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ECH: An Enhanced Clustering Hierarchy Approach to Maximize Lifetime of Wireless Sensor Networks

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ABSTRACT In order to gather data more efficiently, a clustering hierarchy algorithm is used for data communication in wireless sensor networks (WSNs). This algorithm is one of the major techniques to improve the energy efficiency in WSNs and it provides an effective manner to maximize the lifetime of WSNs. Hierarchical protocols based on clustering hierarchy are proposed to save energy of WSNs in which the nodes with higher remaining energy could be used to collect data and transmit it to a base station. However, most of the previous approaches based on clustering hierarchy have not considered the redundant data collected by the adjacent nodes or nodes overlap each other. In this paper, an enhanced clustering hierarchy (*ECH*) approach has been proposed to achieve energy efficiency in WSNs by using sleeping-waking mechanism for overlapping and neighboring nodes. Thus, the data redundancy is minimized and then network lifetime is maximized. In contrast of previous hierarchical routing protocols where all nodes are required for collecting and transmitting data, the proposed approach only requires the waking nodes to do these tasks, which are keys of energy consumption in WSNs. We implement (*ECH*) approach in homogeneous and heterogeneous networks. Results of the simulation show its effectiveness.

INDEX TERMS Wireless sensor networks (WSNs), energy efficiency, clustering, hierarchical protocols, cluster head selection, data redundancy.

I. INTRODUCTION

In applications of wireless sensor networks (WSNs), the sensor nodes are used to monitor and collect data about their environment of interest and forward these collected data to the user via base station (BS). A WSN is composed of several such of sensor nodes which use radio waves to carry out sensing and communication tasks [1]–[3]. The sensor nodes are mostly powered by non-rechargeable batteries and scattered over environment at a high density. Because of the high density, the data sensed by different sensor node is ordinarily and spatially correlated [4]–[6]. Hence, for network lifetime maximization, the sensor nodes need to decide their sensed data rates to the BS in order to report the total network information while decreasing data redundancy in their sensed data reports. Besides, the communication planning itself must enhance energy efficiency and energy harvesting in the network [7] and [8].

In [9] and [10], the technique of clustering hierarchy based routing protocols have been proposed for improving energy efficiency in WSNs since only some sensor nodes, namely cluster heads (CHs), are allowed to be in contact directly with the web server or BS. The CHs are responsible for collecting the data from respective cluster members, compressing this data, and then conveying it to the web server or BS. By organizing the sensor nodes into clusters with the assistance of data aggregation/fusion mechanism, energy efficiency usage is obtained since the overall amount of data sent to the BS is considerably minimized, intra-cluster communication authorizes to minimize the communication distance of cluster members and then minimize energy dissipation. The hierarchical routing protocols [11] based on clustering algorithm have been proposed in order to manage the data communication in WSNs. These protocols use a probability model to form the clusters in order to gather information and transmit it to the BS. However, predominantly, the sensor nodes are randomly distributed, thus some sensor nodes collect and transmit same data (redundant data) to the BS and then to the user. Furthermore, as redundant data communication is one of the major sources of high energy dissipation, the longevity in the network lifetime will be minimized. Indeed the distribution of sensor nodes is not uniform the neighboring and

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overlapping sensor nodes may transmit redundant data to the CHs and then a BS through a long distance, thus the energy dissipation is maximized which means minimized lifespan of network. Consequently, the redundant sensed data is one of the major challenges in WSNs applications. In addition, during the WSN employment, communication task predominantly depletes the most energy as compared with other tasks. In hierarchical routing protocols, each node transmits the detected information to its CH even its distance from the BS is minimal than that from the CH. Thus, energy is consumed which causes decreasing in network lifetime.

In this paper, we propose an enhanced clustering hierarchy (*ECH*) approach to maximize the lifetime of WSNs by minimizing data redundancy and data communication distance. After the random deployment of nodes in the network area, information sharing among the nodes is performed with *update* packet. The nodes with the sensing range either partially or fully overlapped with the sensing of others are organized into groups. For every round, in each group, one or more nodes are selected as waking nodes as long as others of group members are selected as sleeping nodes. During this round, only the waking nodes perform the sensing, computation and communication tasks, while, the radio circuitry of sleeping nodes remain off and cease the communication with other nodes. Therefore, the sleeping nodes conserve their energy by disabling their functionality of sensing, computation, and communication. In addition, the nodes that do not belong to any group of neighboring are selected as unpaired nodes and remain as waking nodes for every round till their lifespan end. The waking nodes and unpaired nodes will participate in process of random CHs election in the current round. More importantly, our proposed approach introduces a mechanism to select the CHs in optimal number and also it uses another mechanism to reduce the overall communication distance, so the energy consumption is minimized which means the maximized lifetime of the network.

The rest of this paper is organized as follow: related work is provided in section II, next, in section III, the description of the proposed *ECH* approach is detailed, section IV shows the performance evaluation, section V concludes this work.

II. RELATED WOK

Routing protocols in WSNs play a significant role in determining the achievable energy efficiency in the network. Specifically, the routing protocols based on the clustering hierarchy algorithm are crucial for the sake of energy efficiency enhancement. In addition, the WSNs are partitioned into homogeneous and heterogeneous networks. In the homogeneous networks, all nodes are initially supplied with the same energy levels, whereas, in the heterogeneous networks, different residual energy are assigned to the nodes. The clustering hierarchy algorithm based routing protocols in WSNs have been presented as various proposed approaches [12]–[14]. However, due to space restriction, only some of these proposed approaches are presented in this section.

Low-energy adaptive clustering hierarchy (LEACH) [15] is one of the routing protocols based on the clustering hierarchy to achieve the energy-efficient in the homogeneous networks. The main goal of this protocol is to reduce global communication in the network by forming of clusters, which are based on minimum distance. In each cluster, a CH is responsible for gathering data from cluster members and transmitting the gathered data to the BS. CHs in LEACH are randomly rotated during the network operation to equilibrium the energy consumption in the network. A given node n generates a random number, between 0 and 1, and compares it with a threshold [16], which is defined as (1).

$$Th(n) = \begin{cases} \dfrac{p}{1 - p.(mod(r, \dfrac{1}{p}))} & \text{if} \quad n \in G \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where r is the current round, p is the expected number of CHs which is described initially, G is the ensemble of nodes which are eligible for CHs selection, and $mod(r, 1/p)$ presents the modulus after the division of r by $1/p$. When the threshold value is bigger than the random number, the node is selected as CH. The network operation, in LEACH protocol, is divided into rounds. Each round begins with a set-up phase when the clusters are organized, followed by a steady-state phase when sensed data are transmitted from the cluster members to the BS through CH.

Threshold sensitive Energy-Efficient sensor Network (TEEN) [17] is a clustering algorithm based on hierarchical routing protocol for the homogeneous networks. The objective of TEEN is to design for the conditions as sudden changes in the sensed attributes. The operation of TEEN is similar to that of LEACH. The difference between TEEN and LEACH lies in the steady-state phase precisely at the frame of data transmission. In LEACH, there is no control on the data communication, whereas, in TEEN when any node has the data to transmit, there is a verification of soft and hard thresholds. At the start time, the nodes send, when the sensed value attains its hard threshold. Maybe next time transmissions occur; only when the sensed value is maximal than a hard value threshold.

