A NEW CLUSTERING ROUTING PROTOCOL FOR HOMOGENEOUS WIRELESS SENSOR NETWORKS POWERED BY RENEWABLE ENERGY SOURCES[*]

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Abstract. The technology of wireless sensor networks (WSNs) is in constant development and it made great progress in many applications. One of the most popular problems in WSNs is the limited energy storage power at every sensor node. This paper aims to propose and develop a new distributed clustering algorithm for energy harvesting wireless sensor networks denoted by DEH-WSN (Energy Harvesting for Distributed Clustering Wireless Sensor Networks Protocol) that relies on matching between clustering and energy harvesting in a distributed topology. DEH-WSN uses initial and residual energy capacity of the nodes to choose cluster heads. Simulation results prove that the proposed method increases network lifetime and the effective throughput.

Key words: WSN, Routing, Clustering, DEH-WSN, Network Lifetime, Throughput.

AMS subject classifications. 68M10

1. Introduction. Wireless sensor networks (WSNs) are one of the fastest-growing technologies; it is enabled by the rapid advances in micro-electro-mechanical-system (MEMS), computer networks, and wireless communication technology. Sensors are developed by the integration of sensing and wireless communication. They consist of low-power small sensor nodes that are able to sense, process and interact over unreliable short-range radio connections. These sensor nodes are deployed in the target area to observe physical or environmental conditions like temperature, sound, vibration, or pressure. The essential subsystems of sensor nodes are used to acquire data for local processing, and for sharing information by wireless communication.

WSNs have attracted enormous attention in diverse areas such as disaster warning systems, environment monitoring, safety, intruder detection, and others [1, 2, 3]. WSNs are characterized by their potential applications in various fields [4], especially for disaster warning systems, ecological monitoring, Healthcare, intrusion detection, fire detection, to name but few.

Sensor nodes can fail due to energy starvation since they rely on batteries with limited energy capacity. Hence, energy harvesting system that harvests energy from renewable energy sources (solar, wind, vibrations, etc) is deemed as a promising solution to overcome the shortage of limited battery capacity by transforming energy-efficient solutions to a distributed Energy Harvesting approach [5]. The energy harvested is used in multiple conditions to implement the power systems such as no energy storage, energy storage without battery, and rechargeable battery [6]. However, since the energy consumption of sensor nodes is much higher than the charging rate, these nodes need to repose for some time to recharge, but this drives a modification in the network's topology. Therefore, new clustering techniques and cluster head (CH) selection are proposed to to maximize the network lifetime.

In this paper, we overcome the energy starvation in the sensors energy source by following a distributed energy Harvesting protocol that relies on a battery that harvests energy based on a renewable energy source. Moreover, the node that has a fewer delay time compared to its neighbors has higher possibilities to be a Cluster Head and it's election is based on their energy level and the energy harvested. After creating a cluster

and selecting a cluster head, each node from its cluster sends packets to the Base Station. To this end, we investigate the aggregation protocol for EH-WSN algorithms, which must run as dynamically as possible to prevent energy harvesting sensors in the block mode from joining the network since they increase the workload and lower the productivity. This protocol aims are to resolve the energy constraints to extend the lifetime of the WSN, to raise the transmission rate and to decrease the network workload.

The rest of this paper is summarized as follows: Section 2 present some related work to enhance the energy consumption by using clustering-based protocols. An overview of the distributed energy efficient protocol is described in section 3. The process of our protocol and its steps including the simulation and an execution are stated in Section 4, and Section 5 presents a summary of the study, including impact, limitations and future work.

2. Related Work. In the past decade, several researchers proposed a considerable number of algorithms that use clustering-based protocols to improve energy consumption. In this section, we introduce and describe the most relevant clustering protocols.

LEACH [7], the Low-Energy Adaptive Clustering Hierarchy is dynamic, where the clusters are randomly distributed. That means that every node can perform a Cluster Head (CH) function with a different probability. The position of cluster heads rotates between the various nodes to limit the breakdown due to energy starvation in any of the nodes. Whilst nodes are connected to the CHs with the smallest energy demanded to reach it. And in turn, the current cluster heads send the data in order through time slots allocation. Another widely used algorithm, Energy-efficient distributed clustering algorithm HEED was proposed in [8], the cluster heads are chosen according to the remaining energy combination and their connection costs.

