EEMCRP: Energy Efficient Multi-hop Clustering Routing Protocol for Wireless Sensor Networks

Samra BOULFEKHAR[1], Fatima BELAMRI[1], Mohammed BENMOHAMMED[2], and Djamil AISSANI[1]
[1]Research Unit LaMOS Modeling and Optimization of Systems
Bejaia university Targa Ouzemmour
BEJAIA 06000, Algeria
{samra.boulfekhar, fatima.belamri, djamil.aissani}@univ-bejaia.dz
[2]Laboratoire d'Informatique Repartie, Constantine 2 university
CANSTANTINE 2500
Algeria ibn@yahoo.fr

JDIM
Journal of Digital Information Management

ABSTRACT: *Clustering is the key to overcoming the energy challenge in the wireless sensor network. For this reason, we propose a novel static clustering routing protocol called Energy Efficient Multi-hop Clustering Routing Protocol for Wireless Sensor Networks (EEMCRP). EEMCRP, partitions the network into static clusters, eliminates the overhead of dynamic clustering and distributes the energy load among high power sensor nodes by using Secondary-cluster-heads. EEMCRP partitions the nodes into unequal size clusters. Clusters closer to the base station have smaller sizes than those farther away from the base station. Thus, cluster heads closer to the base station can preserve some energy for the inter-cluster data forwarding. We, also, propose an energy-aware multihop routing protocol for inter-cluster communication based on Energy-Efficient Routing Protocol for wireless sensor networks (EERP). Simulation results show that our protocol balances the energy consumption well among all sensor nodes and achieves an obvious improvement on the network lifetime.*

Subject Categories and Descriptors: [C.2 COMPUTER-COMMUNICATION NETWORKS]; Wireless communication [C.2.2 Network Protocols]; Routing protocols

General Terms: Network Protocols, Wireless Sensor Networks

Keywords: Wireless Sensor Networks, Energy Efficiency, Cluster-Based Routing, Lifetime, EERP Protocol

Received: 19 December 2021, Revised 1 March 2022, Accepted 9 March 2022

Review Metrics: Review Scale: 0/6, Review Score: 5.25, Inter - reviewer consistency: 87.2

DOI: 10.6025/jdim/2022/20/2/35-45

1. Introduction

Wireless Sensor Networks (WSN) are deployed in a physical area; they consist of several tiny sensor nodes able to collect helpful information and transmit it through wireless links to sink nodes [1][2]. The potential applications of WSNs are highly varied, such as environmental monitoring, target tracking and military [3], [4], [5], [6]. WSNs have specific characteristics that make them different from other types of networks; such a network sensor node has limited energy resources, representing the biggest challenge for WSNs [7][8]. Due to the sensor's little power, innovative techniques that improve energy efficiency to prolong the network lifetime are highly required [9], [10], [11], [12]. For this reason, researchers focus on reducing the energy consumption by the network protocols within the communication stack. To achieve this target, network and data link layers are the two layers most investigated in WSN. Multihop transmission and node clustering are critical design criteria of energy[1]aware data gathering strategies [13], [14], [15] [16]. In WSN, the cost of data bit transmission is higher than the computation process [17]. Thus, partitioning the network nodes into clusters is advantageous since only some sensor nodes, namely cluster heads, are allowed to communicate directly with the base station BS. CHs are the nodes which collect and gather data from cluster members (data aggregation can be used to eliminate the data redundancy and reduce the communication load [18]). As the nodes will communicate data over shorter distances in such an environment, the energy spent in the network will likely be substantially lower than when every sensor transmits directly to the BS.

Indeed, within a clustering organization, intra-cluster communication can be a single hop or multihop, as well as inter-cluster communication [19]. Previous research (e.g., [20]) has shown that multi-hop communication between a data source and a data sink is usually more energy efficient than direct transmission because of the characteristics of the wireless channel. Be that as it may, the hotspots issue emerges when utilizing the multihop sending model in inter-cluster communication. Since the cluster heads closer to the data sink are burdened with overwhelming transfer activity, they will die much faster than the other cluster heads, reducing sensing coverage and causing network partitioning. Although many protocols proposed in the literature reduce energy consumption on forwarding paths to increase energy efficiency, they do not necessarily extend the network lifetime due to the continuous many-to-one traffic pattern [21], [22].

This paper proposes EEMCRP (Energy Efficient Multihop Clustering Routing Protocol for Wireless Sensor Networks). EEMCRP is a static clustering routing protocol; its primary purpose is the elimination of dynamic clustering overhead and engaging high power sensor nodes for power consummation tasks to prolong the network lifetime. In each cluster, EEMCRP chooses two cluster-heads (CHs): primary CH (PRI-CH) and secondary (SEC-CH). In the proposed multihop routing protocol for inter-cluster communication, a cluster head chooses a relay node from its adjacent cluster heads according to the Energy-Efficient Routing Protocol for wireless sensor networks (EERP) [23].

In EEMCRP, energy efficiency is distributed and improved by

1. We are optimizing the selection of cluster heads in which both residual energy of the nodes and total power consumption of the cluster are considered.

2. We are optimizing the number of nodes in the clusters according to the size of the networks and the total power consumption of the cluster.

3. Rotating cluster-heads' roles to average the power consumption among cluster-heads and normal nodes.

The remainder of this paper is divided into seven sections: Section 2 presents related work in energy-efficient clustering mechanisms in wireless sensor network environments. and Section 3 shows our system model and assumptions. Section 4 exhibits the details of EEMCRP. Section 5 analyzes some properties of the EEMCRP protocol. Section 6 evaluates the proposed protocol. Section 7 gives the conclusion and future work.

2. Related Work

To address the energy-aware routing issues, various clustering algorithms have been proposed [24], [25], [26], [14]. However, almost all take into consideration the number of clusters formed. Generally, clustering algorithms segment a network into non-overlapping clusters comprising a CH and Cluster members CM. Each CM transmit sensed data to CHs, where the sensed data could be aggregated and transmitted to the base station. Clustering algorithms may be distinguished by the way the CHs are elected. In this section, we explore some related research works in the routing domain in wireless sensor networks.