Stable Election Protocol (SEP) [18] has been proposed for heterogeneous networks. Based on remaining energy, the nodes are divided into two categories, known as normal and advanced nodes. The advanced nodes having α times more energy in comparison to normal nodes. In addition, E_o is the initial energy of normal node and then $E_o(1 + a)$ is the initial energy of advanced node. So, it is clear that advanced nodes have more chance to become the CHs due to their significant probabilities. The probabilities for normal and advanced nodes could be obtained via (2) and (3), respectively.

$$p_{nrm} = \frac{1}{(1 + \alpha.m)} \tag{2}$$

$$p_{adv} = \frac{p.(1 + \alpha)}{(1 + \alpha.m)} \tag{3}$$

where m is the fraction of advanced nodes. The network operation, in SEP protocol, is similar to the LEACH protocol.

Distributed Energy-Efficient Clustering (DEEC) [19] is one of the clustering algorithms to achieve energy efficiency in heterogeneous networks. In DEEC, at the network operation start, all nodes are supplied by different energy levels. The probability of the CHs selection is based on the remaining energy of nodes to the average energy of the network. This means that each node with higher remaining energy has more probability to be a CH for the current round. The CHs selection and clusters formation in DEEC are similar as in LEACH, TEEN, and SEP. In addition, the probability of any node to be a CH could be obtained by (4).

$$p_n(r) = \frac{p_{opt}.N.(1+\alpha).E_n(r)}{(N + \sum_{n=1}^{N} \alpha_n).\overline{E(r)}} \tag{4}$$

where, p_{opt} is the probability of CHs in each round r, N is the total number of nodes, $E_n(r)$ is the remaining energy of a node, and $\overline{E_n(r)}$ is the average energy of the network.

In [20], authors proposed away CHs with adaptive clustering habit $(ACH)^2$ for WSNs. The objective of proposed $(ACH)^2$ is to maximize the stability period, network lifetime, and the throughput of the WSNs. The prettiness of $(ACH)^2$ is its away CHs selection and free association methods. The $(ACH)^2$ verifies the mechanism of CHs selection to ensure a uniform load on CHs. Further, the free association method eliminates back transmissions in network. So, the operation of the network, in $(ACH)^2$ technique, minimizes the overall energy dissipation in the network. In addition, the proposed $(ACH)^2$ has been implemented in homogeneous and heterogeneous networks. Thus, the performance of WSNs is more efficient as compared to other approaches.

III. PROPOSED CLUSTERING HIERARCHY APPROACH

Regarding the lifetime of WSNs, many protocols of network layer have been proposed [15]–[20]. However, in these protocols, the energy efficiency is not maximized which leads to network lifetime minimization. Firstly, these protocols depend on only a probability model to select CH. So the problem of CHs selection can be solved such as [21], [22]. Moreover, the clusters number is not optimal. Thus, the nodes are organized into clusters of different sizes which conducts to non equilibrium energy dissipation. Secondly, the nodes can transmit data over long communication distance i.e., the cluster members transmit sensed data to its CH even if its communication distance from the BS is less than from its CH. So the energy efficiency can be minimized. Thirdly, some nodes in the network could send the same data to the BS for analysis i.e., the neighboring and overlapping nodes could collect and transmit redundant data to the BS which causes maximized load on nodes. Thus, energy efficiency is minimized which means minimized lifetime of WSNs. In order to overcome these challenges, we propose an enhanced clustering hierarchy (ECH) approach to maximize lifetime of WSNs. In this section, we first provide the network model of our proposed approach, next, analyze maximizing network lifetime of WSNs by avoiding data redundancy, present the algorithm description of ECH, and then evaluate the accuracy and complexity of ECH algorithm.

A. NETWORK MODEL

In this work, we consider the applications of WSNs in which n nodes are distributed randomly in order to surveil and monitor the environmental parameters. The data detected by nodes is transmitted to a base station (BS) positioned at the centre of the environment of interest. all network nodes achieve sensing task to surveil and monitor the various environmental changes and forward the collected data directly to the BS or to the associated CH or in CH mode to collect information, compress it and transmit to the BS. In addition, some hypotheses are defined as follows:

1) All nodes and the BS are motionless after distribution.
2) Each node performs set periodic tasks, $M_i = \{S_i, A_i, C_i\}$, where S_i is the sensing task (i.e., data collection), A_i is computation task (aggregation, data processing, etc.), and C_i is the communication task (transmission and reception of data).
3) It is on the basis of the received signal strength, we can calculate the distance between the nodes in the network.
4) The wireless link is symmetric such that energy dissipation of data communication distance between node X and node Y is the same as that of data communication distance between node Y and node X.
5) We suppose that the nodes are all moment synchronized and begin the first phase at the same moment. This could be realized, for instance, by having the BS forward out synchronization pulses to network nodes.

B. MAXIMIZING NETWORK LIFETIME OF WSNS BY MINIMIZING DATA REDUNDANCY

An important characteristic of random deployment of nodes is that the data collected by the neighboring and overlapping nodes represent redundant data owing to the spatial-temporal data correlation characteristics of the neighboring and overlapping nodes. Therefore, each node carries out reliable sensing along the sensing range R_{sense}. In the fact, there is no need to transmit the same information more than time to the BS for analyzing. Reducing the overall traffic by removing the data redundancy can be beneficial in terms of efficient energy and hence network lifetime maximization.

The concept of our proposed ECH approach is illustrated in Fig. 1. In this figure, we consider a network that consists of the set of wireless nodes, represented as $n = \{n_1, n_2, n_3\}$, these nodes that are within the sensing range of each other and can communicate directly with the node destination (i.e., BS). Moreover, each node n_i performs the periodic tasks $M_i = \{S_i, A_i, C_i\}$. Let $e_i^s(l)$, $e_i^a(l)$ and $e_i^c(l, d)$ denote the energy consumption for sensing, aggregation and communication one data unit (l) over distance d (n_i, BS), respectively; and

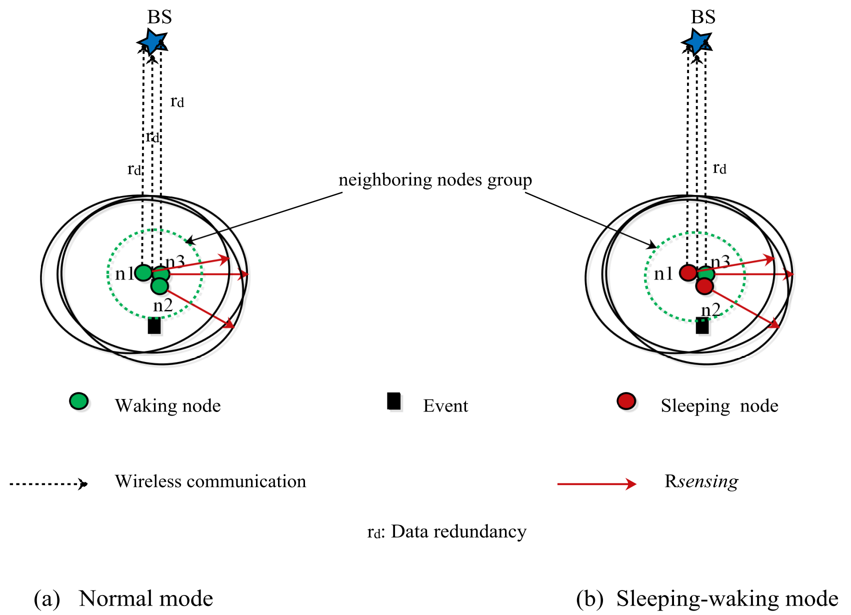


FIGURE 1. Illustration reducing data redundancy by using sleeping-waking mode: (a) Normal mode. (b) Sleeping-waking mode.