EECS [9], EEUC [10], EDUC [11] and EADUC [12] are coverage-aware and energy-efficient algorithms. Consequently, they focus on effective size of clusters factor, which is the distance from cluster heads to the base station. Such algorithms improve the distribution of energy throughout the network and extend the network lifetime.

A Centralized Balance Clustering (CBC) [13] protocol is implemented in 3 steps. Initially, it computes the number of clusters due to the network conditions. Then, CH is selected for each block. In the final step, it is scheduled to send data while still avoiding any collision.

Later, a Hybrid Unequal Clustering with Layering Protocol (HUCL) was proposed in [14] that extends the network lifetime. This protocol is used to solve the problem of clustering overhead in case of dynamic clustering. HUCL first presents a simple compression algorithm to reduce the excess in data transmission and then proposes a mixture of static and dynamic clustering that greatly reduces the clustering overhead when compared to other dynamic aggregation techniques.

Amgoth et al. in [15] proposed an algorithm named ERA (Energy-Aware Routing Algorithm) that forms clusters according to the level of energy in the CHs. ERA organizes Clusters at different levels to be able to build the virtual backbone of the routing data.

The study in [16] suggested Energy and coverage-aware distributed clustering ECDC method that introduces coverage importance measures for the region and the whole coverage of points. ECDC increases the lifetime of the network by affecting these measures in calculating the waiting time and finding forwarding data the way to the sink.

Energy-Harvesting Stable Election Protocol (EH-SEP) [17] is based on the SEP algorithm introduced in [18]. EH-SEP is energy harvested clustering protocol. The probability of newer nodes is greater than that of older nodes, and hence the remaining energy is dedicated to the cluster heads.

CRBS algorithm (Clustering Routing Algorithm Based on Solar Energy Harvesting) [19] is another algorithm that uses both of the soft and hard thresholds to connect nodes to the network in the next round in case some nodes die. The main advantage of this protocol is that it increases the number of alive nodes and enhances the stability.

Later in [20], authors propose a novel NEEC protocol (Novel Energy Efficient Clustering), which is implemented in a centralized and distributed manner. NEEC uses hybridization such as static and dynamic clustering. In NEEC, the packets repaired in the Base Station are enhanced by supporting the consumed energy in the WSN.

S-LEACH presented in [21], is one of the most relevant studies conducted in WSN, which is based on energy

harvesting sensor nodes from solar energy and they relies on a battery as a backup power source. In S-LEACH, the BS chooses the CHs and then these CHs select a new one.

In [22], authors improved the previous methods by proposing a hybrid unequal energy-efficient clustering that prolongs the network lifetime. A novel clustering strategy is used based on arrangement of nodes in a network. Under this strategy, we can determine whether the information of the neighbors' nodes should be used or not. Hence, overhead is considerably reduced.

A clustering algorithm for heterogeneous WSNs based on a solar energy supply was presented in [23]. The CH is selected based on the self-replenishment state and the remaining energy of the nodes. Authors demonstrated that the proposed algorithm can effectively increase the network lifetime in addition to improving the network efficiency and stability while still balancing the energy consumption compared with previous algorithms.

Later in [24], authors presented a new hybrid and unequal multi-hop clustering protocol that aims to prolong the network lifetime. CHs are selected only by comparing the status of each node to its neighboring nodes. For each node, authors studied the following factors: the residual energy, the distance from this node to the base station, the number of neighboring nodes, and the placement of the layer node.

In [25], authors proposed an "energy-efficient clustering routing protocol" based on the deployment of each high-QoS node with an inter-cluster routing mechanism. For this basis, authors defined several formulas that is based on twofold coverage for information integrity, validity, and redundancy. Authors demonstrated that the deployment strategy of the proposed protocol has higher information integrity and validity, as well as lower redundancy.

