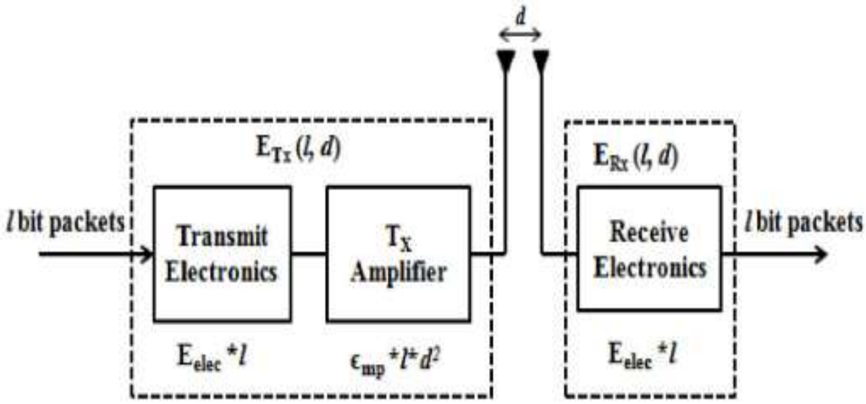

Figure 2: Radio propagation model [12], [13].

5. The Proposed Energy-Saving, Multi-hop, Clustering, and Hierarchy Protocol

5.1 The Stage of Determining the Ideal Number of CHs

Most hierarchical clustering algorithms are based on randomly dividing the network into several clusters. If the number of clusters in the network is too small, the cluster heads will bear a heavy load (because there are a large number of devices that will send a large number of data packets to them), so some cluster heads will die early due to rapid power loss. However, if the number of clusters formed in the WSN is too large, this will result in an unnecessarily large overhead because the cluster heads (CHs) will broadcast more messages to all sensors in the WSN. Suppose a number of sensors (*NO*) are randomly distributed over a square area (A×A). Suppose the sink is stationary on one edge of the square area. So, the distance from any CH or nodes to the sink (*D.BS*) is equal to or less than (d_0), where [18]:

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \quad (6)$$

So, the optimal number of CHs (*OPT-CHs* $_{NO}$) in the network can be found according to the following formula:

$$Opt - CHs_{NO} = \left(\sqrt{\frac{NO}{2\pi}}\right) \times \frac{A}{D.BS} \quad (7)$$

However, if the distance between some nodes or CHs and the base station is greater than (d_0), then the optimal number of CHs is calculated as:

$$Opt - CHs_{NO} = \left(\sqrt{\frac{NO}{2\pi}}\right) \times \left(\sqrt{\frac{E_{fs}}{E_{mp}}}\right) \times \frac{A}{D.BS} \quad (8)$$

5.2 The Stage of Determining the Cluster heads

The set-up phase is the first step of the suggested protocol, during which the network architecture is configured by selecting appropriate cluster heads and connecting nodes with each other to create clusters. The network set-up stage of the proposed algorithm begins according to the following scenario: Sink broadcasts hello messages (requests for information) to every sensor within the operating environment. When sensor nodes receive control messages from the base station, each node will reply with an information packet that involves the node's address (ID), its location coordinates, and how much power it has. When the sink receives information packets from the sensors, it stores the sensors' information in its memory (the addresses of the devices, their location coordinates, and how much power they have), so the base station learns about the overall network topology. Then, the sink computes the opportunity of each sensor to represent a cluster head node using the chance function (*CF*), which depends on four important parameters (node density, node centrality, node energy, and distance to the base station). The chance function value for each sensor is estimated using the following model:

$$CF_{sensor} = \frac{(S.C + S.RE + S.D)}{D.BS} \quad (9)$$

where the following subsections describe the full details of the Eq. (9) parameters:

1) Sensor centrality (S.C): This parameter refers to how much the sensor is mediated among its neighbors (ambient sensor). A sensor with a higher value (SC) has a higher chance of acting as a CH node. Sensor centrality can be calculated based on the following mathematical models [19], [20], and [21]:

$$S.C = \frac{\sqrt{\sum_{i=1}^{S.D} \frac{(Dist_i)^2}{S.D}}}{E_{Dim}} \quad (10)$$

Here, (*S.D*) refers to the sensor degree (number of adjacent one-hop sensors within a sensor's radio-communication range). ($Dist_i$) refers to the distance between (*ith*) adjacent sensors. (E_{Dim}) indicates the dimensions of the working environment (A x A).

