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Enhanced Energy-Balanced Lifetime Enhancing Clustering for WSN (EEBLEC)

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Abstract

Wireless sensor networks (WSNs) have emerged as an important application area resulting from the advancement of efficient short-range radio communication and miniaturization of computing devices. Nodes in a WSN are deployed with limited battery energy and therefore enhancement of network lifetime by minimizing energy-usage is of utmost importance. One of the solutions to reduce such energy-usage is clustering of network nodes. In this paper a clustering scheme in WSN is proposed where cluster heads are selected based on relative contribution of the nodes towards keeping the network alive for an extended period of time by balancing energy consumption. The contribution is measured not only based on residual energy of the nodes but also on their relative positions in the cluster. Performance of the scheme is measured in terms of network lifetime. Exhaustive simulation is performed varying different parameters that greatly influence network lifetime. Results in each case are compared with an existing clustering scheme that shows the present scheme outperforms the existing one.

Keywords: Coverage, Connectivity, Energy-Balancing, Network Lifetime, Wireless Sensor Network.

INTRODUCTION

The advent of efficient short range radio communication and advances in miniaturization of computing devices have given rise to strong interest in wireless sensor networks [1], [2]. A wireless sensor network (WSN) consists of hundreds or thousands of MEMS-based sensor nodes with the ability to communicate to the external world via base station either directly (single hop) or via other nodes (multi hop) around it in a cooperative manner. Such a network typically suffers from a number of unavoidable problems, such as resource-constrained nodes, random node deployment sometimes in an unattended open field etc. In some critical applications e.g. medical instrument monitoring it is very difficult to replace/ recharge battery. Therefore, the network as a whole must minimize the energy usage in order to enable untethered and unattended operation for an extended period of time.

Many works are so far reported towards minimization of energy usage. One of the ways to minimize such energy usage is employment of clustering. Clustering is defined [3] as the grouping of similar objects or the process of finding a natural association among some specific objects or data. It is used in WSN to transmit processed data to base station minimizing the number of nodes that take part in long distance communication leading to lowering of total energy consumption of the system.

A number of works related to energy saving approaches exploiting cluster-based data gathering in WSNs have been defined in literature [4-9].

However, in the cited schemes, minimization of energy-consumption is the only focal issue; these works are silent about ensuring coverage. Further, as the communication network takes shape after node deployment, it may get changed dynamically over time due to depletion of node-battery, static or moving obstacles, presence of noise etc. These dynamic changes in the network can severely affect the network longevity and coverage. Thus maintaining better network coverage is also a major issue of concern while devising an energy-efficient solution for prolonging network lifetime.

In the present work, we have developed a clustering technique where cluster heads are selected in such a manner that energy is consumed in a balanced way and thereby enhances network lifetime while ensuring coverage. The rest of the paper is organized as follows. Section II describes the proposed scheme followed by the supporting algorithm. Performance-evaluation and simulation results are presented in section III. The entire work is concluded in section IV.

PROPOSED SCHEME

This section presents the proposed scheme, EEBLEC followed by the algorithm of the scheme. The objective of the scheme is to select cluster-heads for the clusters so that all the clusters remain energy-balanced resulting in prolonged network lifetime. A Network Model we consider a WSN with the following properties [4]-[5], [8]-[9]: All sensor nodes are immobile and homogeneous in terms of initial stored energy. The nodes are equipped with power control capabilities to vary their transmitted power. Network adopts continuous data flow model. Base station is fixed and not located among the sensor nodes. Base station knows locations of all the sensor nodes deployed in the network.