A hierarchical Low-Energy Adaptive Clustering LEACH is proposed in [27]. This protocol is counted among the most cited in the literature on sensor networks. A randomized rotation of cluster heads is used to distribute energy consumption over all nodes in the Network. Then, in the data transmission phase, each cluster heads an aggregated packet forwards directly to the base station. An energy-aware variant (TL-LEACH: for Two-Levels Hierarchy for Low-Energy Adaptive Clustering Hierarchy) of LEACH is proposed in [28]. The authors use a random rotation of local cluster base stations (primary and secondary cluster-heads) in this work. This allows better distribution of the energy load among the sensors in the Network, especially when Network is in a high-density state. A new LEACH-based clustering algorithm is proposed in [29] to enhance WSN performance. In EMLEACH, the cluster head selection is based on the remaining energy and the communication model is improved by two processes, levelling and generic multi-hop routing. The EM-LEACH optimizes the network reliability, preserves the energy consumption and extends the network lifetime.

The Energy-Efficient Level Based Clustering Routing Protocol for wireless sensor networks (EELBCRP) is proposed in [30]. In EELBCRP, the Network is partitioned into annular rings by using various power levels at the base station, and each ring contains multiple sensor nodes. Moreover, EELBCRP considers the node residual energy and the distance from Base Station to nodes as the principle of cluster-head election. Authors of [31] proposed an enhanced cluster hierarchy (ECH) scheme to handle the load balancing problem in WSNs. In ECH, authors used neighboring nodes' wake-up and sleep time to optimize network life. The proposed approach requires only the waking nodes for collecting and transmitting data. As a result, the data redundancy is minimized, and the network lifetime is maximized.

In [32], the authors proposed an improved ant colony optimization-based approach with a mobile sink for wireless sensor networks. In the IACO-MS protocol, the sensor field is divided into several clusters, each with only one CH. Then, the mobile sink uses an improved ACO algorithm to find the shortest et at the path to communicate with all CHs. As a result, the network lifetime is extended. Gupta et al. [33] proposed an improved Cuckoo Search-based CHs selection algorithm for WSNs. The iCSHS protocol considers the problem of cluster head selection by using the cuckoo search algorithm based on the residual node energy, degree of a node, intra-cluster distance and coverage ratio. In addition, an improved harmony search-based routing algorithm is proposed for routing the data packet from CHs to the sink. In [34], the authors proposed the Distance Energy Evaluated (DEE), based on the clustering approach for WSN to crease its lifetime. They consider several parameters when choosing Cluster Head, such as energy, degree and distance. In addition, the authors have introduced a layered architecture for the topology that supports elasticity in multi-hop communication. In DEE, the unequal size of clusters optimizes the energy consumption and improve the reliability and lifetime in WSN. In [35], the Location-Energy Spectral Cluster Algorithm (LESCA) is proposed. In LESCA the number of clusters in a network is determined automatically, and the CH is selected with high stored energy and the distance to the Base Station and the distance from the cluster's centroid of a sensor node to optimize the selection of CHs. The LESCA algorithm attains an efficient energy consumption.

Our work is closely related to the Energy-Efficient Protocol with Static Clustering (EEPSC) presented in [36]. Zahmati et al. propose a hierarchical static clustering-based protocol, which eliminates the overhead of dynamic clustering, engages high-power sensor nodes for power-consuming tasks, and prolongs the network lifetime. The main difference between our protocol and the protocols presented in this section are described below: –

To distribute the energy load among high-power sensor nodes, EEMCRP benefits new idea of using two CHs (PRI-CH and SEC-CH).

– EEMCRP utilizes a static clustering scheme, eliminating the overhead of dynamic clustering.

– To eliminate the hot spots problem, EEMCRP partitions the nodes into clusters of unequal size, and clusters closer to the base station have smaller sizes than those farther away from the base station.

– EEMCRP adopts the multi-hop communication among the SEC-CHs during the inter-cluster communications, based on EERP protocol.

3. Network Model

In this paper, we assume a sensor network model, similar to those used in [27], with the following properties:

1. There is one base station fixed and located in the middle of a given sensor network.

2. The battery of the base station is infinite.

3. Base station is capable of both omnidirectional and sectorized uni-directional communications.

4. Base station can transmit various power levels.

5. All nodes are immobile, i.e., all nodes remain stationary after deployment.

6. All nodes are homogeneous in terms of energy, communication and processing capabilities. Each node is assigned a unique identifier (ID).

7. Nodes are location unaware, i.e., they are not equipped with any GPS device.

8. The nodes can transmit at variable power levels depending on the distance to the receiver, as in [37].

9. The nodes can estimate the approximate distance by the received signal strength, given the transmit power level is known and the communication between nodes is not subject to multipath fading.

10. Each node makes its decision based on local information only.

11. The base station can reach each node.

12. We use the energy model presented in [37].

4. EEMCRP Protocol Design

EEMCRP is a self-organizing, static clustering method that forms clusters only once during the network action. The operation of EEMCRP is broken up into rounds, where each round is accomplished in two phases: The cluster-heads election phase and the data transmission phase. In the following sub-sections, we discuss each of these phases in detail.

4.1. Cluster Formation

According to the static clustering scheme used in EEPSC [36], cluster formation is performed only once at the beginning of network operation. For this aim, the base station broadcasts nbLV different messages with different transmission powers, which nbLV is the desired number of levels (see Eq. (1)), i.e., the base station transmits a level-1 signal with a minimum power level. All nodes, which hear this message, set their level as 1. After that, the base station increases its signal power to attain the next level and transmit a level-2 signal. All the nodes that receive the message, but do not set the previous level set their level as 2. This procedure continues until the base station transmits corresponding massages to all levels.