2) Sensor energy: This parameter represents how much power is left in the sensor after each data transmission, reception, or processing. The proposed algorithm uses the following energy model to calculate the amount of energy consumed (in the two processes of receiving and sending data packets) [22], [23], and [24]:

$$S.RE = S.CE - (E_{(\boldsymbol{Tx})} + E_{(\boldsymbol{Rx})}) \quad (11)$$

Here, (*S.RE*) is the residual energy of a particular sensor. (*S.CE*) indicates the current sensor energy. ($E_{(Tx)}$, $E_{(Rx)}$) refers to the cost of transmitting and receiving power, calculated based on Eqs. (2) and (3), respectively.

3) Sensor density (S.D): This parameter indicates the total number of sensors that are inside the broadcast range of the respective sensor. The sensor density value can be determined using the following formulas [25], [26], and [27]:

$$S.D = \sum_{S \neq A} \{dis_{(S,A)} < T.R_S\} \quad (12)$$

Here, (S) is a given sensor. (A) is the number of adjacent nodes. ($Dis_{(S,A)}$) indicates the distance between a given sensor and adjacent nodes. ($T.R_s$) indicates the range of transmissions for a given sensor.

4) Distance to the base station (D.BS): This parameter represents the distance between the assigned sensor and the base station within network range. The distance between the selected sensor and the base station can be calculated based on the Euclidean model, as follows [26], [28]:

$$D.BS_{(S,BS)} = \sqrt{(X_S - X_{BS})^2 + (Y_S - Y_{BS})^2} \quad (13)$$

Here, (X_S, Y_S) represents the location coordinates of a particular sensor. (X_{BS}, Y_{BS}) represent the location coordinates of adjacent sensors.

After calculating the opportunity values of every sensor (depending on the chance function) in the base station, the base station will assign these values to each sensor. Then, the optimal number of nodes with the highest opportunity values will be determined to represent the cluster head nodes in different regions of the network. In addition, the cluster head sensors closest to the base station will represent the advanced cluster head sensors (ACHs), which are responsible for passing data packets from distant cluster heads directly to the base station, thus realizing the hierarchical structure of the network and saving more energy. This scenario is repeated for every new transfer round until the battery power on all sensors reaches zero.

5.2 Clusters Formation Stage

The set-up phase includes another important process, namely the cluster formation process. The cluster formation stage comes after the process of electing the appropriate sensors to represent the CHs nodes in the current cycle. Elected cluster head sensors start broadcasting announcement messages to all surrounding sensors using the carrier-sense multiple access MAC approach, informing nearby sensors that they can associate with them and form clusters. Non-CHs sensors receive several announcement messages from multiple cluster heads, so they will decide to associate with the appropriate cluster head depending on how close they are. Non-CHs nodes estimate the distances using the received signal strength indicator (RSSI) scale. The relationship between the received signal strength indicator and the communication distance is expressed in the following formulas [29], [30], and [31]:

$$RSSI\ (dis) = RSSI\ (d_0) - 10 \times n \times log\ (dis\ /\ d_0) - X\sigma \quad (14)$$