For a complete survey on the clustering routing techniques in WSN with energy-efficient considerations, you can refer to the survey of energy-aware cluster head selection techniques in WSN in [26].

for reducing energy consumption

3. Distributed Protocol Overview. Li et al. in [27] proposed a distributed energy-efficient clustering algorithm. The main idea behind this Clustering Algorithm is to reduce energy consumption then increase the scalability and lifetime of the network. Following the thoughts of LEACH [27], [28], this protocol is an energy-efficient protocol for heterogeneous WSNs and it becomes homogenous after many rounds.

The field is divided into different clusters. Each cluster has a CH and some sensor nodes. CH receives from a cluster the information from the sensor nodes, and then sends it to the BS. To consider the node as Cluster Head CH, a probability function is defined to compute the residual energy and the average energy of networks. This probability function computes the ratio between the remaining energy in each node and the network's average energy. The nodes with high computation have a better chance to be elected as a CH.

There are two phases in the distributed protocol:
- Setup phase: the clusters are created and the cluster heads (CHs) are selected.
- Steady phase: the data from non-cluster heads are transmitted to the sink.

The proposed algorithm is divided into four steps:
1. Initialization Phase: the possibility of being CH changes according to the capabilities of the nodes. The desired number of CH is selected according to their location. When the range of CH is defined, CH sends a membership request message to all the nodes in its range, then request to reply with their current energy status. All nodes with high residual energy and processing power will be identified and they are made to sleep, they become the backup nodes. In case the nodes are not in the range of CH, they join the cluster by sending a message to the nearest cluster member.
2. Steady State Phase: the cluster members send the sensed data to the CH in the allotted time using TDMA schedule, and the non-cluster members to the cluster head through the intermediate cluster member.
3. Final Phase: CH will aggregate the data from all the nodes in its cluster, and then it will transmit this data to the base station.
4. Cluster Reconfiguration Phase: CH will activate the backup node if the CH residual energy reaches to the threshold value, then it will make the backup node as new CH, and transmit the new CH information to all other nodes and CH, and the old CH will become the general node in the last phase.

TABLE 4.1
Description of the parameters used in equation 4.1.

Parameters	Description
$E_{rem}(i, r)$	Remaining energy in node i during round r
$E_{eh}(i, r-1)$	Energy harvested by node i during previous round $r-1$
$E_{max}(i)$	highest energy storage capacity in node i

TABLE 4.2
Description of the parameters used in equation 4.1.

Parameters	Description
μ_i	Energy harvesting rate of node i during the round $r-1$
$P_{(h,min)}(r-1)$	Probable minimum energy harvesting rate for all nodes during the round $r-1$
$P_{(h,max)}(r-1)$	Probable maximum energy harvesting rate for all nodes during the round $r-1$

4. The Proposed Algorithm. We presented and evaluated a new routing protocol that relies on matching between clustering and energy harvesting in a distributed manner, which aims to maximize network lifetime and to become unlimited, by using energy harvesting instead of energy efficient Clustering protocols. At First, we introduced the model network, and then we explain the proposed algorithm.

4.1. Network Model. Energy scavenging in WSN is provided with Energy Harvesting nodes and a base station with unlimited network supplies. The data is taken by the sensor nodes and is sent to the base station. Some assumptions are made about the sensor nodes and the network model:
- N energy harvesting sensor nodes are distributed randomly in a $(N \times N)$ field.
- Nodes are aware of their location.
- The transmission power is detected according to the distance.
- CH can reach the base station in one hop or multiple hops.

4.2. Energy Harvesting Model. Energy harvesting (or energy scavenging) sensor nodes harvest the energy from the environment. The harvested energy uses a storage capacity defined by $E_{i,r-1}^{eh}$. However, the batteries have a limited amount of energy and they require a periodic charging replacement. In addition, renewable energy is not constant and it changes over time.

Based on the exponentially weighted moving average (EWMA) we used a forecast model for modeling energy harvested from sunlight [29, 30, 31].