First order radio model [4] is adopted here for measuring energy consumption by sensor nodes while communicating. According to the cited model, energy consumption by a sensor node while performing communication and data aggregation is:

- Energy required for transmitting *l*-bits at a distance *d*,

$$E_{TX}(l,d) = E_{TX-elec}(l) + E_{TX-amp}(l,d)$$

$$= \begin{cases} lE_{elec} + l \in_{fs} d^2 & d < d_0 \\ lE_{elec} + l \in_{mp} d^4 & d \geq d_0 \end{cases}$$

- Energy required for receiving *l*-bit message,

$$E_{RX}(l) = E_{RX-elec}(l) = lE_{elec}$$

- Energy required for transmitting *l*- bits at a distance *d*,

$E_{TX}(l,d) = E_{TX}\text{-}elec(l) + E_{TX}\text{-}amp(l,d)$

where *d* refers the distance between a member-node and its cluster-head or between cluster-head and base station (BS) and d_0 is threshold distance; E_{elec} is the transmitter/receiver electronics' energy-expense and ϵ_{fs}, ϵ_{mp} are transmitter-amplifier energy-expenses by a node when d <d_0 and d ≥ d_0 respectively.

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}}$$

Energy-balance: A clustered network is considered to be energy balanced when energy consumption rate of sensor nodes in all the clusters is same. B Protocol Architecture

The EEBLEC is a self-organizing, static clustering scheme in which clusters are formed only once during the network's lifetime. The whole network-operation is comprised of several rounds where each round is further divided into three phases-setup phase, responsible node selection phase, and finally the steady-state phase. Each of these three phases is described in the following subsections.

1) Set-up Phase:

In this phase to start with static clusters are formed similar to EEPSC [9].

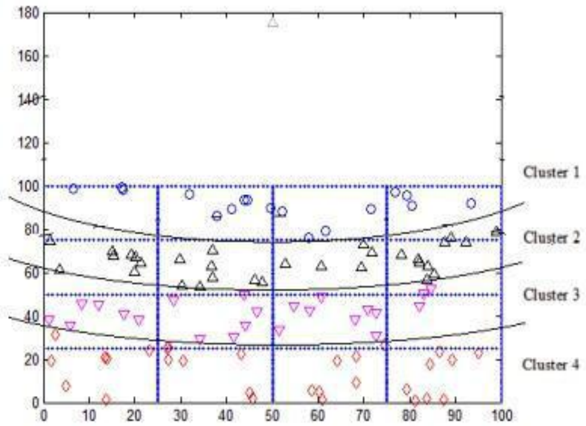


Figure 1. Network with clusters and grids

The base station broadcasts (k-1) messages one-by-one with different transmission powers, where k is the desired number of clusters known to base station a priori. Nodes listening these messages, i=1,2,3,…,(k-1), set their cluster-id to **i** and inform the base station their willingness to join the clus

In addition to transmission and reception of data, data aggregation performed at CHs needs a significant amount of energy (E_{DA}).

Further, we define relevant parameters based on which the performance of the scheme has been evaluated.

Coverage: A unit area is said to be covered, if every point in the area is within the sensing range of at least one active node [10].

Connectivity: A network is considered to be connected, if any active node can communicate with any other active node including sink either in single hop or in multiple hops.

Network lifetime: The network lifetime is defined in terms of coverage and connectivity of the network. It is the time till the proportion of dead nodes exceeds a certain threshold, which may result in loss of coverage and connectivity of a certain region, and/or network partitioning. via JOIN-REQ message. At last, nodes that haven't heard any message set their cluster-id to **k** and inform the base station via JOIN-REQ message. Sensor nodes use CSMA to prevent collision while transmitting the JOIN-REQ messages to base station. Once the clusters are formed, base station partitions the whole network area into N number of equal size square shaped grids where side of grid is less than or equal to the sensing range (R_s) of a node to ensure that even if a grid contains just a single node, each and every event happening inside the grid can be reported to base station. Fig. 1 shows the a network area after clusters and grids are formed.

Grid Size Selection:

If A is the length of a grid side, to ensure the coverage of the grid ≤ is to be satisfied. To ensure connectivity of the grid, A is to be chosen such that, if at least one node is alive in a grid, it is sufficient to maintain the connectivity. Now the maximum distance from a point in a grid to another point in any of its neighbor grids is less than or equal to $2 * \sqrt{2}A$ which should be less than or equal to communication range (R_c) of the node. So $R_c \geq 2 *$

$\sqrt{2}A$ or, $R_s \geq \sqrt{2}A$ (assuming communication range

$R_c = 2 * R_s$) or, $A \leq R_s/2$.