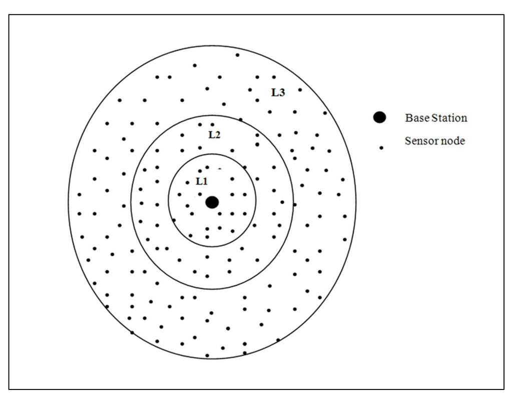

Figure 1. Determination of the levels

So, each sensor node in a wireless sensor network is assigned its level from the external base station. A level is given in the form of a concentric circle using the signal strength of the base station, as shown in figure 1.

The number of levels (nbLV) is defined as:

$$nbLV = \sqrt{N^2/SizeofArea} \tag{1}$$

(1) Where *N* means the number of nodes in a wireless sensor network.

For example, when the size of a network field is 100m ×100m and the number of all sensor nodes is 300, then the number of levels is defined a $\sqrt{300^2/(100 \times 100)} = 3$ That is, the wireless sensor network is divided into three levels in this example

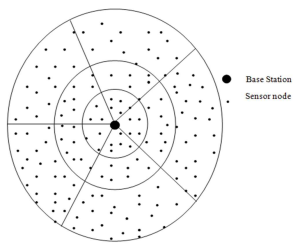

Figure 2. Cluster formation

Because we assume that the base station's battery is infinity, the base station can send the level information to all sensor nodes regardless of the distance between sensor nodes and itself. The number of these levels is depended on various parameters such as the network size and the number of sensor nodes.

Afterwards, the base station uses a bi-directional communication model to determine the clusters. Figure 2 shows the network area divided into C clusters with different broadcast messages from the base station.

The base station in our protocol is capable of both omnidirectional and sectorized unidirectional communications. Depending on the antenna beamwidth used, the number of clusters C varies. The optimal number of clusters C is estimated to be 5% of the total number of nodes [27], [38].

To address the hot spots problem, we introduce an unequal clustering mechanism to balance the energy consumption among cluster heads. Clusters closer to the base station have smaller sizes than those farther away from the base station; thus, cluster heads closer to the base station can preserve some energy for inter-cluster data forwarding.

4.2. Clusters-head Election

After the clusters are established, the network starts its regular operation, and the Cluster Head Election Phase begins. In this phase, two cluster heads are elected. The primary cluster head (PRI- CH) and the second cluster head (SEC-CH). A sensor node elects itself as a (PRI-CH) by evaluating a weight function P_i. To optimize energy management, this weight function should help choose nodes with the highest energy capacity, the network's diameter, and which have been less frequently cluster-head.

The weight P_i of a node i is given by:

$$P_i = \frac{1}{1+NBR_{PRI-CH}} + \frac{RE}{IE} + \frac{1}{d(i,cnt)} \tag{2}$$

Where

NBR_{PRI-CH}: The number of times that the node i is selected as PRI-CH ;

RE: The residual energy;

IE: The initial energy;

$d\,(i,cnt)$: The distance between the node *i* and cluster center.

SEC-CH is a node of the same cluster that maximizes the objective function F of PRI-CH (see Eq. (3)).

Let j be the PRI-CH neighbour of the same cluster.

$$SEC-CH = \{i \backslash F_i = maxF_j\} \tag{3}$$

$$F_j = \frac{RE}{IE} + \frac{1}{d(PRI-CH,j)} + \frac{1}{d(j,SB)} \tag{4}$$

Where:

RE: The residual energy of the node *j* ;

IE: The initial energy;

$d(j, SB)$: The distance between the node *j* and the base station .

The objective function provides a good estimate of the communication cost. The F_i of a node i is a measure of the expected intra-cluster communication cost, between PRI-CH and SEC-CH, if this node becomes a SEC-CH.

A PRI-CH ensures the following tasks:

– A PRI-CH (based on the number of nodes in its cluster) sets up a TDMA (Time-Division Multiple-Access) schedule and transmits this schedule to its members during bt (see figure 4).

A PRI-CH collects data from the other nodes in its cluster, aggregates the received DATA-PK ”Data pa a single data packet using data fusion technique, and transmits the compressed data to the SEC-CH. This latter, in its turn, sends the received data to the base station (see Sec 4.3.2).

The DATA-PK consists of the node ID, energy level and collected data.

– As the PRI-CH node consumes more energy than other nodes within the cluster, the current PRI-CH elects another node with the most residual power as the next PRICH. It also chooses the next SEC-CH for the next round based on the objective function F (where F is as defined previously).

– During wt (see figure 4), nodes are informed about their newly elected PRI-CH and SEC-CH. In other words, the current SEC-CH sends the INFO-PK "Information Packet," including the new responsible sensor IDs for the next round. Whereas a SEC-CH ensures the following tasks:

– Each intermediate SEC-CH forwards the data to a chosen neighbour SEC-CH in its NIT table "Neighbour Information Table" (see table 1).

– The primary motivation for using the SEC-CH is to distribute the load among several nodes, thus avoiding the bottleneck caused by a single CH. Therefore, If the PRI-CH (of the same cluster) dies, the SEC-CH replaces it for completing the tasks of this PRI-CH (during the current round).

Id	Energy	State	Cost function

Table 1. SEC-CH neighbours information table

4.3. Data Transmission

In a clustered network, the communication is divided into intra-cluster and inter-cluster communication. The intra-cluster communication is from the nodes inside a cluster to the head. The inter-cluster communication is from the heads to the base station. (see figure 3)

Intra-cluster Communication The communication phase operation is broken into frames, where nodes send their data to the PRI-CH at most once per frame during their allocated transmission slot. The length of each slot time in which a node transmits data is constant, so the time to send a frame of data depends on the number of nodes in the cluster.