Equation 4.1 calculates the amount of energy model for an energy harvesting node i:

$$E_{rem}(i, r) = min(E_{max}(i), E_{rem}(i, r-1) + E_{eh}(i, r-1)) \tag{4.1}$$

Table 4.1 shows a description of the parameters used in equation 4.1.
Equation 4.2 calculates the amount of energy harvesting:

$$E_{eh}(i, r-1) = \mu_i \Delta t \tag{4.2}$$

Equation 4.3 calculates the energy harvesting rate:

$$\mu_i = rand(P_{(h,min)}(r-1), P_{(h,max)}(r-1)) \tag{4.3}$$

Table 4.2 shows a description of the parameters used in equations 4.2 and 4.3.
The Energy harvested in any node has a low and high threshold. Each node will be automatically blocked if the node's energy is below the low threshold and will not participate in the current round, or has the ability to

Parameters	Description
D	The delay in node i
ϵ	A very small number, if the parameter is zero, ϵ does not affect the equation
$|NL(i)|$	The neighbors' number of node i
$\alpha(i)$	The number of times that node i is elected as CH.
T_2	The time needed for the next phase
V_r	A number ranging between 0.1 and 0.2

transfer data when the power state has not reached the required level. That means that the node will continue to recharge the battery. When the energy capacity in the battery of the blocked node becomes above the low threshold, the node will switch to active mode. In other words, the node will be able join the network at the next setup stage and will begin sending and receiving data in the next round.

4.3. DEH-WSN Protocol (Energy Harvesting for Distributed Clustering Wireless Sensor Networks). In this section, we introduce a new protocol, named DEH-WSN (Energy Harvesting for Distributed Clustering wireless sensor networks). We consider that the sensor nodes know the information about their location depending on the frequency power.

In DEH-WSN, the selection of the cluster head is based on the following factors: (i) constant probability value, (ii) initial energy level, (iii) processing power and (iv) the amount of harvested energy. Moreover, some nodes are selected as cluster head based on their location.

This protocol is performed in a distributed manner and distributed into two rounds, where each one implemented in two phases: Setup State and Steady data transmission State. In the setup phase, the cluster heads are selected and the normal clusters are formed according to the algorithm discussed later, then a matching between energy harvested and cluster heads are performed for moving to the next step. For the data transmission phase, the network schedule is divided into multiple rounds. In each one, cluster heads receive sensed data from the cluster member's nodes and collect data before transferring them to the base station.

4.3.1. Steady Phase:. The implementation of this phase requires four steps presented as follows:

Step 1: Calculation of delay time:. The selection of cluster heads depends on the energy level and capacity of the harvested energy. According to equation 4.4, the nodes calculate delay time, which help to choose the appropriate cluster head.

$$D(i,r) = \frac{E_{max}(i)}{E_{rem}(i,r)} \times X \times Y \times d_{i,BS} \times Z \times V_r \times T_2 \tag{4.4}$$

where:

$$X = \frac{1}{max(E_{eh}(i,r),\epsilon)}, \qquad Y = \frac{1}{max(|NL(i)|,\epsilon)} \qquad Z = max(\alpha(i),\epsilon)$$

The parameters of equation 4.4 are described in Table 4.3.

Step 2: Selection of a cluster head. Selection of cluster heads obeys the following rules:
- All nodes must wait to finish the delay time.
- The node that has smaller delay time has more possibility to be selected as a CH.
- If the node doesn't receive a message from the nearest neighbors, it declares itself as a CH.
- If the node receives CH massage, it has no possibility to be cluster head at all.
- In case any two nodes have similar delay times, the selected node should have a smaller ID.

