New Approach for Selecting Cluster Head based on LEACH Protocol for Wireless Sensor Networks

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Abstract: From hierarchical routing protocols, Low-Energy Adaptive Clustering Hierarchy (LEACH) has been considered as one of the effective algorithms that optimize energy and prolong the lifetime of network. In this paper, we propose a new approach of electing Cluster Head (CH) based on LEACH protocol. The selection of Cluster Head (CH) in LEACH is carried out randomly. In our proposed approach, we consider three fundamental criteria: the remaining energy, the number of neighbours within cluster range and the distance between node and CH. In fact, in our algorithm, we include these factors in calculation of threshold. Simulation results shows that our proposed approach beats LEACH protocol in regards of prolonging the lifetime of network and saving residual energy.

1 INTRODUCTION

Wireless Sensor Network (WSN) consists of large number of tiny devices called sensor nodes (Anastasi et al., 2008). These Nodes are deployed randomly in a geographical area. Their roles are to sense, collect, aggregate and send data between each other or to a Base Station (BS) located outside of the sensor area. This communication costs important energy consumption. On the other hand, sensor nodes use batteries as power source that are limited resources. In addition, this power source is usually not replaceable or rechargeable. Hence, the need to extend the lifetime of nodes and minimize the energy consumption is necessary.

Due to the energy constraints of the large number of deployed sensors, routing in WSN becomes very challenging and many routing protocols have been developed (Al-Karaki and Kamal, 2004). In hierarchical routing protocols, network is divided in a number of clusters. In each cluster, there is only one node that communicates with the BS called Cluster Head (CH). By selecting a CH, the routing overhead of non CH nodes is reduced since these nodes have only to send data to CH. These protocols use data aggregation and fusion in order to reduce the number of transmitted messages to the BS. And furthermore, all nodes have a chance to be a CH (Al-Karaki and Kamal, 2004), (Katiyar, 2011). From hierarchical routing protocols, Low Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman et al., 2000), (Heinzelman, 2000) is one of the most famous protocols that use dynamic clustering. We will give an overview of this protocol and its shortcomings in the following section. In this paper, we propose a new approach for selecting CH to avoid some deficiencies of LEACH protocol. Since LEACH does not take into account remaining energy of the node and the distance between node and BS in choosing the CH. In our new algorithm, the selection of CH is based on three factors: residual energy, distance between the CH and sink and the number of neighbor nodes within the cluster range. Thus, elected CH must have at the same time a high residual energy, maximum number of neighbor and finally a low distance to sink. By considering these factors, we can save energy consumption and prolong the lifetime of the network and good results will be shown by simulations later in the paper.

The rest of the research work is organized as follows. Related work is presented in section 2 Section 3 details the proposed algorithm to select CH. Simulation results are shown and discussed in section 4. We conclude in section 5.

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2 RELATED WORK

Over recent years, various hierarchical protocols and algorithms are developed to enhance the energy efficiency in WSN. In this section, we give an overview of some of them.

Low Energy Adaptive Clustering Hierarchy (LEACH) has been introduced by Heinzelman, et al. (2000) to reduce power consumption. LEACH divides network to clusters and only one node (CH) in each cluster is the leader and it changes each round. CH communicates directly with the BS to send data and uses data aggregation technique what reduce energy consumption and prolong the lifetime of the WSN.

LEACH centralized (LEACH-C) has been proposed also by Heinzelman (2000), (Geetha et al. 2012). This is a centralized clustering algorithm. It uses the BS to elect CHs. In fact, the BS receives information about the position and energy level of each sensor node in the WSN. Then, BS elects a number of nodes as CH for each round and finally based on minimal power for transmitting, clusters are formed.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS) has been elaborated by Lindsey & Raghavendra (2002). This greedy algorithm is based on forming a chain structure from sensor nodes. In fact, each node in the network transmits and receives data only from a neighbor. Only one node is selected from the chain to send data to the sink. It uses data aggregation like LEACH protocol but don't use clustering. The use of chain and the absence of clusters train several threats and attacks and furthermore, communication overhead is increased.