E_o is the initial energy of node n_i. We suppose that p_i^s is the power consumption at the node n_i when it detects one data unit, p_i^a is the power consumption when it aggregates one data unit, and p_i^c is the power consumption when one data unit is transmitted from the node n_i to the BS over distance $d\ (n_i, BS)$. Thus, the energy residual E_i and the power consumption rate p_i at node n_i, which generates data rate r_d, could be obtained via (5) and (6), respectively.

$$E_i = E_o - (e_i^s + e_i^a + e_i^c) \tag{5}$$

$$p_i = r_d(p_i^s + p_i^a + p_i^c) \tag{6}$$

In this work, we define the lifetime L_i of node n_i as (7).

$$L_i = \frac{E_i}{p_i} \tag{7}$$

The network lifetime is presented as the lifetime of the wireless node of network that dies last. The problem of maximal network lifetime asks the given data how to reduce the data redundancy so that the network lifetime could be maximized. We suppose that L is the lifetime of the wireless nodes network, i.e., $L = \sum_{i=1}^{|n|} L_i$. The maximal network lifetime problem could be formulated as formula (8).

$$\begin{aligned} &Maximize\ L \\ &\text{subject to}: p_i L \le E_i \quad \forall i \in n \end{aligned} \tag{8}$$

Our main objective in (8) is to maximize the network lifetime, i.e., minimizing the energy dissipation at any node n_i with the lifetime of the network is no more than its energy residual E_i, i.e.,

$$p_i L \le p_i L_i = E_i \quad \forall i \in n \tag{9}$$

In order to maximize the network lifetime, there are three constraints in solving the problem (8). Firstly, we determine a group of neighboring nodes (or overlapping nodes) that include all nodes with sensing range either partially or fully overlapped (refer Fig. 1(a)). In this neighboring nodes group, all nodes may detect the same information (i.e., same event), compute and transmit it to the BS, so energy consumption of the nodes is further maximized. Secondly, the total energy-efficient in the neighboring nodes group should be optimized, which leads to a demand for minimizing the number of waking nodes in the wireless nodes set n and then decreasing power consumption for either sensing e_i^s, data aggregation e_i^a, communication e_i^c of each node n_i. Thirdly, the routing algorithm uses sleeping-waking mode (refer Fig. 1(b)) to minimize the redundant data transmissions r_d and thus save energy in sleeping nodes i.e., network lifetime is maximized. In the next subsection, the proposed clustering hierarchy (ECH) approach will be described in details.

C. PROPOSED ECH CLUSTERING HIERARCHY APPROACH

In order to optimize the energy efficiency and the lifetime of WSNs by minimizing the data redundancy in network, we propose the enhanced clustering hierarchy approach, namely ECH. In this subsection, we describe the ECH technique that optimizes the energy consumption in WSNs and decreases the failure probability of the nodes by using the sleeping-waking mode. The pictorial representation of the network model is shown in Fig. 2. The nodes (WSC nodes), in network model, are divided into sleeping nodes, waking nodes, and CHs. The waking nodes detect data from environment of interest, aggregate these data, and transmit it to the BS via associated CHs, whereas, the sleeping nodes remain off during the current round. In next round, each node can change its status. In this way, the energy consumption is optimized in

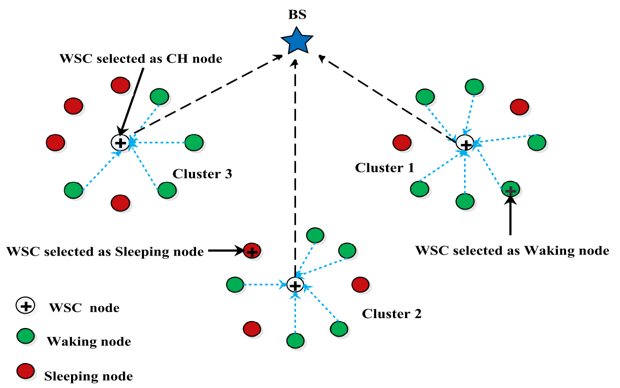


FIGURE 2. Pictorial representation of the network model of ECH.

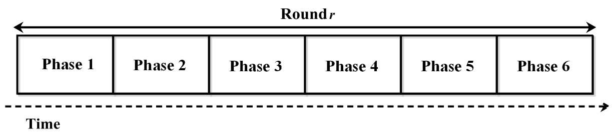


FIGURE 3. Timeline showing enhanced clustering hierarchy approach operation.

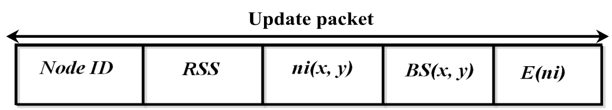


FIGURE 4. Update packet format.

the network because the sleeping nodes conserve their energy by not communicating with others nodes.

The operation of the proposed approach is divided into rounds. Each round consists of six phases as shown in Fig. 3; (1) formation of neighboring nodes groups, (2) selection of sleeping and waking nodes, (3) random election for the CHs selection, (4) CHs selection, (5) free organization, and (6) data transmission. The following paragraphs describe each phase of the round.

1) FORMATION OF NEIGHBORING NODES GROUPS

Once nodes are randomly distributed in an environment of interest, each node broadcasts an *update* packet (shown in Fig. 4) with information about its ID, received signal strength (RSS), relative position (x, y), relative position of BS (x, y), and remaining energy $E(n_i)$ over the network. In order to reduce packets collisions, the random back-offs [23] has been used by nodes before broadcasting the *update* packet.

For every node n_i, we define a group of neighboring nodes $Q(i)$ that includes all nodes with sensing ranges either partially or fully overlapped with the sensing range of node n_i. The group of neighboring nodes is defined as (10).

$$Q(i) = \{n_j | d(n_i, n_j) \leq 2.R_{sense}, i > 1\} \tag{10}$$

where, $d(n_i, n_j)$ is the Euclidean distance between nodes n_i and n_j, and i is the number of nodes in $Q(i)$.

