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A New Method for Optimizing Energy Consumption in Wireless Sensor Networks Using Enhanced LEACH Protocol

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Abstract: Energy limitations in wireless sensor networks have always been a vital issue. Most studies in the field of wireless sensor networks are performed to decrease electric power consumption. As a result, energy consumption is an important parameter for designing new routing protocols. LEACH protocol is a clustering algorithm that is used for routing in wireless sensor networks in order to save energy and to improve the network lifetime. In this study, a new method is proposed to improve LEACH algorithm. This method tries to select appropriate clusters by considering the distance between nodes and node residual energy to optimize energy consumption of wireless sensor networks. The proposed approach is simulated using MATLAB. The simulation results show that the proposed approach is better than the conventional LEACH algorithm and two recent LEACH-based algorithms in terms of number of nodes that saved energy. Although, this method requires more iteration to determine the number of clusters however, it satisfies the number of optimum iterations that can be proved by mathematical methods.

Key words: Wireless sensor network, LEACH protocol, remained energy, data aggregation, clustering

INTRODUCTION

Nowadays Wireless Sensor Networks (WSNs) play an important role in many applications such as transportation, smart health monitoring, battlefield surveillance, weather forecasting, satellite communications and etc (Mohammadi *et al*., 2015; Sheng *et al*., 2013; Acampora *et al*., 2013; Zeng *et al*., 2013; Chen *et al*., 2011). Low-cost, suitable radio power and take advantage of the special conditions are attractive features of WSNs which increase their daily usage. Each WSN includes a large number of sensor nodes. They receive analog data like temperature and humidity from the environment. Then, analog data are converted into digital form in order to easy processing. After processing data they should be integrated and sent to the sink node (Wei *et al*., 2011).

WSNs suffer from some problems like the coverage area, security, energy efficiency and etc. Among them energy efficiency is a basic problem, because sensor nodes are supplied by batteries, as a result, saving energy is essential. Usually most of energy in WSN is consumed by data transmission. Therefore, optimizing energy consumption is very important (Li *et al*., 2013; He *et al*., 2012; Song *et al*., 2014).

Clustering is one of the solutions used to decrease the number of transfers within the network. In clustering, sensor nodes are divided into a number of clusters. One node in each cluster is determined as the cluster-head (Zeng *et al*., 2013; Chen *et al*., 2012; Wei *et al*., 2011; Li *et al*., 2013; He *et al*., 2012; Song *et al*., 2014; Sharma *et al*., 2016).

LEACH routing algorithm was designed to collect and send data to sink, for increasing networks lifetime, reducing energy consumption by each sensor node in the network and using data aggregation for decreasing communication messages. LEACH protocol applies the sequential method to divide network to set of clusters. Each cluster is managed by its cluster-head that performs data aggregation. First data are collected from cluster-heads and after that are sent to the sink node. Finally, the TDMA-based schedule is constructed. A time interval is assigned to each node in a cluster in which it can send data (Halder and Bit, 2014).

Features of the LEACH protocol are as follows: distributed arrangement of the cluster-heads, local processing, random selection of cluster-heads and Energy efficiency. According to these features, LEACH algorithm can be selected as a base for clustering-based algorithms. The LEACH algorithm aims to distribute energy among nodes by cyclic selection of cluster-heads in order to increase networks lifetime.

There are several disadvantages that load balance in the network is not as expected (Li *et al*., 2013). There is

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no control on selection of cluster-head nodes. Each node which can generate a random number smaller than a threshold value can be selected as the cluster-head. The number of cluster-head nodes effects energy consumption in the routing protocol. In order to control the inherent random characteristics of the LEACH protocol, an approach should be applied to handle the number of cluster-head nodes. Moreover, a lot of energy consumption by the LEACH protocol is related to data transmission between nodes and the cluster-heads and between the cluster-heads and sink node. Thus, for selecting the cluster-head nodes these distances should be considered.

As another disadvantage, LEACH algorithm defines node's role in the network without considering amount of the residual energy. This selection is done based on a pre-defined probability. Although, the selected cluster-head node does not have any chance to be chosen again during the routing period but it is still possible that it consumes more energy compared to other nodes. For example, if the node has a long distance with the sink when it is being selected as the cluster-head or when there are more nodes in the cluster. Therefore, in next work period of the network, the probability of selecting it as the cluster-head is equal with other nodes. While it has less residual energy compared to others (He *et al*., 2012). Finally, when a few numbers of clusters are created, since nodes are not distributed uniformly, the probability of selecting a node that is located far from the sink as the cluster-head is very high; therefore it is forced to connect directly to the sink. In this case, sine the relationship between energy consumption and distance is exponential; these nodes will be lost in a short period of time (Halder and Bit, 2014). Moreover, some nodes are selected as cluster-heads inevitably and have to connect to the sink directly while they have not been selected based on their residual energy (He *et al*., 2012).