The Hybrid Energy Efficient Distributed (HEED) has been developed by Younis & Fahmy (2004). In this is clustering protocol, probability to elect a CH take into account three factors residual energy, communication cost and average minimum reachability power (AMRP). It uses the same communication method as LEACH protocol but HEED protocol has a well balanced energy and longer network lifetime than LEACH.

Reference (Taheri et al., 2010) presents the protocol HEED Non-Probabilistic approach and Fuzzy Logic (HEED-NPF). In this protocol, election of cluster head selection is based on Fuzzy Logic which uses node degree and node centrality as input parameters. The output is the Fuzzy cost. Each node in network chooses the CH with least cost and joins it. This technique is more effective to prolong the lifetime of network than HEED.

Reference (Taruna et al., 2012) proposes a new approach based on LEACH and covers the CH selection phase. In fact, the proposed algorithm calculates the center point between the sensor node and the Base Station. Then, the node chooses the closest CH to the center point and gets bind to it to form clusters.

In the reference (Singh et al., 2013), authors focus on selecting CH to save energy consumption and lifetime of the network. They consider the remaining energy of nodes and give analysis and simulations when the BS is inside or outside the network area.

Optical-LEACH (O-LEACH) is an improved of LEACH. It was introduced in (El Khediri et al., 2014) as a clustering hierarchy, an optical and adaptive protocol that minimizes energy consumption. In this reference, the node should have a current energy greater than ten percent to become a CH.

The reference (Sharma et al., 2015) calculates a new threshold which is based on node energy, distance between sensor node and BS, distance between CH and BS. The analysis of simulation results proves that this new algorithm is better in term of balancing the node energy and prolonging the network lifetime.

In the reference (Li and Huo, 2016), authors propose a new algorithm that firstly calculate the optimal cluster number by considering location adaptability and data aggregation rate. Secondly, they present a new threshold based on remaining energy, initial energy, average energy consumption, and node degree to select CH. Thirdly, a self-adaptive uneven clustering algorithm is proposed that takes node degree into consideration and solve the “hot spot” problem. And finally, they propose a solution to solve “isolated nodes problem”.

3 LEACH PROTOCOL

LEACH (Heinzelman et al., 2000), (Heinzelman, 2000) is a hierarchical protocol that is based on data aggregation, dynamic allocation of CH and local control on data transmission. It operates by round to round and each round comprises three phases: Advertisement phase, cluster set-up phase and steady-state phase.

Advertisement phase: Firstly, each node in the network decides if it will be a Cluster Head (CH) or not for present round. This decision depends on the desired percentage of CHs in the network and the number of times the node is served as CH so far. In fact each node i choose a random number between 0 and 1. If this number is less than a threshold T(i), i becomes a CH.

$$T(i) = \begin{cases} \frac{P}{1-P*(r \bmod \frac{1}{P})} & \text{if } i \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Where P is the desired percentage of cluster heads, r is the current round, and G is the set of nodes that have not been cluster-heads in the last $\frac{1}{P}$ rounds. After CH election phase, each CH broadcasts advertising messages to the remaining nodes inviting it to choose which of the CHs they will join and finally, clusters are created for the current round. The choice of remaining sensor nodes will depends on the signal strength of the received broadcasting messages.

Cluster setup phase: Each remaining node communicates its decision to the chosen CH node that it will be belong to the cluster. To receive this information, all CHs keep their receivers on during this phase. Based on the number of nodes in the cluster, the CH creates a time division multiple access (TDMA) schedule and informs other sensor nodes when it can transmit.

Steady-state phase: In this phase, transmission data starts. Sensor nodes send their data in their own time slot and their radio can be turned off. CH must keep their radio on to receive all data from nodes.