The nodes do not belong to the groups $Q(i)$, in their sensing ranges, they are marked as unpaired nodes n_{up} (i.e., the nodes which have not the neighbors in sensing range). In addition, we do not assume a full coverage problem in this work. To minimize the number of waking nodes while assuring that each point Z of the sensing range is supervised by at least one node, each node needs to locate the overlap of its sensing range with the sensing ranges of its neighboring nodes. Therefore, we suppose that the nodes are equipped with systems of localization (e.g., GPS). Considering each node's location and its energy level, for each point Z of the sensing range $2.R_{sense}$, we define the total energy $E_t(Z)$ that is available for monitoring that position as (11).

$$E_t(Z) = \sum_{n_j : Z \in 2.R_{sense}} E(n_j) \tag{11}$$

where $E(n_j)$ is the energy level of node n_j.

2) SELECTION OF SLEEPING AND WAKING NODES

After the formation of neighboring nodes groups, the subset of nodes, in these groups, is chosen to achieve the periodic tasks M_i for the current round, while the rest nodes go to sleep. The chosen waking nodes afford total monitor over sensing range in the course of this round. In the process of sleeping nodes and waking nodes selection, which is shown in *Algorithm* 1, each node assigns itself a time slot $(_{n_i})$ that is proportional to its current weights described as functions (12), (13), and (14), respectively. In this manner, the nodes with smaller weights have a higher probability to become awake. Each node then waits for this period time before determining whether it will stay awake over the current round. While waiting for its time slot $(_{n_i})$ to run out, the node receives the WAKING notifications from its neighboring nodes, which have minimal weights, if they decide to become awake node over the current round. If, after its time slot $(_{n_i})$ runs out, the node determines that its sensing range is fully monitored by its neighboring nodes, it turns itself off for the current round. Otherwise, the node broadcasts a WAKING notification to inform its neighbors about its status to remaining waking nodes. In this manner, the minimal weight nodes have priority to decide whether they should be awake. The weight function (12) is based on the total energy $E_t(Z)$ available for monitoring each position in the node range, whereas the other weight functions (13) and (14) evaluate the node's ability to take part in the sensing and communication tasks based on its residual energy $E(n_i)$ and its distance to BS $d(n_{i\_} - BS)$.

$$Weight_1(n_i) = \frac{1}{E_t(Z)} \tag{12}$$

$$Weight_2(n_i) = \frac{R_{sense}}{E(n_i)} \tag{13}$$

$$Weightt_3(n_i) = \frac{d(n_{i\_} - BS)}{E(n_i)} \tag{14}$$

In addition, the nodes which are marked as waking nodes and unpaired nodes will participate in process of CHs selection in the current round. Furthermore, unpaired nodes remain as waking nodes for every round till their energy depleted.

Algorithm 1 Selection of Sleeping and Waking Nodes

1. $N = \{n_i | E(n_i) > 0\}$, $E(n_i)$- is residual energy of node n_i
2. $n_i \in Q(i)$
$_{n_i} \propto W(n_i)$, $W(n_i) \in \{(Weight_j(n_i))_{j=1,2,3}\}$
3. During period $_{n_i}$
n_i receives WAKING notifications from its neighboring nodes
4. $_{n_i}$ expired
5. n_i verifies whether its sensing range $2.R_{sense}$ is fully monitored
6. **if** $2.R_{sense}$ is not fully monitored **then**
7. n_i send WAKING notification to its neighboring nodes
8. **end if**

3) RANDOM ELECTION FOR THE CHS SELECTION

Once waking nodes and unpaired nodes are selected to perform periodic tasks M_i, these nodes elect themselves to be a candidate for CHs selection. Each node (unpaired node and waking node) generates a random number *Random*, between 0 and 1, and compares it with the threshold *Th*. For this, two cases are defined:

- **Case 1** ($Random > Th$): Node can not be elected for the phase of CHs selection, and is indicated as a normal node N.
- **Case 2** ($Random \leq Th$): If the node has not selected as CH for the last rounds, then it appertains to candidate group ($'C'$) and is indicated as candidate node n_c for the CHs selection in the current round.

4) CHS SELECTION

After the random election of candidate nodes n_c for the CHs selection, an optimal number of clusters will be needed. In order to achieve this need, employment or no employment of certain mechanisms takes place, which results in equal load on CHs. The CHs selection depend on the optimal number of clusters, as function of the scalability, and after the uniform spreading of waking nodes in the area of network. The optimal number of clusters is confirmed by the fact that the total energy dissipation is lower, and energy dissipation per round is well distributed over all the network nodes. In this work, to calculate the optimal number of clusters, the first order radio model shown in [24] and [25] has been adopted to model the energy dissipation. As a distance between the source node and destination node is less than a threshold value d_o, the free space model (d^2 power path loss) is employed. Otherwise, the multipath fading channel model (d^4 power path loss) is used. Equation (15) represents the amount of energy consumed for transmitting l bits of data to d distance, while equation (16) illustrates the amount of energy consumed for receiving l bits of sensed data.

$$E_{Tx}(l,d) = \begin{cases} lE_{elec} + l\epsilon_{fs}d^2 & \text{if} \quad d < d_o \\ lE_{elec} + l\epsilon_{mp}d^4 & \text{if} \quad d \geq d_o \end{cases} \tag{15}$$

$$E_{Rx}(l) = lE_{elec} \tag{16}$$

E_{elec} is the energy consumption per bit of the transmitter or receiver circuits. ϵ_{mp} and ϵ_{fs} are two constants for energy consumption. The reference distance d_o is obtained via (17).

$$d_o = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{fs}}} \tag{17}$$

Each CH dissipates its energy when receiving data from the cluster members, aggregates these data, and transmits it to the BS. Since the BS is far from the CHs, presumably the energy dissipation follows the free space model (d^2 power path loss). Thus, the energy consumed by the CH during a round is given by (18).

$$E_{CH} = lE_{elec}\left(\frac{n_w + n_{up}}{k} - 1\right) + lE_{DA}\left(\frac{n_w + n_{up}}{k}\right) + lE_{elec} + l\epsilon_{fs}d_{BS}^2 \tag{18}$$

where k is the number of clusters, n_w is the number of waking nodes, n_{up} is the number of unpaired nodes, E_{DA} is the energy dissipated by CH in terms of data aggregation, and d_{BS} is the distance from CH to BS.

The energy consumed by a normal node N for transmitting l bits to the CH could be represented as (19).

$$E_N = lE_{elec} + l\epsilon_{fs}d_{CH}^2 \tag{19}$$

where d_{CH} is the distance between a normal node N and its CH. The surface employed by a cluster is approximately M^2/k. Predominantly, this is an arbitrary-shaped zone with a distribution $\rho(r,\theta)$ of node. The foreseeable squared distance between the nodes and their CHs could be represented as (20).

$$E[d_{CH}^2] = \int_0^{2\pi} d\theta \int_0^{\sqrt{\frac{M^2}{\pi k}}} r^3 dr = \frac{M^2}{2\pi k} \tag{20}$$

The energy dissipation of the whole cluster is presented as formula (21).

$$E_{cluster} = E_{CH} + \left(\frac{n_w + n_{up}}{k} - 1\right)E_N \simeq E_{CH} + \frac{n_w + n_{up}}{k}E_N \tag{21}$$

The total energy consumed by the network for a round is given by (22).

$$E_{Total} = kE_{cluster} + n_sE_{n_s} = l(2(n_w + n_{up})E_{elec} + (n_w + n_{up})E_{DA} + \epsilon_{fs}(kd_{BS}^2 + (n_w + n_{up})\frac{M^2}{2\pi k})) \tag{22}$$

where E_{n_s} is energy consumed by sleeping node n_s (i.e., $E_{n_s} = 0J$).