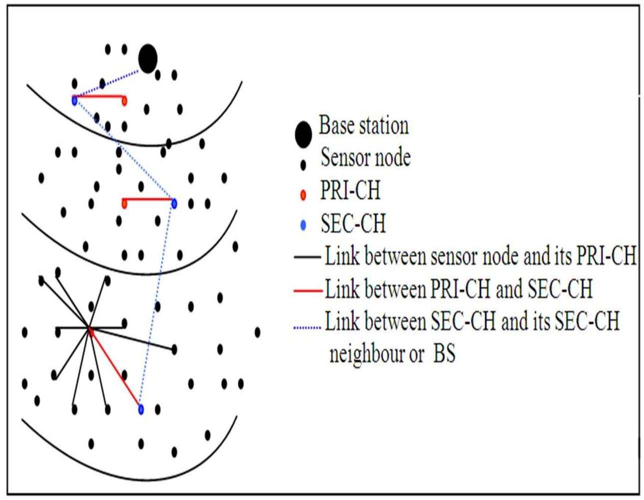

Figure 3. Data communication

Figure 4 shows the timeline for one round of EEMCRP. We assume that the nodes are all time synchronized and start the communication phase at the same time. This could be achieved, for example, by having the BS send out synchronization message to the nodes during the waking time (wt). The PRI-CH must be awake to receive all the data from the nodes in the cluster. To reduce energy dissipation, each non-cluster head node uses power control to set the amount of transmit power based on the received strength of the PRI-CH. Moreover, the radio of each non-cluster head node is turned off until its allocated transmission time. Since we optimize our design for the circumstance when all nodes have data to send to the PRI-CH, employing a TDMA schedule is an efficient bandwidth and represents a low-latency and energy-efficient approach.

Once the PRI-CH receives all the data, it performs data aggregation to enhance the common signal and reduce the uncorrelated noise among the signals. The resultant data are sent from the PRI-CH to the SEC-CH during break time (bt).

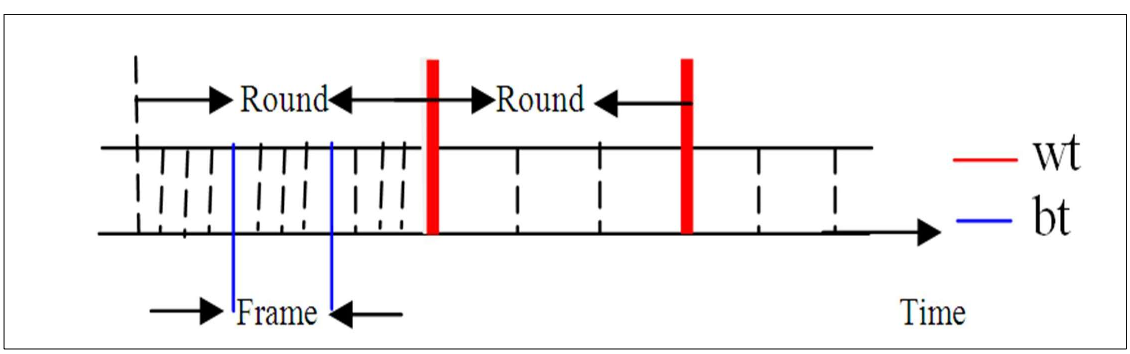

Figure 4. Time line showing communication operation

Inter-Cluster Communication Currently, there are two types of inter-communication modes, single hop and multi-hop [19]. Here we adopt the multi-hop mode to achieve the inter-cluster transmission. The cluster heads transmitted their aggregated data to the base station bypassing several other cluster heads. In this paper, we design an energy-aware multi-hop routing protocol for inter-cluster communication based on our protocol EERP [23].

The base station initiates the connection by flooding the network in the direction of the source node. It transmits G-INFO-PK "Global Information packet". At the beginning of this process (during wt), each SEC-CH broadcasts this packet "G-INFO-PK" across the network at a certain power which consists of its node ID, residual energy and cost function (f). The concrete scheme of choosing the best relay SEC-CH is explained as follows.

When a SEC-CH receives this broadcast message, it checks whether it has an entry in its NIT for the SEC-CH that transmitted the message. If not, it adds an entry consisting of Id, remaining energy, state (concerned, not concerned) determined according to an energy threshold alpha (see algorithm 1) and cost function.

If the G-INFO-PK is sent from SEC-CHj to SEC-CHi, SECCHi calculates the cost function fi of the path as:

$$f_i = min f_{ij} + 1/RE_i \tag{5}$$

$$f_{ij} = f_j + c_{ij} \tag{6}$$

$$c_{ij} = (E_t + E_r)_{ij} \tag{7}$$

Where:

$\boldsymbol{RE_j}$**:** Residual energy of the $node_j$

$\boldsymbol{(E_t + E_r)}$**:** the energy used to transmit and receive on the link ij.

It then retransmits the G-INFO-PK but changes the id field to its id and energy level field to its remaining energy level, and fj by fi. Every SEC-CH in the network retransmits the G-INFO-PK once (during each wt in each round) to all its SEC-CHs neighbours. Thus, each node SEC-CH has several"SEC-CHs" neighbours through which it can route packets to the base station. A SEC-CH bases its routing decision on two metrics: state and cost function. A SEC-CH searches its NIT for all its SEC-CHs neighbours concerned with minimum cost function (see algorithm 2). This is continued till the data packet reaches the base station (see figure 3).

Algorithm 1: Upon reception of G-INFO-PK

Let $SEC\text{-}CH_i$ be the $SEC\text{-}CH$ of the cluster i
Let $SEC\text{-}CH_j$ be a $SEC\text{-}CH$ neighbour of $SEC\text{-}CH_i$
Let RE_j be the residual energy of $SEC\text{-}CH_j$
Let NIT_i be the SEC-CHs neighbours of $SEC\text{-}CH_i$
Let α_i be the energy threshold of $SEC\text{-}CH_i$
For all *G-INFO-PK* received by $SEC\text{-}CH_i$ **do**
if $SEC\text{-}CH_j$ between $SEC\text{-}CH_i$ and base station **then**
    if $RE_j > \alpha_i$ **then**
        State ($SEC\text{-}CH_j$) : = concerned
    else
        State ($SEC\text{-}CH_j$) : = not concerned
    end if
    Add $SEC\text{-}CH_j$ in NIT_i
    Update fields of *G-INFO-PK* message and broadcast it
else
    Discard the packet
end if
end for