LEACH Protocol has several advantages (Heinzelman, 2000), (Haneef and Deng, 2011): Comparing with direct communication, LEACH protocol achieves more than 7 reductions in dissipated energy. In addition, lifetime of the network is raised due to dynamic clustering. By using aggregation technique, LEACH reduces data message sent to the BS. During setup phase, it uses TDMA mechanism to minimize the conflict between clusters. Finally, since LEACH is a distributed protocol; it doesn't need global knowledge of network. But also it has a certain number of shortcomings (Heinzelman et al., 2000), (Haneef and Deng, 2011), (Yan, and Liu, 2011): CHs are elected randomly and residual energy of the node is not taken into account for cluster formation. CHs in the network have not a uniform distribution. It happens that sometimes these nodes are concentrated in one part of network which trains loss of energy. After aggregation, CHs send data to the sink in single hop for that LEACH is not applicable to large networks. In each round, all sensor nodes participate in forming new clusters which dissipates energy. Data aggregation is applied each round if there is a change in data packages or not which cost some unnecessary energy of cluster-heads.

4 PROPOSED WORK

4.1 Cluster Head Selection Approach

The main shortcoming of LEACH is the random selection of CH that is applied to all sensor nodes without taking into account any factor. In reality, to increase the lifetime of network and energy efficiency, we need to change the threshold of electing CH. In other words, we must consider three essential factors: the distance between the node and the BS, the residual energy and the number of neighbor nodes within the cluster range, to calculate the threshold. Therefore, by including distance between the node and the BS, data transmission overhead is minimized. The flowchart shown in Figure 1 explains as well our proposed approach.

When considering the remaining energy of node each round and alive neighbors, we can optimize the election of CHs. Thus, nodes having at the same time high residual energy, short distance to the sink and several neighbors are chosen as CHs. By incorporating above criteria, we can use a cost function which is expressed as:

$$\mathrm{cost}(i) = \alpha \frac{E_{rem}(i)}{E_{init}} + \beta \frac{N_{nb}(i)}{N_{alive}} + \gamma \frac{D_{toBS}(i) - D_{toBSmin}}{D_{toBSmax} - D_{toBSmin}} \quad (2)$$

Where $E_{rem}(i)$ is the remaining energy of node i, E_{init} is the initial energy, $N_{nb}(i)$ is the number of neighbors of node i, N_{alive} is the number of alive nodes, $D_{toBS}(i)$ is the distance between the node i and the BS, $D_{toBSmin}$ is the distance between the closest node to the BS and the BS and $D_{toBSmax}$ is the maximum distance to the BS. Then the threshold can be written as follows:

$$T(i) = \begin{cases} \frac{P}{1 - P * (r \bmod \frac{1}{P})} * \mathrm{cost}(i) & \text{if } i \in G \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

After selecting CHs, the remaining nodes have to choose its cluster for each round. The choice of nodes is based on the distance between the node and the CH. Nodes opt to the closest one and gets bind to it to form clusters.