The optimal number of CHs is obtained by derivation of E_{total} with respect to k to zero,

$$k_{opt} = \sqrt{\frac{(n_w + n_{up})M}{2\pi d_{BS}}} = \sqrt{\frac{2(n_w + n_{up})}{2\pi 0.765}} \tag{23}$$

Therefore, the optimal probability p_{opt} of a node (i.e., waking node and unpaired node) to become CH for the current round could be obtained via (24).

$$p_{opt} = \frac{k_{opt}}{n_w + n_{up}} \tag{24}$$

Immediately after the election of candidate nodes for the CHs selection, such that the group of the candidate nodes C is completed. $Card(C)$ is the number of candidate nodes n_c that belong to the group C, it is compared with k_{opt}. There are three cases:

- **Case 1** ($Card(C) = k_{opt}$): Operation of the algorithm is passed to the phase 5.
- **Case 2** ($Card(C) < k_{opt}$): Re-election for CHs selection.
- **Case 3** ($Card(C) > k_{opt}$): Number of CHs must be minimized.

In case 2, the CHs re-election process is based on average distances between the normal node N and all candidate nodes n_c for CHs selection. After soon receiving re-election message from candidate nodes n_c, each normal node N calculates average distance between itself and all candidate nodes n_c and compares this average distance to distance from BS. If average distance is strictly greater than the distance from BS, then this normal node N will participate in the CHs re-election process by generating a *Random* number between 0 and 1 (shown in phase 3). However, in case 3, which is described in *Agorithm* 2, each n_c exchanges *C_message* to one another using CSMA/CA [26], [27]. As receiving *C_message*, each n_c calculates the *chance* based on energy level $E(n_c)$ and local distance $L_d(n_c)$ (refer eqn.(25)). Then, the n_c broadcasts *Back_message* with its *chance*. This message means that the n_c is the candidate for going back to normal node N with the value of *chance*. Once n_c sends a *Back_message* to another, the n_c waits *Back_messages* from others n_c. If the *chance* of itself is minimal than each value of *chance* from other candidate nodes n_c, then this candidate node n_c went back as the normal node N during the current round. The candidate nodes n_c which stayed as CHs will advertise themselves by broadcasting their *update* packets to other nodes N. Therefore, the clusters are well formed and organized in the network. In addition, to get a *chance* value, our proposed approach uses two fuzzy descriptors that are used in the fuzzy $IF - THEN$ rules are defined like follow:

- **Energy** $E(n_c)$: Energy level of the candidate node n_c.
- **Local Distance** $L_d(n_c)$: Sum of distances between the candidate node n_c and the candidate nodes n_c which is within the network area. The local distance could be obtained by (25).

$$L_d(n_c) = \sum_{i=1}^{c-1}(d_i) \quad : \forall c \in C \tag{25}$$

In this work, the method of heuristic fuzzy is employed with the principle rule: A candidate node n_c which holds less energy level $E(n_c)$ and maximal local distance $L_d(n_c)$ has higher chance to go back as a normal node N.

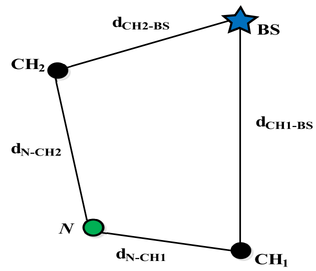


FIGURE 5. Organization of a node with CH.

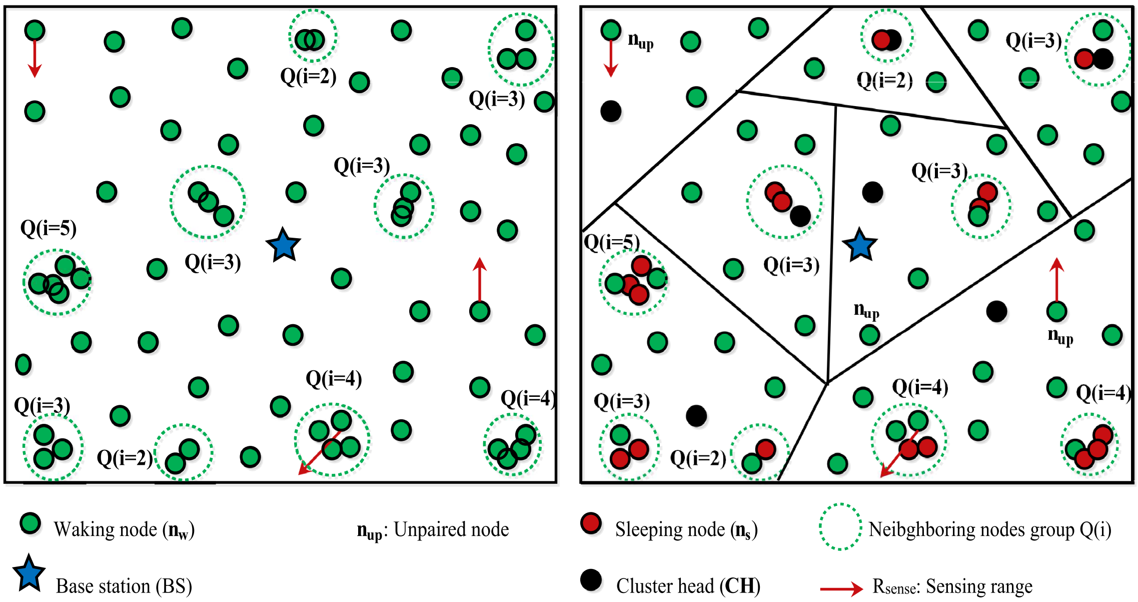
Algorithm 2 Minimize number of CHs

1. $C = \{n_c | E(n_c) > 0\}$, $E(n_c)$-is residual energy of node n_c
2. **while** $n_c \in C$ **do**
 n_c exchanges *C_message* to one another
3. $CH(n_c) = n_c$
4. $chance(n_c) = fuzzylogic(E(n_c), L_d(n_c))$ // n_c calculates its *chance* using fuzzy $IF - THEN$ rules
5. n_c broadcast($chance(n_c, C)$) // *Back_message*
 On receiving *Back_message* from other n_c^i // $\forall n_c^i \in C$
6. **if** ($chance(n_c) < chance(n_c^i)$) **then**
7. $n_c = N$ & $n_c^i = CH(n_c^i)$; //n_c is back to normal node N and n_c^i stays as CH for the current round
8. $n_c \notin C$
9. **end if**
10. **end while**

5) FREE ORGANIZATION

Immediately after the determination of optimal number of clusters, sensed data report process of normal nodes N requires to be transmitted. The CHs broadcast *update* packet to the normal nodes N. The normal nodes record the update notification along with the *update* packets during the phase 1, and based on this record the update notification these decide the sensed data reporting procedures which are based on the short overall transmission distance. In order to reduce communication distance, we use *update* packet in which each node has a global vision about the network. Once normal nodes N received the *update* packets from all CHs and also BS, they assess their received signal strength (*RSS*). If they receive stronger *RSS* (i.e., minimum distance) from BS as compared to the CHs, then the locally sensed data send directly to BS. On the contrary, if a given node N received a stronger *RSS* from any of the CHs are compared to BS, then in the better benefit of the node in terms of short communication distance and energy efficiency.