Algorithm 2 : Inter-cluster Communication

Let $SEC\text{-}CH_i$ be the $SEC\text{-}CH$ of the cluster i
Let $SEC\text{-}CH_j$ be a $SEC\text{-}CH$ neighbour of $SEC\text{-}CH_i$
Let NIT_i be the *SEC-CHs* neighbours of $SEC\text{-}CH_i$
Let $NIT\text{-}CONC_i$ be the *SEC-CHs* neighbours of $SEC\text{-}CH_i$ with concerned state
Let α_i be the energy threshold of $SEC\text{-}CH_i$
For all DATA-PK received by $SEC\text{-}CH_i$ **do**
if $NIT_i <> 0$ **then**
    Select $SEC\text{-}CH_j$ from $NIT\text{-}CONC_i$ s.t. $f_j = minf(NIT_i)$;
else
    Calculate a novel α_i
    Determinate $NIT\text{-}CONC_i$
    Select $SEC\text{-}CH_j$ from $NIT\text{-}CONC_i$ s.t. $f_j = min\, f(NIT_i)$
end if
    Send *DATA-PK* to $SEC\text{-}CH_j$
end for

After each round (during wt), new PRI-CHs and SEC-CHs are elected, and new relays are formed.

5. Additional Considerations

This section presents the analysis and benefits of EEMCRP. We first discuss the message complexity of the cluster formation phase.

Lemma. The message complexity of the cluster formation algorithm is $O(1)$ in the network.

Proof. According to the static clustering scheme which is used in EEMCRP, cluster formation is performed only once at the beginning of network operation. For this aim, base station broadcasts nbLV different messages.

with different transmission powers, which nbLV is the desired number of levels.

The main advantages of EEMCRP are the following:

- A node is covered by only one PRI-CH.

Discussion: According to the static clustering scheme used in EEMCRP, cluster formation is performed only once at the beginning of network operation. And the SEC-CH is the sensor node with the utmost energy level as CH for the current round. Therefore, we have only one cluster head (PRI-CH) for each cluster.

- EEMCRP forms its clusters with the minimum energy dissipation.

Discussion: EEMCRP partitions the network into static clusters, eliminates the overhead of dynamic clustering and utilizes the SEC-CH to distribute the energy load among high-power sensor nodes; thus, extending network lifetime.

- EEMCRP avoids the hot spots problem.

Discussion: We introduce an unequal clustering mechanism to balance the energy consumption among SECCHs. Clusters closer to the base station have smaller sizes than those farther away from the base station; thus, SEC-CHs closer to the base station can preserve some energy for inter-cluster data forwarding. Moreover, we propose an energy-aware multihop routing protocol for inter-cluster communication (algorithm2).

- EEMCRP balances the energy consumption among PRICH and member nodes. Furthermore, it maximizes the network lifetime.

Discussion: The main goal of the rotation is to balance the energy consumption among cluster heads and member nodes; thus, it could hardly balance the energy consumption among cluster heads in the inter-cluster multihop routing scenario. We also argue that using the node's residual energy as the only criterion when selecting PRICHs is insufficient to balance energy consumption across the network. Choosing PRI-CHs with more residual energy can only help balance the energy consumption among nodes in a localized area in the long term. Balancing loads among different cluster heads is ineffective in avoiding the hot spot problem. For that, we introduce an unequal clustering mechanism to balance the energy consumption among cluster heads. Clusters closer to the base station have smaller sizes than those farther away from the base station; thus, SEC-CHs closer to the base station can preserve some energy for inter-cluster data forwarding. We use two CHs to distribute the energy load among high-power sensor nodes. Moreover, we propose an energy-aware multi-hop routing protocol based on the EERP protocol for inter-cluster communication.

6. Simulation Results

In this section, we conduct some simulations to evaluate the performance of EEMCRP by comparing its performance with TL-LEACH and EEPSC protocols.

6.1. Performance Metrics

We use the following metrics to capture our protocol's performance and compare it with TL-LEACH and EEPSC protocols:

The Average Energy Consumption (AEC). To compute the average cumulative energy consumption in the network, we need to estimate the energy required to relay data from each node to a base station through a multi-hop path. It is calculated as following:

$$AEC = \frac{\sum_{i=1}^{n} E_i}{n} \tag{8}$$

Where:

n: The number of nodes in the network.

E_i: The energy consumed by the node i, i.e., initial energy - residual energy.

The Data Messages Received (DMR) This metric represents the total number of data messages received by the base station over the number of rounds of activity.

The network lifetime can be defined as the time elapsed until the first node (or the last node) in the network depletes its energy (dies). It can also be defined as the number of alive sensor nodes over time [39]. In our simulation, it measures:

- The number of rounds until the last node dies.

- The number of rounds until the first node dies.

- The number of nodes still alive over the simulation time.

6.2. Radio Energy Dissipation Model

The energy costs for the various protocols discussed in the previous section were compared with those of the proposed protocol using the first order radio model [27], [37]. The transmitted and received energy costs for the transmission of a k-bit data message between two nodes separated by a distance of d meters are given by Eqs. 8 and 9, respectively.

$$E_{tx} = k \times E_{elec} + k \times E_{amp} \times d^2 \tag{9}$$

$$E_{rx} = k \times E_{elec} \tag{10}$$

Where:

E_{elec}: The electronics energy.

E_{amp}: the amplifier energy.

6.3. Results and Discussions

The protocol EEMCRP was implemented in the J-SIM simulator [40]. This section presents the simulation scenarios that were used to evaluate the EEMCRP protocol, followed by the results and discussion. The key simulation parameters are summarized in table 2 below, and the parameters of the radio model are the same as LEACH [37].

Parameter	Value
Dimension	$100m \times 100m$
Node numbers	50-300
Initial energy	0.5 j
Data rate	250 kbps
Transmission range	25 m
Threshold α_i	Half the maximum of the remaining energy of SEC-CH_i neighbours
E_{elec}	50 nJ/bit
E_{amp}	10 $pJ/bit/m^4$

Table 2. Simulation parameters

The improvement gained through EEMCRP compared to TL-LEACH and EEPSC protocols is further illustrated by figures 5-9 which indicate the average energy consumed is decreased, overall number of mes-sages received at base station is increased and the lifetime of network is extended.