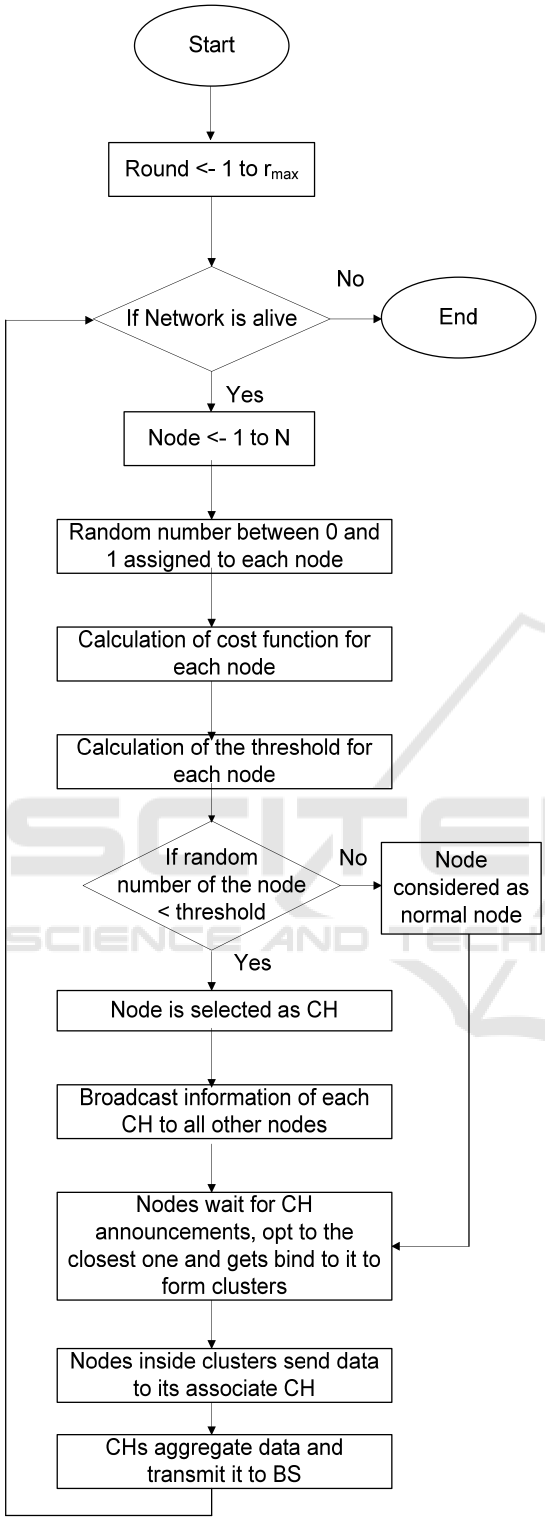

Figure 1 : Flowchart of the proposed approach.

α, β and γ are weights parameters between 0 and 1 that are determined through Analytic Hierarchy Process (AHP) method.

First, the energy weight parameter should be greater than β and γ. In fact, the node to become CH should have the maximum energy level (Li et al., 2014) that influences results in terms of the first node dead (FND). Then, considering the reference (Li and Huo, 2016), the node neighbors factor is more effective than the distance between the node and the base station so β should be greater than γ.

Based on this information and by applying the AHP method, we can elaborate the paired comparison matrix as shown in Table 1 where A is the remaining energy criterion, B is alive neighbor criterion and C is the distance to BS criterion.

Table 1: Paired Comparison Matrix.

Criteria	A	B	C	Priority vector
A	1	3	7	64,34%
B	1/3	1	5	28,28%
C	1/7	1/5	1	7,38%
Sum	31/21	21/5	13	100%
λ_{max}=3.0967, CI=0.0484, CR=8.34% < 10% (acceptable)				

Note that the priority vector is obtained from normalized Eigen vector of the matrix and presents the α, β and γ weights values respectively. The diagonal of the matrix is always 1 and the lower triangular matrix is filled using formula $a_{ji}=1/a_{ij}$. Where a_{ij} denotes the ratio of the i^{th} criterion weight to the j^{th} criterion weight. As shown in Table 2, the fundamental 1 to 9 scale can be used to rank the judgments.

λ_{max} is the Eigen value and is obtained from the summation of products between each element of Eigen vector and the sum of columns of the reciprocal matrix.

CI is the Consistency Index and is calculated by:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

CR is the Consistency ratio and is calculated by:

$$CR = \frac{CI}{RI} \tag{5}$$

Where RI is the Random Index whose values are cited in table 3.

Table 2: A fundamental 1 to 9 scale.

Number Rating	Verbal Judgment of Preferences
1	Equally preferred
3	Moderately preferred
5	Strongly preferred
7	Very strongly preferred
9	Extremely preferred

Table 3: Random Consistency Index (RI).

Dimension	RI
1	0
2	0
3	0,58
4	0,9
5	1,12
6	1,24
7	1,32
8	1,41
9	1,45
10	1,49

4.2 Energy Model

In our research, we have used the same energy model as the traditional LEACH (Heinzelman et al., 2000), as shown in Figure 2.