Here, *RSSI (dis)* indicates the received signal strength indicator in dBm for a given distance (*dis*) between a specific node and the anchor sensor. *RSSI* (d_0) indicates the received signal strength indicator in dBm for the reference distance (d_0) between the reference node and the anchor sensor. (X) stands for the Gaussian noise random variable. (σ) represents the standard deviation. (n) indicates the amount of loss in the communication channel, usually compensated with values from 2 to 4 (depending on the nature of the carrier medium). Using Eq. (14), the distance (*dis*) can be calculated as in the following models [29], [32], and [33]:

$$dis = d_0 \times 10 \times ((RSSI\ (d_0) - RSSI\ (dis) - X\sigma)\ /\ 10 \times n) \quad (15)$$

Depending on the previous context, the non-CHs sensors will be associated with the cluster head closest to them by sending a response message that includes the address of the cluster head they chose to join. According to the previous scenario, the converging sensors will organize with each other and with their parents (CHs), thus forming clusters in the network structure.

5.4 Choosing Secondary Cluster heads

After the clusters form, there is a possibility that some selected cluster heads will lose power very quickly (especially if the distance between them and the sink is very large). To avoid this situation, other nodes in the clusters will be selected to represent secondary cluster heads (SCHs). The SCH is accountable for aggregating data from other sensors and passing it to the main CH, thus reducing the waste of CH power and the power waste of other member sensors by reducing the transmission distance towards CH. The decision to select a SCH node depends on the current power of the main CH (*E (CH)*) and the distance from it to the base station (*Dis (CH)*), as follows: If (*E (CH)* < E_{AV} and *Dis (CH)* > D_{AV}), then select SCH with maximum energy; otherwise, the SCH is not required. (E_{AV}) represents the average energy of all sensors in the cluster. (D_{AV}) denotes the average distance between sensors in the cluster and the base station. The average energy and average distance can be estimated according to the following models:

$$E_{AV} = \sum_{1}^{N} E(S)_{Cluster} \quad (16)$$

$$D_{AV} = \sum_{1}^{N} D(S)_{Cluster} \quad (17)$$

In clusters that choose a SCH node, the SCH node will broadcast a control message to the rest of the cluster members and then create a schedule for the nodes using the Time Division Multiple Access (TDMA) mechanism. In clusters that do not need a SCH, the main CH will broadcast control messages and set scheduling (using a TDMA mechanism) to the rest of the cluster members.

5.5 The Stage of Sending Data Packets

The packet transmission stage (steady-state stage) begins after the formation of clusters by linking child nodes (non-CH) to parent nodes (CHs) and forming a hierarchical network structure. The selected CHs use the TDMA mechanism to schedule the transmission of data packets to them and avoid packet collisions. The TDMA mechanism involves allocating time slots within a specific time frame to each sensor (child) to send its data packets within the allotted time. That means each sensor can send its data to the CH node at the assigned time, except for the node that will wait for its allotted time. According to the TDMA mechanism, when the sensor has data to send in the allotted time, it will turn its radio into wake-up mode, and when it has no data to forward, it will go into sleep mode. So, the TDMA mechanism will definitely reduce the power consumption of sensors. Using the TDMA mechanism also reduces packet loss due to collisions, which increases network throughput. CHs are responsible for aggregating packets from the connected sensors (children) and sending them directly to the sink if the distance between them is small. However, when the distance between the CHs and the base station is too great, it sends data packets to the sink through the advanced CHs sensors (CHs nodes near the base station), according to the Carrier-Sense Multiple Access (CSMA) mechanism.

6. Simulation and Evaluation of Results

In this part, we investigate the performance of the suggested protocol towards reducing power consumption and extending network lifetime for WSNs by introducing various performance metrics computed on the basis of several experiments conducted using MATLAB R (2020 a) software. To demonstrate the stability and efficacy of the ESMCH protocol for WSNs, its results are compared with those of the LEACH algorithm [8] and the SEP algorithm [34] in the same homogeneous setting. Simulation parameters with their values are given below in Table 1 [35], [36], and [37].

Table 1: Network settings.