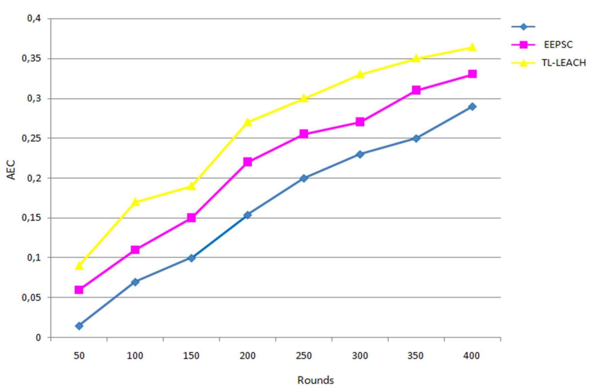

Figure 5. Average energy consumed in the network

Figure 5 illustrates the average energy dissipation graph, revealing that EEMCRP consumes energy consumed more efficiently than the TL-LEACH and EEPSC protocols (this is due to fact that in TL-LEACH and EEPSC, CHs transmit their data directly to the BS; therefore, the energy consumption is much higher). This may be due to the following reasons. First, alternating the role of PRI-CH and using two kinds of CHs (PRI-CH, SEC-CH) can balance energy consumption among cluster members. Second, EEMCRP eliminates the overhead of dynamic clustering. Third, our protocol adopts the multi-hop communication among cluster heads during inter-cluster communications, based on the cost function (Eqs. 4, 5, 6), thus saving more energy in nodes.

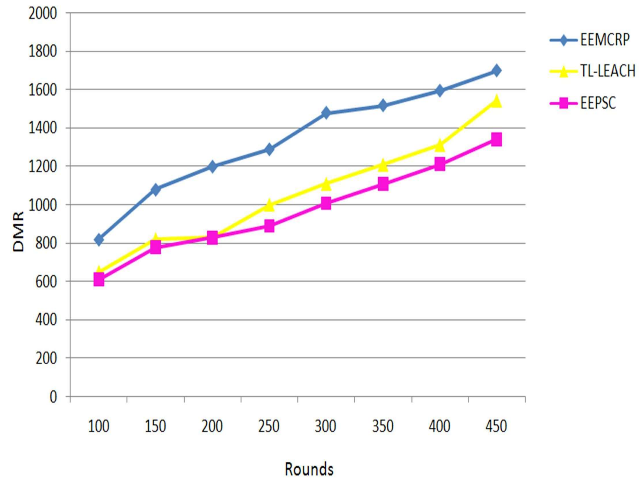

Figure 6. Number of DATA-PK received at base station

Next, we analyze the number of data messages received by the base station for the three routing pro-tocols. Figure 6 shows the total number of data messages received by the base station over the number of activity rounds. Comparing with TL-LEACH and EEPSC protocols, EEMCRP receives more data. Because, EEMCRP uses multiple routes, based on EERP protocol, hence the probability to reach the base station is better than TL-LEACH and EEPSC (all cluster heads in TL-LEACH and EEPSC, respectively, send data directly to the base station).

As can be noticed, TL-LEACH sends much more data to the base station than EEPSC. Such a result can be justified by the fact that, in TL-LEACH, the nodes are forced to transmit to smaller distances (TL-LEACH uses two hierarchy levels).

Finally, we discuss the energy efficiency of three protocols by examining the network lifetime. Figure 7 shows the number of sensor nodes still alive over the simulation time. EEMCRP improves the network lifetime (the time until the first node dies and until the last node dies: figures 8-9) over TL-LEACH and EEPSC. In TL-LEACH and EEPSC, all cluster heads send data directly to the base station. Thus, some nodes (CHs) consume more energy and die too early, especially the heads far from the base station.

Moreover, in TL-LEACH, there is only a two-level hierarchy; also, the overhead of dynamic clustering is not avoided (the messages exchanged in the set-up phase to build a two-level structure have been taken into account in terms of energy spent in the network). This is avoided in EEMCRP because energy consumption is well balanced among nodes. EEMCRP partitions the network into static clusters, eliminates the overhead of dynamic clustering, and uses SEC-CH to distribute the energy load among high-power sensor nodes, thus extending the network lifetime.

The small interval between the time until the first node dies and the time until the last node dies implies that