TABLE 4.4
Description of the parameters used in above equatios

Parameters	Description
$E_{TX}^{CH_i,CH_j}(i,l,d)$	The energy needed to send data from CH_i to CH_j.
$E_{TX}^{CH_i,next\_hop_j}(j,l,d)$	The energy needed to send data from CH_j to the next phase
$E_{RX}(j,1)$	The energy needed to receive data in node j
$M(j)$	The number of member nodes in CH_j
$R(j)$	The number of CHs, where node j acts as relay node and receive the CHs data

Step 3: Cluster formation. For cluster formation, we followed the following rules:
- A selected CH node forwards a message including the energy level to the non-cluster-head.
- The non-cluster-head follows the cluster head among the lowest energy needed to transmit data to CH.
- A cluster head schedule nodes according to Time Division Multiple Access (TDMA) [32]. The further nodes must forward data as soon as possible and the further CH calculates the average energy.
- CH calculates the distance thresholds, where $d_{(c)}$ is the closest, and $d_{(f)}$ is the furthest nodes. The nodes that have a distance lower than $d_{(c)}$ lay in the first layer and the nodes that have a distance more than $d_{(f)}$ are laid in the second layer.

Step 4: Route Construction. Member nodes have the chance to turn to the sleep mode. Tthe first layer nodes plus nodes with distances smaller than d_0, from base station transmit the RR message (Route Request) into the network. The second layer nodes that receives the message must update their routing tables. After that, they will begin to transmit RR message to upper layers. The cluster heads found in the first layer must directly send data to the base stations. The cost to transfer data to BS is computed thanks to equation 4.5:

$$cost_i = E_{TX}^{CH_i,BS}(i,l,d) \tag{4.5}$$

In addition, the evaluation parameter to transfer data to a base station, or to the central Cluster-Head is computed as follows (equation 4.6):

$$cost_0 = \begin{cases} T_{c1} & if \ \ E_{rem}(i,r) \geq E_{TX}^{CH_i,CH_j}(i,l,d) \ \ and \ \ E_{rem}(j,r) \geq T_{c2} \\ Inf & Otherwise \end{cases} \tag{4.6}$$

where:

$$T_{c1} = E_{TX}^{CH_i,CH_j}(i,l,d) + E_{TX}^{CH_j,next\_hop_j}(j,l,d) + E_{RX}(j,l) \tag{4.7}$$

$$T_{c2} = E_{TX}^{CH_j,next\_hop_j}(j,l,d) + (E_{RX}(j,1) \times (M(j) + R(j) + 1)) \tag{4.8}$$

Table 4.4 shows a description of the parameters used in the above equations.

Hence, CH is chosen as the cheapest relay cost; thereafter CH_i sends a Route-Reply-message to the selected CH. Routing to the base station is made according to the route exposure phase without disruption during routing. Just if during intra-cluster routing a cluster head is not held in a layer.

Algorithm 1 states the pseudo code of the Setup phase of the proposed DEH-WSN algorithm.

4.4. Data Transmission Phase. Data transmission is performed thanks to the Carrier Sense Multiple Access (CSMA) method [30]. We use the Time Division Multiple Access (TDMA) where any cluster has only one node to send packets. First, nodes send all data to the cluster head. Then, Cluster head sends the packets to BS. By default, nodes that are in the first layer can send directly to BS.

Algorithm 2 shows the pseudo code of the Data Transmission Phase of the proposed DEH-WSN algorithm.