Fig. 5 shows how a node N picks a CH in terms of short communication distance and energy efficiency. The given node N compares the relative *RSS* (i.e., distances) received from both the CHs i.e., CH_1 and CH_2. As a relative position



(a): Formation of neighboring nodes groups Q(i) (b): Formation of clusters

FIGURE 6. **Example of random deployment scenario: (a) Formation of neighboring groups *Q*(*i*). (b) Clusters formation during a round *r*.**

of this node N, the RSS from CH_1 is greater than that CH_2. Thus, node N joins CH_2 even if its distance ($d_{N\_CH_1}$) from CH_1 is less than that from the CH_2. To demonstrate that this association is for the better benefit of the node N in terms of short communication distance and energy efficiency, we consider the following assumptions:

$d_{N\_-CH_1}$: Distance between node N and CH_1.

$d_{N\_-CH_2}$: Distance between node N and CH_2.

d_{N_-BS}: Distance between node N and BS.

By calculating the euclidean distance,

$$d_{N\_BS} = \begin{cases} d_{N\_-CH_1} + d_{CH_1\_-BS} & \text{if } N \text{ joins } CH_1 \\ d_{N\_-CH_2} + d_{CH_2\_-BS} & \text{if } N \text{ joins } CH_2 \end{cases} \quad (26)$$

In terms of energy, equation (26) becomes

$$E[d_{N\_-BS}] = \begin{cases} E[d_{N\_CH\_1\_BS}] = E[d_{N\_-CH_1}] + E[d_{CH_1\_-BS}] \\ E[d_{N\_CH_2\_-BS}] = E[d_{N\_-CH_2}] + E[d_{CH_2\_-BS}] \end{cases} \quad (27)$$

From eqn. (27), we can conclude that $E[d_{N\_-CH_2\_-BS}] < E[d_{N\_-CH_1\_-BS}]$, thus the node N transmits sensed data to BS via CH_2 (short communication distance), so energy dissipation over data communication distance d_{N-BS} is minimized which means maximized network lifetime. In this work, our objective is to optimize energy efficiency in WSNs by minimizing also the communication distance. As result, if a node picks its CH closest to itself and BS, the distance of their data transmission is minimal. Which means that energy dissipation of nodes N and CHs in reduced, so conducting to maximizing network lifetime. The formation of neighboring nodes groups and clusters during a round is depicted in Fig.6

6) DATA TRANSMISSION

Once the nodes are associated with CHs or BS. The CHs receive sensed data from their respective cluster members. In a similar way, BS receives data from the CHs and nodes intended to associate with it. These received data are organized by the scheduling of data, where CHs create Times Division Multiple Access (TDMA) schedule and send this schedule to their associated nodes, and the BS then assigns TDMA schedule to the CHs and associated nodes, telling them when to send data. The data transmissions, with the presumption that nodes and CHs always have data to transmit, start soon after the fixed allocation for TDMA schedule. These data transmissions reduce the energy dissipation due to the CHs selection and free organization of nodes. The radio of each node is turned off until its allocated time in TDMA, thus the energy dissipation is further reduced. The radio of CH is kept on to receive all the sensed data. The CH, after receiving collected data from cluster members, uses data aggregation/fusion mechanism in order to compute and aggregate sensed data into a one packet. These packets are then transmitted to the BS for analysis. When the data transmission phase is at its end, the next round starts with the phase 1. The flowchart of the proposed approach is illustrated in Fig.7.

D. EVALUATING THE ACCURACY AND COMPLEXITY OF ECH ALGORITHM

In order to prove the accuracy of our proposed algorithm, we demonstrate the following lemmas:

- **Lemma 1:** Each node defines its single group of neighboring nodes after a finite time.

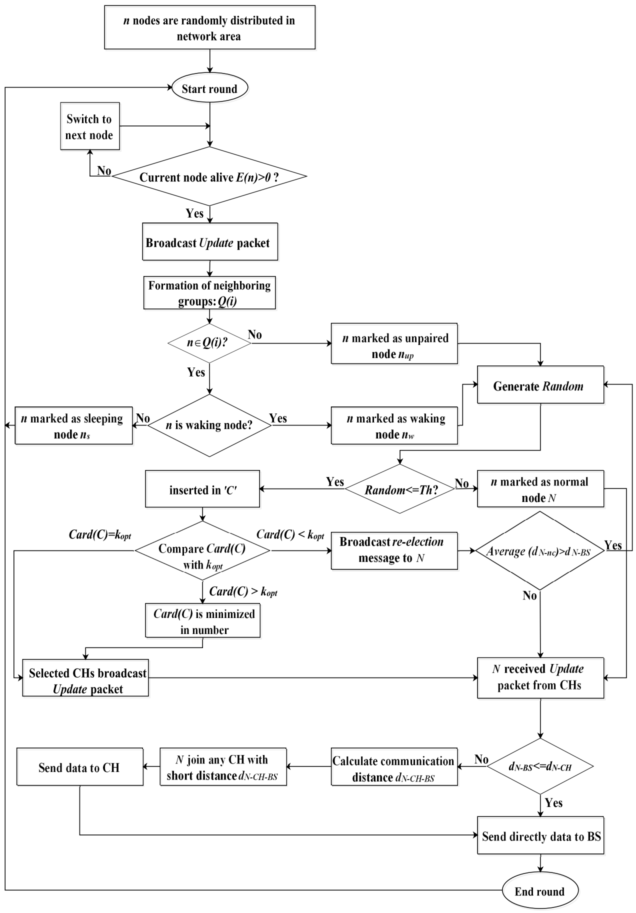


FIGURE 7. The *ECH*: Flowchart.

- **Proof 1:** Each group of neighboring nodes includes all nodes with sensing ranges either partially or fully overlapped with sensing range of every node. The groups of neighboring nodes therefore are formed after a finite time.
- **Lemma 2:** Each node defines its membership destination (BS or CHs) after a finite time.
- **Proof 2:** Each node calculates the distance that separates it from BS and CHs. It is therefore necessary to determine its destination of membership after a finite time.
- **Lemma 2:** Each node belongs to a single cluster.
- **Proof 3:** For the network to be connected, each node calculates the distance from it to BS via CH and it chooses its CH in terms of short communication distance and energy efficiency, then each node belongs to at least one cluster.
- **Lemma 4:** Enhanced clustering hierarchy *ECH* algorithm ends after a finite time.
- **Proof 4:** Since each node can determine its group and destination of membership after a finite time (Lemma 1 and Lemma 2) and the clusters are separated (Lemma 3), then the enhanced clustering hierarchy *ECH* algorithm ends in a finite time.