Parameters	Values
Simulation area size	100 x100 m^2
Number of simulation devices	100
Packet size	4000 bits
Announcement packet size	25 bytes
Base station location	(50,100)
Initial energy of each node	0.5 J
Electronics energy (E_{elec})	50 nJ/bit
Free space form of sender amplifier (E_{fs})	10 pJ/bit/m^2
Multi-path form of sender amplifier (E_{mp})	0.0013 pJ /bit/m^4
Energy of data aggregation (E_{DA})	5 nJ / bit / signal
RSSI coefficient (n)	4
Standard deviation (σ)	4.1
RSSI for one meter with Chipcon CC2420	-95 dBm

Three important performance metrics related to power consumption are used to evaluate the performance of the ESMCH protocol by comparing its results to those of the LEACH and SEP protocols for 12000 rounds, as described in the subsections below:

1) Network lifetime: This metric indicates the time calculated from the moment the network formed to the moment the network completely shut down (the last device in the network dies). Figure 3 displays the lifetime of the WSN when using the ESMCH protocol compared to the network lifetime when using the LEACH and SEP protocols. By comparing the results, we can easily observe that the stability period (the time calculated from the start of network operations to the time of death of the first device in the network) of the WSN is improved using the ESMCH protocol compared to the network stability period when the LEACH and SEP protocols are used. With the ESMCH protocol, the first node died after 1500 rounds, while with the LEACH and SEP protocols, the first node died after 600 and 1200 rounds, respectively. Figure 3 also shows that the WSN lifetime increases significantly with the ESMCH protocol compared to the LEACH and SEP protocols. Since the last node in the network died after 9240 rounds when using the ESMCH protocol, while with the LEACH and SEP protocols, the last node died after 6985 and 7276 rounds, respectively, This means that the ESMCH protocol increases the lifetime of WSN by 32% compared to the LEACH protocol and by 26% compared to the SEP protocol. The good performance of the ESMCH protocol is due to several reasons: firstly, by determining the ideal number of CH, which reduces the wasted power of network sensors; secondly, by using the effective chance function (based on effective parameters), which provides great accuracy when selecting new cluster head nodes in each round, thus balancing the power consumption of the network; thirdly, by reducing the energy consumption of the nodes by using the multi-hop method (in/out clusters) which reduces the transmission distance, and fourthly, the secondary cluster heads mechanism adopted, which reduces the energy consumption of the main cluster heads, thus ensuring a complete delivery of sensor data. Finally, the use of CSMA and TDMA mechanisms reduces the occurrence of data packet collisions in the network, increasing the stability and efficiency of the network. Table 2 shows a comparison of the number of dead devices for the three protocols per round.

Table 2: No. of dead nodes, per rounds.

Protocols	First sensor die	Middle sensor die	Last sensor die
ESMCH	1500 R	2539 R	9240 R
LEACH	600 R	992 R	6985 R
SEP	1200 R	1882 R	7276 R

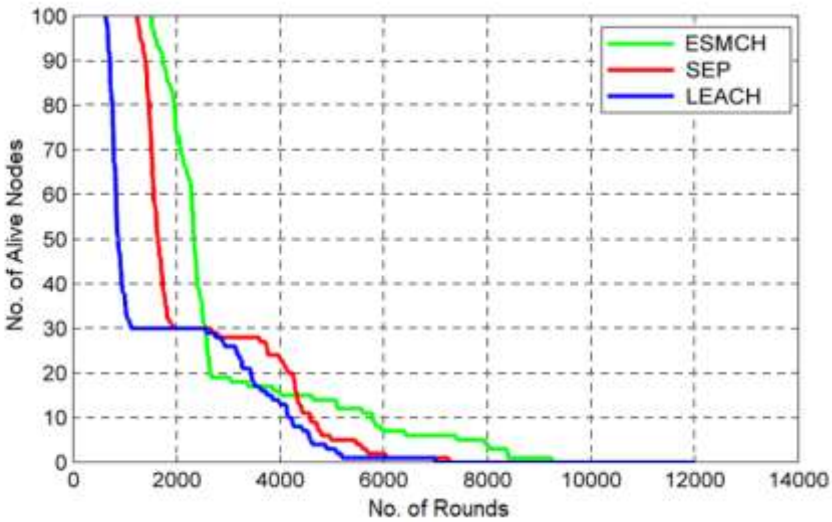

Figure 3: Network lifetime.