Algorithm 1 Setup phase of DEH-WSN

1: **BEGIN**
2: **if** $S[i].state=$"CHP" **then** ▷ $S[i]$ is the sensor node and "CHP" is the Cluster Head P, i.e. the period that the network is operational
3:     exit
4: **else**$S[i].state = node$
5: **while** $CT < TimePh1$ **do** ▷ CT is the calculation time of a cluster and $TimePh1$ is the time of the first phase
6:     $V_r = rand(0.1, 0.2)$ ▷ V_r ranges between 0.1 & 0.2.
7:     Compute the Delay Time $D(i,r)$ by equation 4.4
8: $T = TimePh1 + D(i,r)$ ▷ T is the delay of a node
9: **while** $CT < TimePh2$ **do** ▷ $TimePh2$ is the Time of the second phase
10:     **if** $CT > T$ **then**
11:         $S[i].state = $ 'CH'
12:         Send Msg_Head
13:         Receive Msg_Head from CH
14:         Store in List_Head $CHL[]$ along with distance ▷ $CHL[]$ is defined as the List of Cluster Head
15:     **else if** List_Head is received from any neighbor **then**
16:         $S[i].state = $ 'CM' ▷ CM is defined as the Cluster Member
17:         Store '[j]' in List_Head $CHL[]$ along with distance
18: **while** $CT < TimePh3$ **do** ▷ $TimePh3$ is the Time of the third phase
19:     **if** $S[i].state = $ 'CM' **then**
20:         Choose the nearest $CHS[j]$ from $CHL[]$ list ▷ $CHS[]$ is defined as the List of Sensor Node
21:         $S[i].head = S[j]$
22:         End JC Msg to $S[j]$ ▷ JC: Join Cluster
23:     **else if** $S[i].state = CH$ **then**
24:         Receive JC Msg from CM
25:         Save in $CM[]$ List
26:         Compute the Avg Energy of Cluster & weak members
27:         Transmit TDMA to $CM[]$
28:         $S[i].state = $ 'CHP'
29: **while** $CT < TimePh4$ **do** ▷ $TimePh4$ is the Time of the fourth phase
30:     **if** $S[i].state = $ 'CHP' **then**
31:         **while** $CT < Tr$ **do** ▷ Tr is the Time Route Msg
32:             Wait and receive Route_Msg from CHs
33:             Broadcast Route_Msg
34:             Save CHs data in Relay_CH List[]
35:     Select the CH of the next hop from Relay_CH List[] by formulas 4.5 and 4.6
36:     **while** $CT < Trr)$ **do** ▷ Tr is the Time Route Replay
37:         Wait and receive Route_Replay from CHs in upper Layer
38:         **if** receive Route_Replay **then**
39:             Store the information of the CHs in upper Layer
40:         broadcast Route_Replay to next hop in lower Layer
41: **END**

Algorithm 2 Data Transmission Phase of DEH-WSN

1: **BEGIN**
2: **while** $CT < TimePh1$ **do**
3:    **if** $S[i].state =' CM'$ **then**
4:       **while** $CT <$ transmition time from TDMA **do**
5:          In case the Sensor is relay for CM farther by TDMA
6:          Receive DP from CM and aggregation DP   ▷ DP is the Data Packet
7:       Transmit DP to BS or next hop from CM by TDMA
8:    **else if** $[i].state = CHP$ **then**
9:       **while** $CT <$ end of TDMA **do**
10:          Receive DP from CM and aggregation DP
11:       **while** $CT < TimePh2$ **do**
12:          **if** $[i].state = CHP$ **then**
13:             **while** $CT <$ base Layering transmission time **do**
14:                In case Sensor is the relay for CH in the upper Layer
15:                Receive DP from CH and aggregation DP
16:       Transmit DP to BS or next hop
17: **END**

TABLE 5.1
Scenarios used for the simulation.

Scenarios	Base Station	Nodes Number	Network Space
Scenario 1	(1500,500)	100	1km × 1 Km
Scenario 2	(500,500)	50	1km × 1 Km

5. Simulation Results. We assess the performance of the DEH-WSN protocol via simulations using MATLAB. We compared our proposed protocol (DEH-WSN) with respect to other NEEC [20] and HUCL [14].

Our study evaluates the stability in the network, the First Node Death (FND), the Half Node Death (HND), the number of alive nodes, the average energy during simulations and the throughput.

We have simulated our WSN in a sensing field of (1km × 1km). In these experiments, two scenarios have been evaluated, as shown in Table 5.1. Other parameters are shown in Table 5.2.

The clusters closer to BS should be smaller, the cluster should have more strength to route higher-level packets to the base stations. In our simulation, we assume that $P_{opt} = 0.1$ and $C = 0.4$, and we set $RL_{max} = 550$ m where $RL_{max} = 1.25 \times 550$ (second and third layers) and $RL_{max} = 1.75 \times 500$ (fourth layer).