Number of grids (□) selection:

N is chosen such that the network area is partitioned symmetrically and is equal to (∗ / ∗) where R*R is the network area and A*A is the area of grid. Once grids are formed, the base station keeps 3-tuple information (node_location, grid_id, cluster_id).

Further, the base station prepares a TDMA schedule for the nodes in each cluster of the network and transmits this to the nodes in each cluster. Once all the nodes receive the TDMA-schedule, set-up phase is complete.

2) Responsible Node Selection Phase:

In this phase, responsible node i.e. cluster-heads (CHs) are selected through the assistance of base station (BS). Each node in the network sends its residual energy-status to the BS. The BS computes the contribution factor (CF) of all the nodes where CF of node_l in grid_m is

$$CF_m^l = \frac{E\_residual_m^l}{\sum_{l=1}^{n_m} E\_residual_m^l}$$

Here n_m is the number of nodes belonging to grid_m. However, if base station finds any grid in the network lacking alive nodes, it disrupts the network operation. Now for each cluster i, the base station takes the weighted mean of CFs of all the nodes to locate a point (X_{CHi} , Y_{CHi}) as a location of the probable CH. It computes weighted mean of location (WML) as follows:

$$X_{CH_i} = \left(\frac{\sum_{m=1}^{N} \sum_{l=1}^{n_m} x_m^l * CF_m^l * I_i(x_m^l)}{\sum_{m=1}^{N} \sum_{l=1}^{n_m} CF_m^l * I_i(x_m^l)} \right), Y_{CH_i} = \left(\frac{\sum_{m=1}^{N} \sum_{l=1}^{n_m} y_m^l * CF_m^l * I_i(y_m^l)}{\sum_{m=1}^{N} \sum_{l=1}^{n_m} CF_m^l * I_i(y_m^l)} \right) \quad (1)$$

where

$$I_i(x_m^l) \text{ or } I_i(y_m^l) = \begin{cases} 1 & \text{if } (x_m^l, y_m^l) \in Cluster_i \\ 0 & \text{otherwise} \end{cases}$$

Then the base station selects a node closest to (XCHi ,YCHi) as cluster head for a cluster i, broadcasts the start of a round and sends the selected cluster head for each cluster.

3) Steady-State Phase:

In this phase, nodes send data collected from environment to the corresponding CH during their pre-allocated fixed time slots.

In a cluster, radios of nodes are kept off until their allocated time slots come but radio of cluster-head is kept on always to receive data from all the nodes. Furthermore CHs and BS communicate following direct transmission. A round terminates after a predefined time-period.

C. Algorithm (EEBLEC)

1. BEGIN

/*Set-up phase performed by the BS */

2. form k clusters based on distances between the BS and the nodes
3. partition the whole network area in N grids
4. record node to grid mapping /* End of Set-up phase */
5. for v← 1 to round

/* round → Total no. of round */

/*Responsible node selection phase */

6. for i ← 1 to k /* for every */
7. for j ← 1 to

/* → No. of nodes in */

8. if E _ residual$_i^j$ $E_{threshold}$
9. send (E _ residual$_i^j$) to BS
10. end if
11. end for
12. end for

/* BS performs the following tasks */

13. for i ← 1 to N /* for every grid */
14. compute E_{grid_i}
15. if ^{E} grid _ i ^{E}threshold
16. exit
17. end if
18. end for
19. for m ← 1 to N /* no. of grids*/
20. for l ← 1 to n_m
21. if E _ residual ^l_m $E_{threshold}$
22. compute CF_m^l E _ residual ^l_m / E_{grid_m}
23. end if
24. end for
25. end for
26. for i=1 to k /* no. of clusters*/
27. compute ($X_{CH\,i}$, Y_{CHi}) from (1)

/*WML based cluster head selection*/

28. select a node
    i. nearest to the ($X_{CH\,i}$, Y_{CHi})
    ii. belong to the cluster i
    iii. residual energy >=
29. end for