TABLE 1. Configuration parameters.

Type of Parameter	Value
Network field	$100m^2$
Number of nodes	100
BS location	$(50, 50)$
E_{elec}	$50nJ/bit$
ϵ_{fs}	$10pJ/bit/m^2$
ϵ_{mp}	$0.0013pJ/bit/m^4$
E_{DA}	$5nJ/bit/message$
Data size	3000 *bytes*
Sensing range: R_{sense}	$10m$

In addition, The complexity of *ECH* algorithm is $O(n)$ where n is the number of nodes distributed in the network area. This complexity corresponds to the number of exchanged messages to select CHs.

IV. PERFORMANCE EVALUATION

In this section, we present the simulation results based on Matlab Environment (R2014b) to evaluate the performance of *ECH* by comparing it with existing approaches (LEACH, TEEN, SEP and DEEC) and $(ACH)^2$ based existing approaches (LEACH-$(ACH)^2$, TEEN-$(ACH)^2$, SEP-$(ACH)^2$, and DEEC-$(ACH)^2$). In simulation, the 100 immobile nodes are randomly distributed in the environment of interest of 100 m^2 and the effects of the propagation interferences of wireless communications are disregarded. As nodes have a limited supply of energy, when they exhaust their energy during the network operation, they stop to send or receive data. During the simulation, energy is depleted whenever a node performs periodic tasks M_i (refer section III). The values used in the first order radio model are shown in Table 1. Moreover, the obtained results are the average of 10 simulation runs with a 90% confidence interval.

A. PERFORMANCE METRICS

The following metrics are used to evaluate the performance of proposed *ECH* approach.

1) **Stability period:** Time interval from the start of the network operation until the death of the first node.
2) **HNA:** Half of the Nodes Alive is the metric for estimating the lifespan of WSNs.
3) **Network lifetime:** Time interval from the start of the network operation until its end.
4) **Consumption energy:** Energy consumed during HNA metric.
5) **Network load:** Average number of packets transmitted to the BS during HNA metric.
6) **Throughput:** Average number of received packets per round at the BS.

B. IMPLEMENTATION OF ECH IN HOMOGENEOUS NETWORKS

LEACH and TEEN are the hierarchical routing protocols proposed for the homogeneous networks. Therefore, in our simulations, each node is equipped with a battery which is set to 0.5J at the beginning of the simulation. Moreover, the value

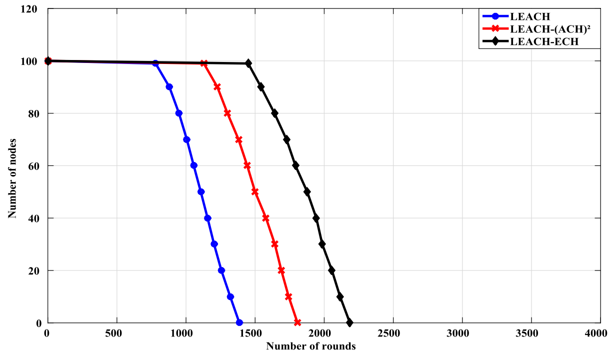


FIGURE 8. Average of alive nodes.

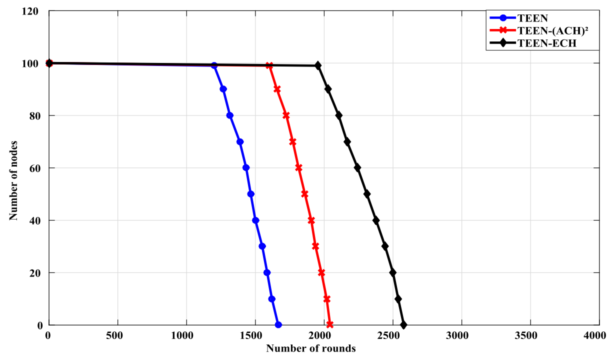


FIGURE 9. Average of alive nodes.

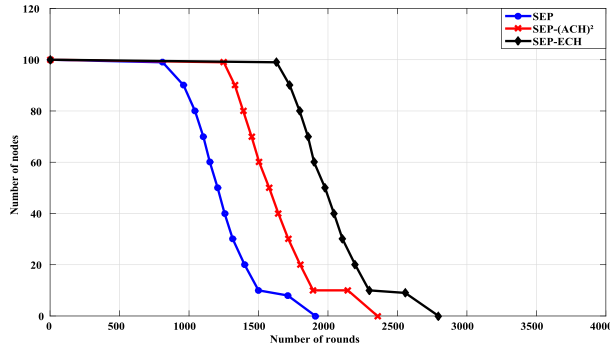


FIGURE 10. Average of alive nodes.

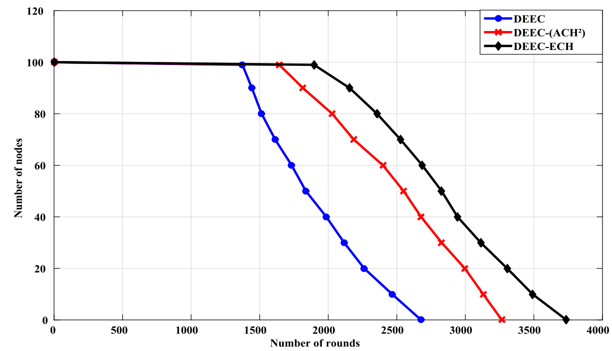


FIGURE 11. Average of alive nodes.

of the soft threshold and the hard threshold of TEEN protocol are fixed at $2F$ and $100F$ (refer [17]), respectively.

Fig. 8 shows the lifetime of WSN over the simulation time for LEACH-*ECH*, LEACH-$(ACH)^2$ and LEACH. Considering the stability period and network lifetime, LEACH-*ECH* is more efficient than LEACH-$(ACH)^2$ and LEACH. The stability period and network lifetime of LEACH-*ECH* is maximized by 22.77% and 17.33% from LEACH-$(ACH)^2$, and 46.2% and 36.56% from LEACH in the order given. It is because of the sleeping-waking mechanism which saves the energy in nodes and direct transmission of nearer nodes to the BS.

It is clear from Fig. 9 that due to sleeping-waking mechanism of nodes, TEEN-*ECH* prolongs the stability period and network lifetime of TEEN-$(ACH)^2$ by 18.09% and 20.79%, respectively. TEEN-ECH, with the effective CHs selection's method and minimal communication distance, maximizes the stability period and network lifetime of TEEN by 38.66% and 35.43%, respectively.

C. IMPLEMENTATION OF ECH IN HETEROGENEOUS NETWORKS

SEP and DEEC are the hierarchical routing protocols based on clustering algorithm for heterogeneous networks. Therefore, In our simulations, we considered different levels of heterogeneity in terms of energy i.e., the nodes in network are initially powered by different energy levels. The performances of protocols SEP and DEEC in terms of stability period and network lifetime are presented in Fig. 10 and Fig. 11, respectively. The heterogeneity of nodes helps to enhance the stability period of network as well as the network lifetime, and this effect is obviously reflected in Fig. 10.