In the first scenario, 100 sensors nodes are distributed randomly in the area, A sink node is at the location of coordinates ($x = 1500$, $y = 500$). In the second scenario, 50 sensor nodes are randomly distributed in the same simulation area with a sink node is at the location of coordinates ($x = 500$, $y = 500$). According to this data information, we presented a comparison between these two scenarios for the two experiments.

Based on LEACH protocol, both energy consumption per bit are used, the free space E_{fs} (d^n power loss) and the multipath fading E_{amp} (d^n power loss), they rely on the distance between the sender and receiver. Where we use the free space model with $n = 2$, if the distance is less than a threshold d_0. Otherwise, the multipath model is used where $n = 4$.

5.1. Experiment 1: Number of alive nodes per time. The first experiment is about the number of alive nodes per time for the three different protocols. Figures 5.1 illustrate the number of alive nodes during simulations, seeking to calculate the average number of alive nodes shown in Table 5.3, the results demonstrate that DEH-WSN has a great performance since it raises the number of alive nodes 25% against HUCL protocol.

TABLE 5.2
Simulation Parameters.

Parameters	Symbols	Value
Energy depletion of the node's electronics circuit to transmit or receive the signal.	E_{elec}	60 nJ/bit
Energy depletion of the booster to deliver at a shorter distance (Free Space)	E_{fs}	10 $nJ/bit/m^2$
Energy depletion of the booster to deliver at a longer distance (Transmit amplifier)	E_{amp}	0.0015 $pJ/bit/m^4$
Energy for data aggregation cost expended in Cluster-Head per signal	E_{DA}	5 $nJ/bit/signal$
First energy of normal nodes	E_o	0.5 J
Data packet size	-	5000 $byte$
Packet header size	-	25 $byte$
Control message size	-	50 $byte$
Lower threshold for energy harvesting	$E_{Th_{down}}$	0.1 J
Upper threshold for energy harvesting	$E_{Th_{up}}$	1 J
Probability rate of CH	P_{opt}	0.1

TABLE 5.3
Rate of the average number of alive nodes.

Protocol	Scenario 1	Scenario 2
DEH-WSN	80.6351	41.7261
NEEC [20]	80.6	40.9
HUCL [14]	60.5	33.5

5.2. Experiment 2: Number of Data Packets per time. The second experiment, evaluate the number of packets transmitted per time (throughput) for the three differences protocols. Figures 5.2 show the numbers of each packet established during the two simulations, the results demonstrate that DEH-WSN has throughput more improved and capable to transfer larger packets versus other protocols.

Tables 5.4 and 5.5 shows the performance evaluation of protocols and the rate parameters FND and HND in the two scenarios. The performance results of the protocol demonstrate that DEH-WSN is more effective for improving FND and HND and for transfering more packets against other protocols. Stability is increased by changing the possibility of nodes to be CH according to the energy status of nodes and the amount of harvested energy. CH consumes more energy consumption balanced between nodes during the simulation. The results prove the efficiency DEH-WSN in increasing of HND against other protocol during the simulation.

6. Conclusion. We presented and evaluated a new routing protocol that relies on matching between clustering and energy harvesting in a distributed manner, which aims to maximize network lifetime and to become unlimited, by using energy harvesting instead of energy efficient Clustering protocols. Starting with these aims, and motivated by the various studies of WSN algorithm, we introduced the model network and the energy harvesting model to match between distributed Clustering and energy harvesting. Based on this approach, we proposed our new Distributed energy Harvesting Clustering algorithm "DEH-WSN".