/ *** Steady-State Phase */**

30. for i←1 to k
31. for j ← 1 to
32. if E _ residual$_i^j$ $E_{threshold}$
33. send data to CH_i

/*Data transmission by Alive_node(s) */

34. end if
35. end for

36. send aggregated data to the base station

/* Data transmission by $_{CHi}$ */

37. end for

38. end for /* End of rounds */

39. END /* End of Algorithm */

PERFORMANCE EVALUATION

A Qualitative Analysis

The network lifetime is defined in terms of coverage. The grid-size is determined in such a manner that presence of a single node within a grid area is sufficient to declare the grid as covered. Further, to keep the network alive, all the grids need to be covered.

To declare the network alive, we can say that for every grid the node with maximum energy among all the nodes within that grid should be greater than a threshold energy level $E_{threshold}$ beyond which the node is considered as dead. Since this must hold for each grid, we can safely consider that only the minimum of these energies should be above thereby guarantees that each grid has sufficient energy to keep the network alive.

That is,

$$Min\left(\bigcup_{grid\_no=1}^{N}\left(Max\left(\bigcup_{l=1}^{n_m}E^{l}_{grid\_no}\right)\right)\right)\geq E_{threshold}$$

Equivalently, Network lifetime (NL) follows:

$$NL\propto Min\left(\bigcup_{grid\_no=1}^{N}\left(Max\left(\bigcup_{l=1}^{n_m}E^{l}_{grid\_no}\right)\right)\right) \qquad (2)$$

$$Min\left(\bigcup_{grid\_no=1}^{N}\left(Max\left(\bigcup_{l=1}^{n_m}E^{l}_{grid\_no}\right)\right)\right)\geq E_{threshold}$$

1) Justification of EEBLEC's supremacy over EEPSC
Base Case Argument:

According to the first order radio model, energy consumption due to data transmission is directly proportional to the square of distance between communicating nodes. If we consider a grid farthest away from the cluster-head as grid_farthest, energy spent by the nodes in the grid_farthest would be maximum. In the proposed scheme EEBLEC, we have assigned a contribution factor CF to each node that has significance while selecting a cluster-head based on the weighted mean of the CFs. As a result, the selected cluster-head is now more shifted towards the grid_farthest and this in turn ensures even energy load distribution reducing the energy consumption in intra-cluster communication.

In order to compare our scheme EEBLEC with the existing scheme EEPSC, similar to EEBLEC we have considered that the whole network area in EEPSC is partitioned into a number of small grids of equal size. In EEPSC, since initially all the nodes are equipped with the same amount of energy, after first round grid_farthest1 will be the grid with minimum value

of $Max\left(\bigcup_{l=1}^{n_m}E^{l}_{grid\_no}\right)$ i.e. $Max\left(\bigcup_{l=1}^{n_m}E^{l}_{grid\_farthest1}\right)$ = $Min\left(\bigcup_{grid\_no=1}^{N}\left(Max\left(\bigcup_{l=1}^{n_m}E^{l}_{grid\_no}\right)\right)\right)$ because it incurs maximum transmission cost. Consequently after the first round,

$$\left[Min\left(\bigcup_{grid\_no=1}^{N}\left(Max\left(\bigcup_{l=1}^{n_m}E^{l}_{grid\_no}\right)\right)\right)\right]_{EBLEC} > \left[Min\left(\bigcup_{grid\_no=1}^{N}\left(Max\left(\bigcup_{l=1}^{n_m}E^{l}_{grid\_no}\right)\right)\right)\right]_{EEPSC} \qquad (3)$$

Inductive logic:

We can claim the same to be true for every subsequent round with proper arguments as follows: At 2nd round, again the node with the maximum energy in a cluster gets selected as cluster-head in EEPSC which is likely to be found closest to the previously selected cluster-head. This in turn causes greater amount of energy expenditure for the nodes in grid_farthest and in its neighborhood. Therefore, evidently again the grid (grid_farthest2) with

$Min\left(\bigcup_{grid\_no=1}^{N}\left(Max\left(\bigcup_{l=1}^{n_m}E^{l}_{grid\_no}\right)\right)\right)$ is necessarily

to be located in the neighborhood of the grid_farthest1 if not itself. Now following the same logic stated earlier, cluster-head in EEBLEC is determined using the weighted influence of each node. As a result, cluster-head is now more shifted towards grid_farthest2 ensuring an even load distribution in the cluster and hence less energy expenditure for grid_farthest2. Therefore, after 2nd round also relationship in equation holds:

In EEPSC as the process goes on continuously, it causes a cumulative effect on the whole network and nodes in the farthest grid deplete energy more quickly. Therefore, after 2nd round also relationship in equation (3) holds.