In this study, a new method is proposed to improve LEACH algorithm by selecting appropriate clusters using distances between nodes and node residual energy to optimize energy consumption of WSNs.

Related works: Clustering-based routing protocol based on optimum energy consumption is under more considerations among different routing protocols. In this section we introduce some previous studies that have tried to optimize energy consumption in wireless nodes.

Some methods like the method proposed in reference (Chen *et al*., 2012) have investigated the effect of data on efficiency of clustering methods in data aggregation. In another work proposed by Song *et al*. (2014), data of a node in a time interval are estimated with a quadratic equation and instead of the data coefficients of the polynomial are sent. In another work, Anastasi *et al*. (2009), it is assumed that each node is able to aggregate data and a method was proposed to increase the networks lifetime based on this assumption.

In (Lotf *et al*., 2010) an algorithm is proposed to find a path to equal nodes that create equal data. In (He *et al*., 2012), sensor nodes send the data pattern which shows how the sensor's data are determined based on pre-defined time intervals. In (Halder and Bit, 2014) super-data negotiations among nodes are used to eliminate data transfer.

In (Li *et al*., 2013) direct propagation proposed as a data aggregation protocol for sensor networks which aimed to monitor events that are sensed by few nodes. Standard methods proposed for this purpose include.

MATERIALS AND METHODS

In CCS method (Lotf *et al*., 2010) the whole network divided into concentric rings and each ring represents a cluster. A certain level assigned to each ring. In each ring nodes form chains and one node is selected as the cluster-head. After transiting data into a ring and delivering data to the cluster-head, available cluster-heads in adjacent rings cooperate in order to deliver data to the sink.

TSC Method proposed by Lotf *et al*. (2010) uses rings and sectors to form clusters. In this method each cluster is like a curved bar.

In EECS algorithm (Song *et al*., 2014) candidates compete for cluster-head. In this competence, each of the candidate nodes announces its residual energy to other neighbors that intend to participate in this competence. Any of the nodes which its residual energy is more than others is selected as the cluster-head.

In method called GSTEB (Chen *et al*., 2012) in each period, the central station assigns each node as the root node, then its identification number and coordinates are sent to all nodes. Then network paths are determined either by sending the tree's data to all nodes by the central station or by the nodes. In both cases, the results are the same. This method has the ability of changing the root and forming a new routing tree with small delay and low energy consumption.

LEACH (Anastasi *et al*., 2009) is the basic routing protocol. In this protocol, cluster-heads are obtained randomly and the cluster-heads are displaced rotationary among nodes to obtain energy balance among sensor nodes. Moreover, TL-LEACH protocol (Anastasi *et al*., 2009) is a method for reserving energy by creating a two-level hierarchy of wireless sensor nodes which includes first level cluster-heads and second level cluster-heads. Another method proposed in (Bandyopadhyay and Coyle, 2003) also used a multilevel hierarchy.

In LEACH protocol, nodes with low energy can act as the cluster-heads. Moreover, LEACH-DCHS (Handy *et al*., 2002) and ALEACH (Ali *et al*., 2008) protocols cluster-heads are selected based on higher residual energy.

ECLEACH protocol by Bsoul *et al*. (2013) distributed the cluster-head nodes uniformly. Ahmad *et al*. (2014) applied ACH^2 protocol to select the cluster-head and assign nodes to each cluster in order to decrease reciprocating messages and improve energy consumption as well.

ESCAL (Jing *et al*., 2008) is a modified clustering protocol in which cluster-heads do not connect directly to the sink. But cluster-heads send the aggregated data to the sink via the closest node.

LEACH-HEM (Chen *et al*., 2012) determines cluster-heads based on the residual energy. The nodes with higher residual energy have more chance for selecting as the cluster-head.