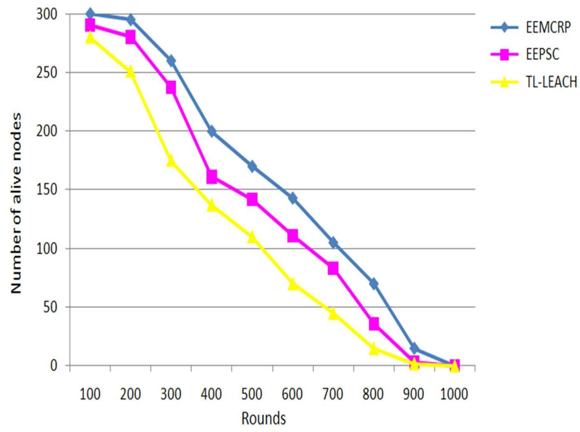

Figure 7. Network lifetime: number of nodes alive over

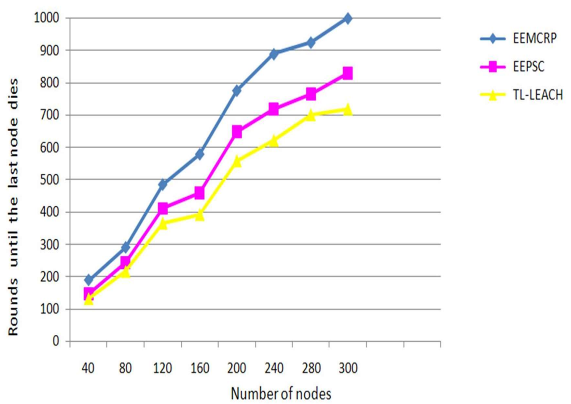

Figure 8. Network lifetime: time until the first node time dies

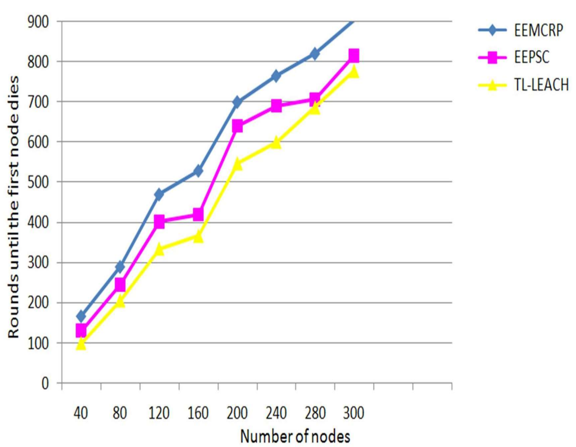

Figure 9. Network lifetime: time until the last node dies

EEMCRP has successfully solved the hot spots problem. EEMCRP, partitions the network into static clusters, eliminates the overhead of dynamic clustering and uses SEC-CH to distribute the energy load among high power sensor nodes; thus, extends network lifetime.

7. Conclusion and Future Work

In this paper, we proposed an Energy Efficient Multi-hop Clustering Routing Protocol, which extends the network lifetime and eliminates the overhead of dynamic clustering. The main contribution of this protocol are:

– Eliminate the hot spot problem by splitting the network into unequal static clusters.

– Eliminating the overhead of dynamic clustering and using two kinds of CHs (PRI-CHs and SEC-CHs) to distribute the energy load among high-power sensor nodes. – Proposition of an energy-aware multi-hops routing protocol for the inter-cluster communication EERP.

Simulation results show that, compared with TL-LEACH and EEPSC, the proposed protocol can achieve apparent effectiveness in saving network energy and prolonging network lifetime.

In future work, we would like to analyze the quality of service sensibility of this proposition in terms of delay and its scalability. Also, to study the adaptability of this protocol in the Vehicular ad hoc network (VANET).

References

[1] Rawat, Piyush., Chauhan, Siddhartha. (2021). Clustering protocols in wireless sensor network: A survey, classification, issues, and future directions. *Computer Science Review*, 40:100396,.

[2] Saleem, Madyen M., Alabadym, Salah Abdulghani. (2022). Improvement of the wmsns lifetime using multi-hop clustering routing protocol. *Wireless Networks*, p. 1–11.

[3] Kandris, Dionisis., Nakas, Christos., Vomvas, Dimitrios., Koulouras, Grigorios. (2020). *Applications of wireless sensor networks: an up-to-date survey*. *Applied System Innovation*, 3 (1) 14, 2020.

[4] Hamdi, Mustafa Maad., Audah, Lukman., Rashid, Sami Abduljabbar., Mohammed, Alaa Hamid., Alani, Sameer., and Mustafa, Ahmed Shamil. (2020). A review of applications, characteristics and challenges in vehicular ad hoc networks (vanets). *In:* 2020 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA), p. 1–7. IEEE.

[5] Lalama, Zahia., Boulfekhar, Samra., Semechedine, Fouzi. (2022). Localization optimization in wsns using meta-heuristics optimization algorithms: A survey. *Wireless Personal Communications*, 122 (2) 1197– 1220, 2022.

[6] Singh, Omkar., Rishiwal, Vinay., Chaudhry, Rashmi., and Yadav, Mano. (2021). Multi-objective optimization in wsn: Opportunities and challenges. *Wireless Personal Communications*, 121 (1) 127–152, 2021.

[7] Ijemaru, Gerald K., Ang, Kenneth Li-Minn., Seng, Jasmine KP. (2022). Wireless power transfer and energy har-

vesting in distributed sensor networks: Survey, opportunities, and challenges. *International Journal of Distributed Sensor Networks*, 18 (3), 15501477211067740.

[8] Khalaf, Osamah Ibrahim., Romero, Carlos Andr´es Tavera., Hassan, Shahzad., Iqbal, Muhammad Taimoor. (2022). Mitigating hotspot issues in heterogeneous wireless sensor networks. *Journal of Sensors*, 2022.

[9] Singh, Abhilash., Sharma, Sandeep., Singh, Jitendra. (2021). Nature-inspired algorithms for wireless sensor networks: A comprehensive survey. *Computer Science Review*, 39. 100342, 2021.

[10] Pantazis, Nikolaos A., Nikolidakis, Stefanos A., Vergados, Dimitrios D. (2012). Energy-efficient routing protocols in wireless sensor networks: A survey. *IEEE Communications surveys & tutorials*, 15 (2) 551–591.

[11] Bin, Wang., Wenxin, Li., Liu Li. (2011). A survey of energy conservation, routing and coverage in wireless sensor networks. *In*: International Conference on Active Media Technology, p. 59–70. Springer, 2011.

[12] Jiwan N, Dehankar., Pragati, Patil., and Agarwal Girish. Survey on energy consumption in wireless sensor network. *International Journal of Engineering Research and Technology (IJERT)*, 2 (1) 1–4, 2013.

[13] Sha, Kewei., Gehlot, Jegnesh., and Greve, Robert. (2013). Multipath routing techniques in wireless sensor networks: A survey. *Wireless personal communications*, 70 (2) 807–829, 2013.

[14] Ghosal, Amrita., Halder, Subir., Das, Sajal K. (2020). Distributed on-demand clustering algorithm for lifetime optimization in wireless sensor networks. *Journal of Parallel and Distributed Computing*, 141. 129–142.

[15] Kumar, Vinay., Jain, Sanjeev., Tiwari Sudarshan. (2011). Energy efficient clustering algorithms in wireless sensor networks: A survey. *International Journal of Computer Science Issues (IJCSI)*, 8 (5) 259.

[16] Liu, Yang., Wu, Qiong., Zhao, Ting., Tie, Yong., Bai, Fengshan., Jin, Minglu. (2019). An improved energy-efficient routing protocol for wireless sensor networks. Sensors, 19 (20) 4579.