Hence from equation (2) we can conclude that Network lifetime$_{EEBLEC}$ Network lifetime$_{EEPSC}$

B Quantitative Analysis

1) *Simulation Environment:* To evaluate the performance of EEBLEC, MATLAB 7.1 is used as a simulation tool. We consider that sensor nodes are deployed randomly across a plain area of 100m x 100m. The base station located at (x=50, y=175) views this area partitioned

into 16 grids of 25m x 25m each. Each node is equipped with equal amount of initial energy (2J) and the channel-bandwidth is set to 1Mbps. Further, we assume that WSN is working in continuous data flow application domain. Table 1 represents various other parameters and their values used in simulation.

Table I. Parameters and Corresponding Values Used In Simulation

Parameter	Parameter's Value
Network Area	100m x 100m
Grid Area	25m x 25m
Sensing Range of a node	30m
Base Station's Position	(50m, 175m)
Initial Energy for nodes	2 Joule
Number of deployed nodes	100
Size of data message	4000 bits
E_{DA}	5nJ
E_{elec}	50nJ
ϵ_{fs}	10pJ/bit/m^2
ϵ_{mp}	0.0013pj/bit/m^4

2) Simulation Metric:

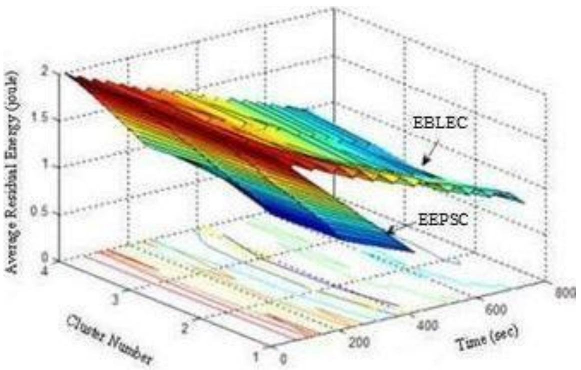
The performance of the scheme is evaluated considering network lifetime (section II.A) as a metric. It is measured using two different yard-sticks:

Average residual energy for a node in a cluster—Clusters left with more average residual energy per node indicates that all the clusters are alive for longer time resulting in improving network lifetime.

Number of data received at base station-- More number of data received at BS implies more nodes are participating in network operation in a grid thereby leading to longer network lifetime.

3) Results and Discussion:

Two sets of experiments are conducted to compare the performance of present scheme EEBLEC with EEPSC [9]. In first set of experiments, network lifetime is compared in terms of the first yardstick and the results are plotted in Fig. 2.



We observe from Fig. 2 that initially both EEBLEC and EEPSC have same average residual energy per node per cluster but over time it increases in EEBLEC compared to EEPSC. According to the definition of network lifetime to keep the network in operation, it is mandatory that all the clusters are to be alive. As in all the clusters average residual energy per node is greater than the EEPSC, it ensures longer network lifetime in EEBLEC compared to EEPSC.

It is evident from the plot that the coverage is dropped after 420 sec. in EEPSC whereas the same happens after 740 sec. in EEBLEC. Thus an improvement of 76.19% has been achieved in terms of network lifetime.

In the second set of experiments, the network lifetime is measured in terms of the second yardstick i.e. number of data received and the results are plotted in Fig. 3(a) and 3(b).