Due to energy conserved by sleeping nodes and the balanced clusters, the stability period and network lifetime of SEP-*ECH* are optimized by 23.31% and 15.43% as compared to SEP-$(ACH)^2$, and 50.3% and 31.68% as compared to SEP as shown in Fig. 10.

From Fig. 11, we remark that DEEC-*ECH* presents 13.34% and 27.56% enlargement in the stability period as compared to DEEC-$(ACH)^2$ and DEEC, respectively. DEEC-*ECH* extends the network lifetime of DEEC-$(ACH)^2$ and DEEC by 12.60% and 28.36%, respectively. As data transmission is one of the major causes of elevated energy dissipation in WSNs, energy is conserved in DEEC-*ECH* because the redundant data transmissions to the BS are minimized. Moreover, the sleeping-waking mechanism of nodes facilitates high energy efficiency in the heterogeneous network.

D. THROUGHPUT, HNA, ENERGY CONSUMPTION ANALYSIS OF ECH APPROACH

The throughput is one of the metrics for evaluating the network performances. In WSNs, the throughput is defined as the number of packets successfully received at the BS. Fig.12 illustrates the average number of received packets per round at the BS. Due to the extended network lifetime,

TABLE 2. Network load and average energy consumption during the HNA metric.

Routing protocols	HNA (rounds)	Network load	Consumed Energy (J)	Ave.(J/round)
LEACH	1107	112	41.66	0.037
LEACH-(ACH)^2	1500	127.5	36.7	0.024
LEACH-ECH	1877	93	29.33	0.015
TEEN	1466	109	37	0.025
TEEN-(ACH)^2	1860	118.33	34.5	0.018
TEEN-ECH	2310	86.6	27.7	0.011
SEP	1206	120.5	43.5	0.036
SEP-(ACH)^2	1577	133	39.85	0.025
SEP-ECH	1979	100.75	33.5	0.016
DEEC	1837	132	45.77	0.024
DEEC-(ACH)^2	2550	145	41.43	0.016
DEEC-ECH	2827	107	36.7	0.012

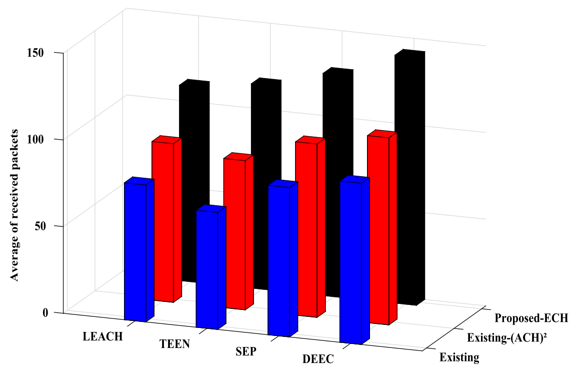


FIGURE 12. Average number of received packets per round at the BS.

the proposed approaches based on *ECH* have the better performance since the BS receives much more data from sensor during network lifetime as compared to other approaches. Moreover, the distance of data communication is reduced by proposed *ECH* approaches, which eases low packet dropping rate and high energy-efficient of WSNs.

In order to assess quantitatively the longevity in the lifetime of proposed *ECH* approach, the metric of evaluation Half of the Nodes Alive (HNA) proposed in [28] and [29] is used in this paper. As shown in Table 2, LEACH-*ECH*, TEEN-*ECH*, SEP-*ECH*, and DEEC-*ECH* are more efficient than LEACH-$(ACH)^2$, TEEN-$(ACH)^2$, SEP-$(ACH)^2$, and DEEC-$(ACH)^2$ about 20.09%, 19.48%, 20.30%, and 10%, respectively. Moreover, the LEACH-*ECH*, TEEN-*ECH*, SEP-*ECH*, and DEEC-*ECH* greatly optimize the poorest LEACH, TEEN, SEP, and DEEC up to 41.02%, 36.56%, 39.06%, and 35.01% in terms of the HNA metric. In addition, Table 2 illustrates also the average energy consumption and network load during the HNA metric. The total energy, in the homogeneous network, is initially 50 joules for a network of 100 nodes due to the initial energy of 0.5 joule for each node; and the total energy, in the heterogeneous network, is initially 55 joules for a network of 100 nodes due to the initial energy of nodes, which is varied from 0.5 joule to 1 joule. It is clear that most of the energy (nearly 80%-85%) is dissipated during the metric HNA. As compared with the existing approaches, the *ECH* based approaches are efficacious in terms of the average energy consumption (joules per round). Therefore, the LEACH-*ECH*, TEEN-*ECH*, SEP-*ECH*, and DEEC-*ECH* save up to 20.09%, 19.71%, 16%, and 11.43% of energy as compared to LEACH-$(ACH)^2$, TEEN-$(ACH)^2$, SEP-$(ACH)^2$, and DEEC-$(ACH)^2$. On the another hand, it is clear that due to sleeping nodes, the proposed approaches based on *ECH* send fewer packets to the BS as compared to other clustering approaches which send sensed data (include also redundant data) to the BS. In addition, as the energy consumption is directly related to the periodic tasks M_i (refer section III), our proposed *ECH* approaches perform the least in comparison with the other approaches. Moreover, the sleeping nodes conserve their energy by not performing the periodic tasks M_i. In addition, the minimized number of data transmissions (i.e., network load) in the proposed *ECH* approach is the major cause of their optimized network lifetime as compared to other approaches. The sleeping nodes also save their energy by minimizing data communication (i.e., idle listening and overhearing) during the sleeping status. The waking and unpaired nodes perform the periodic tasks M_i for every round till their energy is exhausted.

V. CONCLUSION

Maximization of longevity in the lifetime of WSNs is a major issue in designing routing protocols for WSNs. To achieve this longevity maximization, many routing protocols based on clustering algorithm have been proposed and hierarchical protocols are the representative ones. These hierarchical routing protocols do not consider redundant data which is collected by neighboring and overlapping nodes in WSNs. The collection, aggregation, and transmission of redundant data by the nodes lead to minimizing energy-efficient in WSNs. In this paper, an enhanced clustering hierarchy approach has been proposed for WSNs, that is *ECH*. The main objective of our approach is to maximize lifetime by minimizing data redundancy in WSNs. To achieve this purpose, we have especially focused on the neighboring and overlapping nodes, which transmit redundant data or same data to the CHs and then to the BS. The *ECH* uses sleeping-waking mechanism for the neighboring and overlapping nodes to minimize data redundancy. Moreover, our proposed approach minimizes the data communication distance and also uses a novel manner to select the CHs. Results of simulation show that the *ECH* based routing protocols are more efficient than other routing protocols.

In this paper, the *ECH* algorithm is proposed for the networks of static sink. As a future work, it can be expanded to handling network of mobile sink. Also, a further direction of this approach will carry out theoretical analysis on the network lifetime maximization, and also include the implementation of *ECH* in recent routing protocols for WSNs.

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