Moreover, in DEH-WSN, we use an estimation scheme to solve the average residual energy for the network that is recharged thanks to a uniform energy harvesting system. Our approach can be applied to the design of several types of wireless sensor network protocols that require network stability, since DEH-WSN can
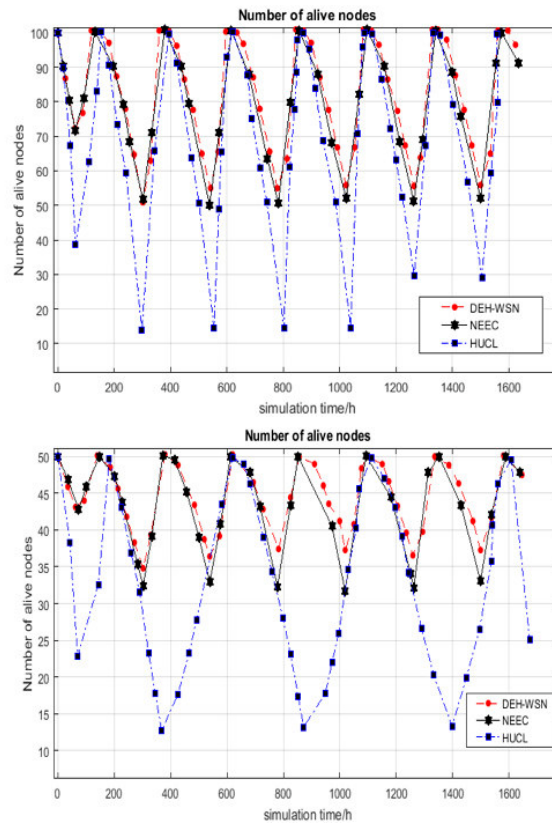
FIG. 5.1. *Number of Alive nodes per time for Scenarios 1 (top) and 2 (bottom)*

TABLE 5.4
Average of FND and HND for scenario 1.

Scenario 1	FND(100 Nodes)		HND(50 Nodes)	
	Time	Packets	Time	Packets
DEH-WSN	23 min	290.6	31 h: 23 min	2.6049e+04
NEEC	30 min	254.9	21 h: 24 min	27163.3
HUCL	24 min	124.2	8 h:30 min	3229.4

TABLE 5.5
Average of FND and HND for scenario 2.

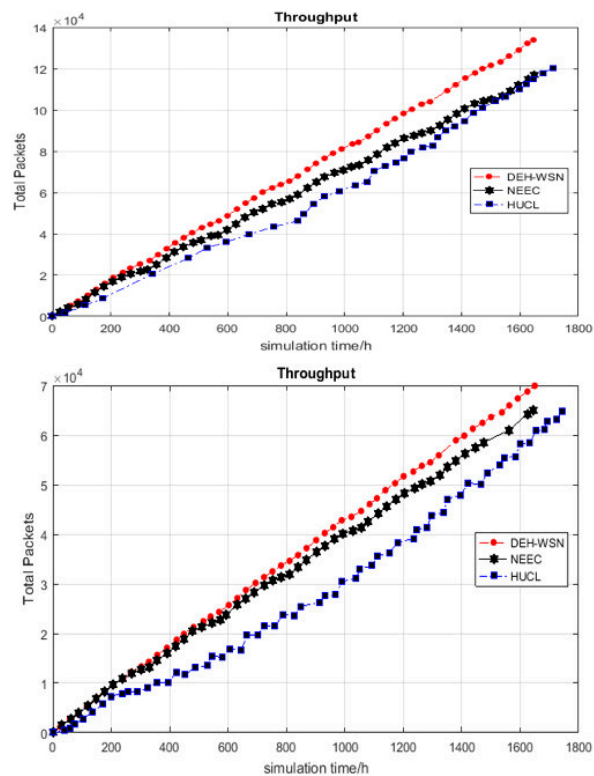| Scenario 2	FND(100 Nodes)		HND(50 Nodes)	
	Time	Packets	Time	Packets
DEH-WSN	1 h:51 min	N	N	N
NEEC	1 h:48 min	876.5	N	N
HUCL	1 h:12 min	599.8	8 h:30 min	3431.6

FIG. 5.2. *Number of packets made per time for Scenario 1 (top) and 2 (bottom)*

significantly improve the First Node Death (FND), the Half Node Death (HND), the number of alive nodes, the average energy, and the throughput. Furthermore, we presented two scenarios to evaluate this algorithm against other protocols. According to the simulation results, we demonstrate that the proposed algorithm balances the energy consumption, increases the number of available nodes and increases the number of repair packets in the BS. In future work, we can take different energy consumption for cluster head selection method to a heterogeneous wireless sensor network.

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