LEACH-M (Long and Jian, 2010) solves the problem of selecting nodes with low residual energy as the cluster-head. This is done by changing the threshold value in LEACH protocol as shown in Eq. 1, it is increases the chance of nodes with higher residual energy:

$$T_{(n)} = \begin{cases} \dfrac{p}{1-p(r \bmod \frac{1}{p})} \dfrac{E_{cur}}{E_{init}} & n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

The proposed method: First according to the equation proposed by Heinzelman *et al*. (2002), optimum number of cluster-heads is obtained. Energy consumed for transmitting L-bits data in distance d is calculated as Eq. 2:

$$E_{TX}(l, d) = \begin{cases} l^*E_{elec} + l^*e_{fs}^*d^2 & , d<d_c \\ l^*E_{elec} + l^*e_{two\text{-}ray}^*d^4 & , d<d_c \end{cases} \quad (2)$$

Where:

E_{lec} = The loss of energy caused by electronic circuits
D_c = The cross distance and is obtained from Eq. 3

$$d_c = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{two\text{-}ray}}} \quad (3)$$

Energy consumed by receiving L-bit data is obtained from Eq. 4:

$$E_{RX} = l^*E_{elec} \quad (4)$$

Let k be the optimum number of cluster-heads. Since, N is the total number of nodes, thus average number of total nodes in each cluster is N/k. Sum of the energy consumed by a cluster in one frame of TDMA is as Eq. 5:

$$E_{cluster} = E_{CH} + \frac{N}{K} E_{non\text{-}CH} \quad (5)$$

where, ECH is the energy consumed by a cluster-head node and is obtained from Eq. 6:

$$E_{CH} = 1\, E_{elec}\, N/K + 1\, E_{DA}\, N/K + l\varepsilon_{two\text{-}ray}\, d^4_{toBS} \quad (6)$$

Enon-CH is energy consumed by a node in a cluster for transmitting data to the cluster-head node and is obtained from Eq. 7:

$$E_{non\text{-}CH} = 1\, E_{elec} + 1 \in_{fs} d^2_{toCH} \quad (7)$$

Where:

$$E(d^2_{toCH}) = \frac{1}{2p} \frac{M^2}{k} \quad (8)$$

Assume that the area occupied by the cluster is a circle with the radius R and the density of the spheres is as follows:

$$\rho(r, \theta) = \frac{k}{M^2} \quad (9)$$

Total energy consumption in one frame is as Eq. 10:

$$E_{total} = k\, E_{cluster} \quad (10)$$

Finding the optimum number of cluster-heads, k is done by differentiating Etotal in terms of k and equating it with zero and is equal to Eq. 11:

$$k = \frac{\sqrt{n}}{\sqrt{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{two\text{-}ray}}} \frac{M}{d^2_{toBS}} \quad (11)$$

In this research, a WSN with N nodes which is located randomly and uniformly in an M*M m^2 area is considered. Other assumptions are given in Table 1.

Based on features analysis of the LEACH protocol, nodes selected as cluster-heads are not suitable to transmit data to sink. For solving this problem, Eq. 12 is proposed to define the threshold value T(n):

Table 1: Units and signs used in this study

Description	Sign
Total number of nodes	N
Network's size	M*M
Number of bits	L
Energy consumed per bit in electroniccircuits	Eelec
Magnification coefficient for free space model	Efs
Magnification coefficient for multi-path model	Etwo-ray
Distance between nodes	D
Cros distance	Dc
Optimal number of cluster-heads	K
Energy consumed by each cluster-head	ECH
Energy consumed by non cluster-head nodes	Enon-CH
Energy consumed for data aggregation	EAD
Energy consumed by each cluster	Ecluster
Total consumed energy	Etotal
Percentage of the nodes which are cluster-heads	P
Nodes which have the conditions to be selected as cluster-head	G
Number of rounds	r

$$T(n) = \left(\frac{p}{1-p(r \bmod \frac{i}{p})} + (1-p)\frac{D_{max}-D_{i\ to\ BS}}{D_{max}-D_{min}}\right)\left(\frac{E_R}{E_0}\right) \quad (12)$$

where, E_R is the residual energy of a node for the current cycle and E_O is the initial energy. In this algorithm, the closest node to the sink is selected as the cluster-head. By this improvement, the residual energy of a node and distance to sink is also involved in the calculations. D_{max} and D_{min} are the maximum and the minimum distance of the node from the sink, respectively. Accordingly, threshold value is calculated based on the residual energy and distance.

RESULTS AND DISCUSSION

MATLAB is used for simulating the proposed method. The 100 nodes are located randomly in a 100*100 area. Initial energy of all nodes is the same and it is assumed that all nodes have identical hardware structures. Connections are symmetric. That is, a certain value of energy is lost in communication among the nodes. Sink is located at the center of this 100*100 area. Other default values are given in Table 2 and are used throughout the study.