2) Residual energy: This measure indicates the total power left in all network devices after the traffic cycle is complete. Figure 4 displays the total residual power in the network devices when using the ESMCH protocol, which is much greater than the remaining energy when using the LEACH and SEP protocols. This means that the amount of energy wasted by WSN nodes when using the ESMCH protocol is much lower than that of other protocols. When using the ESMCH protocol, network nodes have more residual power in most of the simulation rounds, with more residual power after 7276 rounds, in contrast to the remaining protocols, which consume the most network nodes' power after 7276 simulation rounds. That is, the ESMCH extends network life more than other protocols. The high performance of the suggested protocol is due to the careful election of new CHs nodes at all rounds, which results in a balance of energy consumption among the network nodes. Besides, using effective mechanisms to reduce energy waste, like determining the appropriate number of cluster heads, selecting secondary CH nodes (when needed), and adopting a multi-hop mechanism to avoid collisions of data packets in the network depending on the TDMA and CSMA mechanisms, reduces the re-transmission of dropped data packets.

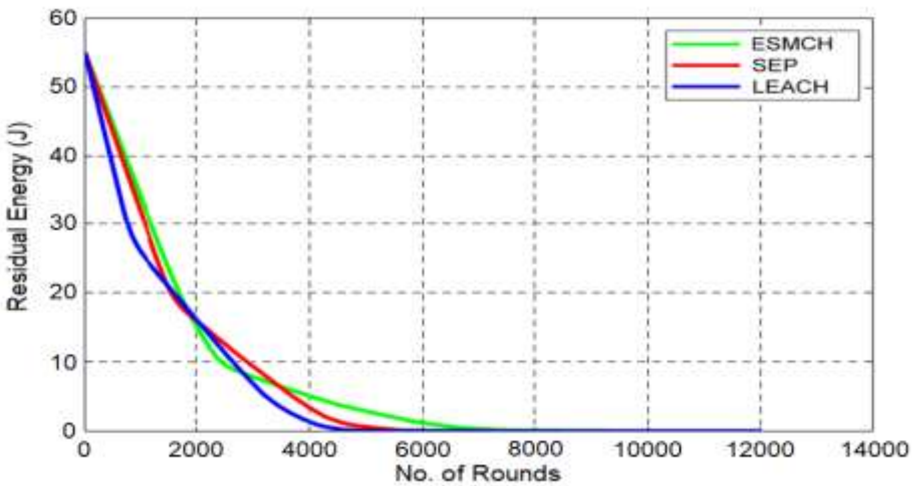

Figure 4: Residual energy (J).

3) Network throughput: It refers to the total number of packets transmitted over the network that successfully reach the base station per second. Figure 5 clearly shows that the total number of data packets successfully received at the sink when using the ESMCH algorithm is much larger than the number of packets when using the SEP and LEACH protocols. This means that ESMCH has achieved higher network throughput compared to other protocols. The LEACH protocol achieves 1765 x 10^4 packets; the SEP protocol achieves 3784 x 10^4 packets received at the base station; and the ESMCH protocol achieves 3971 x 10^4 packets received at the sink. This means that the ESMCH protocol has improved the network throughput by about 16.8% compared to its throughput when using the SEP protocol and by 30% compared to its throughput when using the LEACH protocol. The higher network throughput obtained by the ESMCH protocol is due to the lower power depletion of network sensors and thus the increase in the number of live nodes (the increase in live sensors leads to an increase in the number of packets that are forwarded through the network). In addition, the use of the TDMA and CSMA mechanisms reduces the number of lost packets. Table 3 shows the total throughput of the WSN when using the ESMCH, LEACH, and SEP protocols per round.