[17] Daanoune, Ikram., Baghdad, Abdennaceur., Balllouk. Bre-leach, Abdelhakim. (2019). A new approach to extend the lifetime of wireless sensor network. *In:* 2019 Third International Conference on Intelligent Computing in Data Sciences (ICDS), p. 1–6. IEEE.

[18] Chen, Joy Iong Zong., Zong, Iong. (2020). Optimal multipath conveyance with improved survivability for wsn's in challenging location. *Journal of ISMAC*, 2 (02) 73–82, 2020.

[19] Wang, Kun., Yu, Chih-Min., Wang, Li-Chun. (2020). Dora: a destination-oriented routing algorithm for energy-balanced wireless sensor networks. *IEEE Internet of Things Journal*, 8 (3) 2080–2081, 2020.

[20] Mhatre, Vivek., Rosenberg, Catherine. (2004). Design guidelines for wireless sensor networks: *communication, clustering and aggregation. Ad hoc networks*, 2 (1) 45–63.

[21] Jain, Neeraj., Sinha, P., Gupta. SK. (2013). Clustering protocols in wireless sensor networks: A survey. *International Journal of Applied Information System (IJAIS)*, 5 (2) 2013.

[22] Singh, Santar Pal., Sharma, Subhash Chander. (2015). A survey on cluster-based routing protocols in wireless sensor networks. *Procedia computer science*, 45. 687–695.

[23] Boulfekhar, Samra., Benmohammed, Mohammed. (2013). A novel energy efficient and lifetime maximization routing protocol in wireless sensor networks. *Wireless personal communications*, 72 (2) 1333–1349, 2013.

[24] Baker, Dennis., Ephremides. Anthony. (1981). The architectural organization of a mobile radio network via a distributed algorithm. *IEEE Transactions on communications*, 29 (11) 1694–1701.

[25] Bharany, Salil., Sharma, Sandeep., Badotra, Sumit., Khalaf, Osamah Ibrahim., Alotaibi, Youseef., Al-ghamdi, Saleh., Alassery, Fawaz. (2021). Energy-efficient clustering scheme for flying ad-hoc networks using an optimized leach protocol. *Energies*, 14 (19) 6016, 2021.

[26] Das, Santosh Kumar., Tripathi, Sachin. (2019). Energy efficient routing formation algorithm for hybrid adhoc network: A geometric programming approach. *Peer-to-Peer Networking and Applications*, 12 (1) 102–128, 2019.

[27] Heinzelman, Wendi Rabiner., Chandrakasan, Anantha., Balakrishnan, Hari. (2000). Energy-efficient communi-cation protocol for wireless microsensor networks. *In:* Proceedings of the 33rd Annual Hawaii international conference on system sciences, p. 10. IEEE, 2000.

[28] Loscri, V., Morabito, G., Marano, Salvatore. (2005). A two-levels hierarchy for low-energy adaptive clustering hierarchy (tl-leach). *In:* IEEE vehicular technology conference, V 62, p. 1809. IEEE.

[29] Al-Sodairi, Sara., and Ouni, Ridha. (2018). Reliable and energy-efficient multi-hop leach-based clustering protocol for wireless sensor networks. Sustainable Computing: *Informatics and Systems*, 20:1–13.

[30] Diwakar, Meenakshi., Kumar, Sushil. (2012). An energy-efficient level-based clustering routing protocol for

wireless sensor networks. *International Journal of Advanced Smart Sensor Network Systems (IJASSN)*, 2 (2) 55–65, 2012.

[31] Alami, Hassan El., Najid, Abdellah. (2019). Ech: An enhanced clustering hierarchy approach to maximize lifetime of wireless sensor networks. *IEEE Access*, 7:107142–107153, 2019.

[32] Wang, Jin., Cao, Jiayi., Sherratt, R Simon., Park, Jong Hyuk. (2018). An improved ant colony optimization-based approach with mobile sink for wireless sensor networks. *The Journal of Supercomputing*, 74 (12) 6633–6645, 2018.

[33] Gupta, Govind P., Jha, Sonu. (2018). Integrated clustering and routing protocol for wireless sensor networks using cuckoo and harmony search-based metaheuristic techniques. *Engineering Applications of Artificial Intelligence*, 68.101–109.

[34] Khediri, Salim El., Nasri, Nejah., Khan, Rehan Ullah., and Kachouri, Abdennaceur. (2021). An improved energy efficient clustering protocol for increasing the life time of wireless sensor networks. Wireless Personal Communications, 116 (1) 539–558.

[35] Jorio, Ali., Fkihi, Sanaa El., Elbhiri, Brahim., and Aboutajdine, Driss. (2015). An energy-efficient clustering routing algorithm based on geographic position and residual energy for wireless sensor network. *Journal of Computer Networks and Communications*, 2015.

[36] Zahmati, Amir Sepasi., Abolhassani, Bahman., Shirazi, Ali Asghar Beheshti., Bakhtiari, Ali Shojaee. (2007). An energy-efficient protocol with static clustering for wireless sensor networks. *International Journal of Electronics, Circuits and Systems*, 1 (2) 135–138, 2007.

[37] Heinzelman, Wendi B., Chandrakasan, Anantha P., and Balakrishnan, Hari. (2002). An application-specific pro-tocol architecture for wireless microsensor networks. *IEEE Transactions on wireless communications*, 1 (4) 660–670, 2002.

[38] Murthy, Garimella Rama., Iyer, Vasanth., Radhika, V Bhawani. (2008). Level controlled clustering in wireless sensor networks. *In:* 2008 3rd International Conference on Sensing Technology, p. 130–134. IEEE, 2008.

[39] Ezhilarasi, M., and Krishnaveni, V. (2019). An evolutionary multipath energy-efficient routing protocol (emeer) for network lifetime enhancement in wireless sensor networks. *Soft Computing*, 23 (18) 8367–8377, 2019.

[40] Mishra, Jaya., Bagga, Jaspal., Choubey, Siddhartha., Choubey, Abha. (2021). Surveying various simulator tools of wireless sensor network. i-Manager's *Journal on Wireless Communication Networks*, 9 (2) 27, 2021.