Value of k shows the optimal number of clusters according to other variables' values which are given in Table 2 and are calculated by considering an interval including minimum and maximum distance from the sink.

The obtained value is consistent with the values obtained in most studies and its value is $4<k<12$. Considering this value obtained for k, most studies calculate p as k/N and have obtained 0.1 for p, this value is used in this study also.

The simulation results of the proposed method are compared with the results of standard algorithm LEACH (Heinzelman *et al*., 2002) and the algorithms proposed in

Table 2: Default values considered in simulation

Sign	Values
EO	0.05 j
efse	10 pJ/bit/m^2
two_ray	0.0013 pJ/bit/m^2
dc	9.26 m
EDA	5 nj/bit/signal
Eelec	50 nj/bit
L	100 bit
N	100
M	100

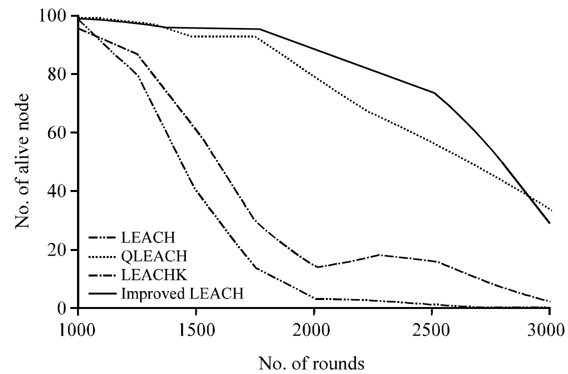

Fig. 1: Performance of the proposed method

(Rabiaa *et al*., 2015; Parsaei and Salehi, 2015; Manzoor *et al*., 2013). The proposed method and each of the above algorithms are performed 10 times for different rounds and the average values are used for comparison. In different studies, the number of survived nodes for different rounds is used to investigate the quality of the algorithms in saving energy. We have done the same in this study.

As shown in Fig. 1, performance of the proposed method which is indicated by improved LEACH in the graph is better in comparison with other three methods because the number of survived nodes is higher obtained from the proposed method compared with the results obtained from standard algorithm LEACH (Heinzelman *et al*., 2002) and the algorithms proposed by Rabiaa *et al*. (2015) and Parsaei *et al*. (2016).

In different studies of this field, number of survived nodes for different rounds is used to investigate the quality of the algorithms in reserving energy; we have done the same in this study.

As shown in Fig. 1, performance of the proposed method, i.e., improved LEACH is better in comparison with other three methods because the number of survived nodes is higher.

Based on the optimum number of clusters mentioned in this study and has also been considered in other studies, we continued running algorithm until the number of rounds reached the optimum number of clusters and we

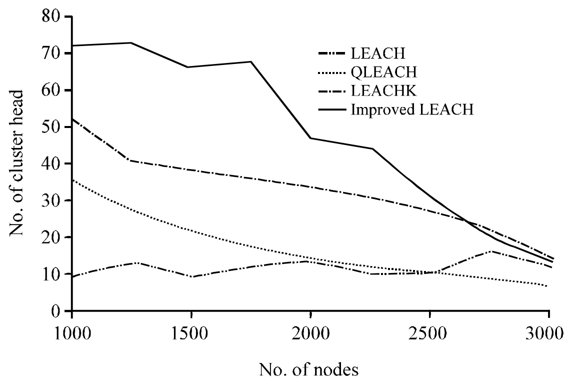

Fig. 2: Achieving the optimal number of clusters nodes

observed that the proposed algorithm requires more rounds for achieving the optimum number of clusters but yet can satisfy this goal. This problem is shown in Fig. 2. We have used an intel Core2Duo computer with 4G RAM for simulating the proposed method.

CONCLUSION

In this study a method to improve energy consumption in WSNs is proposed by modifying the LEACH protocol. By considering the feature of the LEACH protocol and the different methods which are implemented based on this protocol, it can be observed that the number of clusters is an important issue. Thus, in this study a method for obtaining the optimum number of clusters with mathematical equations is proposed. In addition, related to effects of nodes' distance to the sink in calculating the networks energy consumption, the modified LEACH protocol improves the energy consumption compered to recent proposed algorithms. The logic used in this study is based on delaying the nodes' death as much as possible and the measure used for this purpose is distance.

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