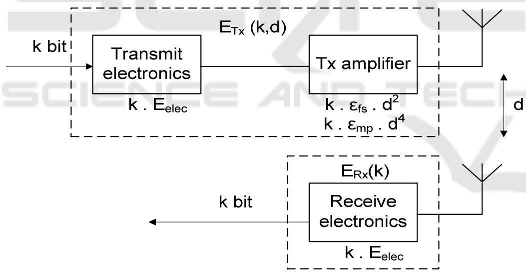

Figure 2 : The radio energy consumption model.

Note that E_{elec} is the energy consumption per bit for running transmitter or receiver circuitry, k is the number of bits, ε_{fs} and ε_{mp} are proportional constant of the energy consumption for the transmit amplifier in free space channel model (ε_{fs} . k .d^2 power loss) and multipath fading channel model (ε_{mp} . k .d^4 power loss), respectively and d is the distance between transmitter and receiver. Thus we can deduce the energy consumed to transmit k bits along a distance d through a free space channel model is:

$$E_{Tx}(k,d) = E_{elec} * k + \varepsilon_{fs} * k * d^2 \quad (6)$$

Or multipath fading channel is:

$$E_{Tx}(k,d) = E_{elec} * k + \varepsilon_{fs} * k * d^4 \quad (7)$$

And the energy to receive these bits is:

$$E_{Rx}(k) = E_{elec} * k \quad (8)$$

5 SIMULATIONS AND NUMERICAL RESULTS

In this section, simulations are performed via Matlab software in the same conditions. We have compared between our proposed approach and LEACH protocol using parameters listed in Table 4.

As shown in Figure 3, we consider a WSN with randomly distributed sensor nodes in 100×100 network field. Initially, all nodes are normal nodes and have the same energy value. Normal nodes appear in blue point and the BS sets outside of the sensor area and appears in green point.

Table 4 : Parameters System.

Simulation area	$100x100m^2$
Number of Round	1000
Number of nodes	200
desired percentage of CH	0.1
Initial energy of node	0.5 J
Transmission/ Reception energy per bit E_{elec}	50 nJ/bit
Transmitter Amplifier energy dissipation free Space ε_{fs}	$10\ pJ/bit/m^2$
Transmitter Amplifier energy dissipation multiPath ε_{mp}	0.0013 $pJ/bit/m^4$
Base Station location	Located at 50x175

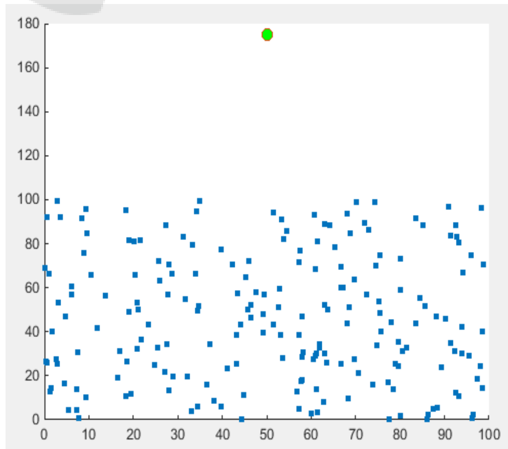

Figure 3 : Initial Wireless Sensor Network.

In order to evaluate the performance and efficiency of our proposed approach, we focus on the number of alive nodes, dead nodes and total residual energy of the network respectively in figures 4, 5 and 6.

Figure 4 shows a comparison between LEACH protocol and our proposed work of the total number of nodes that are still alive in each round. Our proposed approach prolongs the lifetime of the network practically between 30% and 40% comparing to LEACH protocol.

Figure 5 gives the number of dead nodes per round in the network. We can see clearly that our proposed algorithm beats LEACH protocol in term of the First Dead Node (FDN). In fact, for LEACH, the FND is after 119 rounds and for our approach is after 274 rounds. This proves that network lifetime is well prolonged by the new cost of selection CHs.