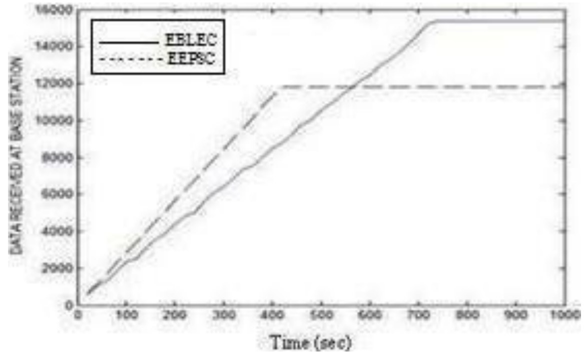


Figure 3(a). No. of data received at BS over time

Here also we observe from Fig. 3(a) that initially data received at BS in EEPSC is greater than that in EEBLEC, but the total number of data received at BS at the end of network lifetime in EEBLEC is 15358 whereas that in EEPSC is 11822 which show a gain of 29.91% over EEPSC. In EEBLEC, nodes are left with greater amount of energy compared to EEPSC leading to prolonged network lifetime.

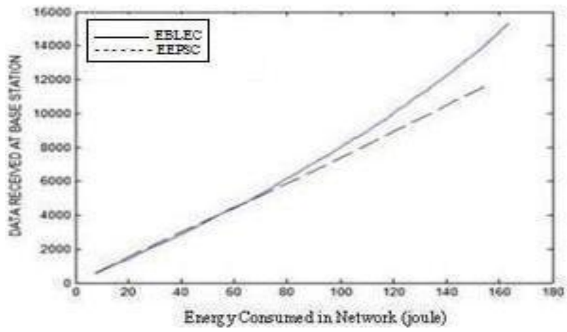


Figure 3(b). No. of data received at BS over energy

Fig. 3(b) plots the number of data received at BS with varying amount of energy consumption. This plot also shows the efficacy of EEBLEC over EEPSC by showing greater number of data received at BS

Figure 2. Average residual energy per node over time consuming a given amount of energy in EEBLEC than that in EEPSC.

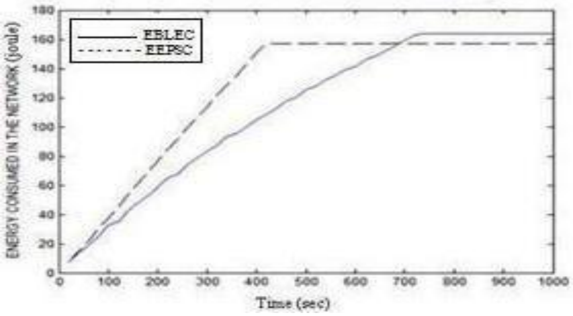


Figure 3(c). Energy consumed in the network over time

More number of data is transmitted means more energy is consumed. So there is a direct relationship between number of data received and energy consumption. Therefore, the results are cross-checked by plotting (Fig. 3(c)) energy consumed in network over time. This plot shows energy consumption in the network over time in both the schemes. It indicates that energy consumption in EEBLEC is lower than that in EEPSC leading to long lasting coverage hence enhancement in network lifetime. From the results of various simulations performed as depicted in Fig. 2 and Fig. 3, summarily it can be stated that the proposed scheme, EEBLEC outperforms EEPSC in terms of network lifetime while maintaining energy-balance.

CONCLUSION AND FUTURE WORK

In this paper an energy-balanced lifetime enhancing clustering EEBLEC for WSN is proposed. The present scheme partitions the network into a number of distance-based clusters. Further, the whole deployment area is divided into a finite number of grids whose dimensions are decided by the sensing range of nodes. In order to ensure even energy load distribution towards keeping the network alive for an extended period of time, cluster-heads are selected based on relative contribution of the nodes where the contribution is measured not only based on residual energy of the nodes but also on their relative position in the clusters.

Finally, efficiency of EEBLEC is measured against EEPSC through simulation, which validates the use of EEBLEC in order to achieve improved network lifetime with enriched coverage by ensuring even energy load distribution among the nodes in every cluster of the network. As a future extension of this work, event-driven applications with heterogeneous energy model of sensor nodes may be investigated.

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