Table 3: WSN Throughput, per rounds.

Protocols	Number of data packets received at the sink
ESMCH	3971x104
LEACH	1765x104
SEP	3784x104

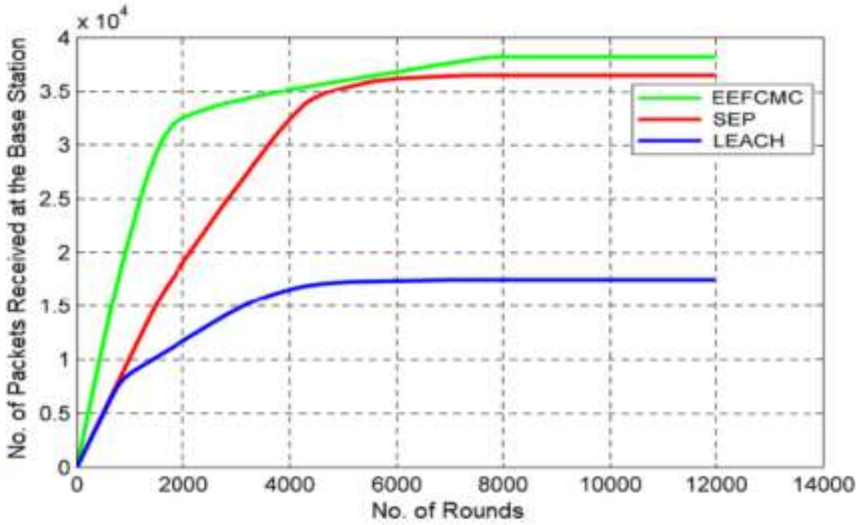

Figure 5: No. packets received at the base station.

7. Conclusions and Future Works

In this work, we suggest an efficient energy-saving protocol that extends the lifetime and throughput of homogeneous WSNs based on several approaches to improve the clustering approach called the Energy Saving, Multi-hop, Clustering, and Hierarchy (ESMCH) Protocol. MATLAB software is used as an emulator to demonstrate the effectiveness of the suggested protocol for WSNs by matching its performance with that of the LEACH and SEP protocols. Simulation experiments demonstrate that the ESMCH protocol has enhanced the stability period, lifetime, and throughput of the WSN compared to other protocols. The results show that the ESMCH approach extends network lifetime by 32% compared to the LEACH approach and by 26% compared to the SEP approach.

The experiments also show that the ESMCH protocol increases the throughput of the WSN by 16.8% compared to its throughput when using the SEP protocol and by 30% when using the LEACH protocol. Therefore, the ESMCH protocol is more effective than other protocols in terms of reducing power consumption and extending network lifetime. The high effectiveness of the suggested protocol is a result of the improved clustering approach by guessing the appropriate number of CHs and the greater accuracy offered by the chance function when selecting new CHs in each passing cycle (more balanced power consumption between nodes). Moreover, the use of multi-hop mechanisms reduces the transmission distance between nodes, thus reducing energy waste. Furthermore, the high throughput of WSN with the proposed protocol is due to the use of TDMA and CSMA mechanics for organizing and ensuring data exchange between sensors in the network, reducing the number of lost packets and increasing the reliability of the network. In future work, we plan to develop the ESMCH protocol by adding new effective parameters to the chance function and comparing its performance with other well-known clustering protocols.

Other plans to improve the proposed algorithm include adding some security features in order to increase the level of reliability and ensure that data packets are delivered in an integrated, reliable, confidante, and authenticated manner. In the near future, we plan to develop the proposed protocol to manage end-to-end integration between WSNs and mobile-based IoT networks. The future development of the ESMCH protocol is possible by including the mechanisms of cross-layer communications algorithms to manage intelligent grid applications. On the other hand, we plan to improve the performance of the proposed protocol for very wide WSNs containing more than one base station, depending on machine learning-based approaches (like neural networks, fuzzy logic, genetic algorithms, reinforcement learning, etc.).

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