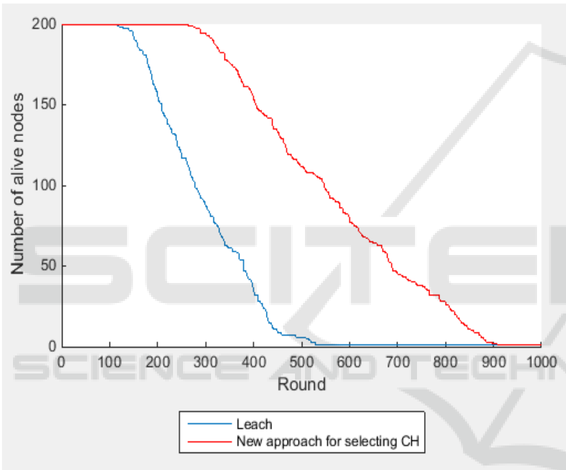

Figure 4 : The number of alive nodes per round.

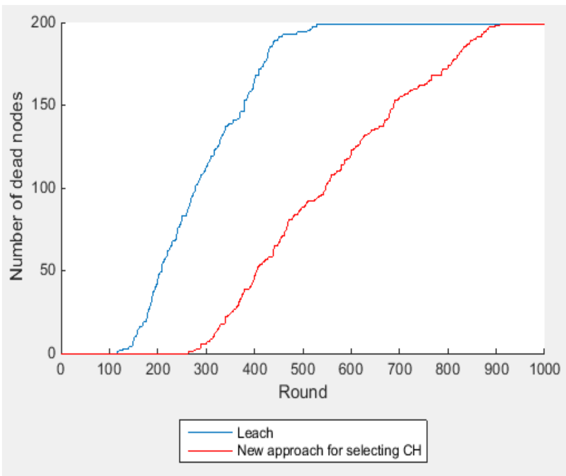

Figure 5 : The number of dead nodes per round.

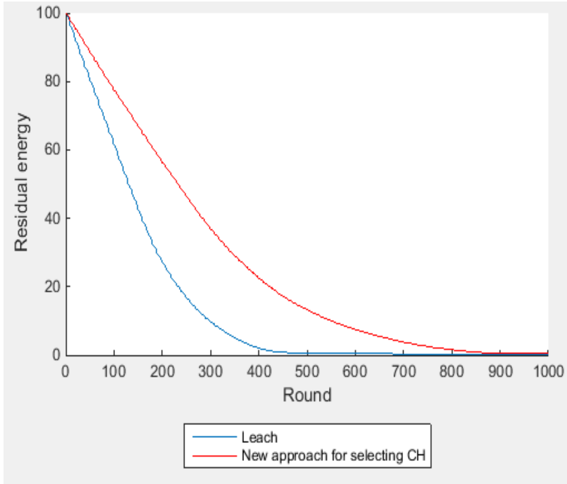

Figure 6 : Total residual energy per round.

Finally, we focus on the total remaining energy of nodes. Figure 6 shows the decreasing of this energy per round. When comparing our approach to the LEACH, it's visible that in our proposed work, residual energy decreases slower than LEACH. In other words, our approach is effective to save energy consumption better than LEACH. This proves that we have chosen an efficient way for selecting CH based on residual energy of the node, the number of neighbours of the node and the distance between the node and the BS.

6 CONCLUSIONS

The main purpose is to increase the lifetime of WSN and saving energy consumption. One of the major shortcomings of LEACH protocol is the probability of selecting CH. We relied on this shortcoming and we have proposed a new strategy to select CH by including residual energy, distance between the node and the BS and the number of neighbor of node within the cluster range. The simulation results show the round that the first node dies is delayed by about 57% than that in LEACH. The lifetime of the network is prolonged about 40%. The remaining energy in our approach decreases more slowly than that in LEACH algorithm. All these results prove that our proposed strategy is effective in reducing the energy consumption and prolonging the network lifetime.

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