The use of a Comprehensive Identification Infrastructure in Enhancing the lifetime of Sensor Networks

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Abstract

Regarding to the application of sensor networks, sensor nodes should be designed so that they are cheap and small. Therefore, the sensor nodes are severely in energy constraints. On the other hand, the increase in the operating time of sensor networks especially in military and environmental applications is a criterion in evaluating the performance of sensor networks. Thus, increasing the lifetime of sensor networks has permanently attracted attention of researchers. The use of a virtual backbone, as well as clustering methods has a significant impact on increasing the network lifetime. Thus, in this paper, we attempted to combine backbone composition-based methods and clustering methods in order to introduce a new method based on the use of convex clusters connected with lower power consumption for data collection in networks. Simulation results show that above mentioned approach has had a significant improvement in comparison with the clustering methods and techniques involved in making a backbone.

Keywords: *Wireless Networks, Lifetime, Clustering, Backbone, Convex Set*

1. Introduction

Wireless sensor networks are composed of many small, inexpensive nodes[2] which are capable of processing, sensing[3] and communicating with each other. Small structure of sensor nodes makes are strict ion in these networks in periods of use. So, many of them are installed in a small area in order for the connection resulted from cooperation between nodes to cover energy constraints as much as possible.

In [1], the topology of sensor networks has been studied in detail. But in general it can be said that the distribution of nodes in the environment is either randomlyor the network administrator regularly distributes nodes in the network environment based on existed information.
One of the major challenges facing sensor networks is incapability of recharging batteries of nodes. According to the release random of nodes in network environment, as well as their low cost, recovery and recharging of the node sare economically unjustified. So, some parts of the work done in the world of wireless sensor networks have been assigned to the area of reducing energy consumption of nodes. Reducing energy consumption of a node is interconnected with another concept known as increasing lifetime of the network. The life of a sensor network depends on the life of its nodes. Life of a node is defined as the time during which the node is able to perform its duties. However, there is no consensus on the definition of the network lifetime, but [2] has provided a detailed description of the various definitions:

- Network lifetime based on the number of live nodes: a network is considered to be alive before the death of its first node.
- Network lifetime based on nodes covering: a network is considered to be alive as long as the areas covered by its nodes are not diminished
- Network lifetime based on nodes connectivity or network connection: a network is considered to be alive as long as all its network nodes are connected together, i.e. the network is not disconnected.
- Definition of the network lifetime based on QoS required in an application:

A network is considered to be alive as long as it is capable of providing desired performance with an acceptable quality of service.

What we are looking for in this article is providing a new method based on energy management and covering techniques for increasing fault tolerance in wireless sensor networks. Accordingly, the reduction of energy consumption of nodes in the process of collecting and sending data to sink has been intended as a target.

In order to achieve this goal, an attempt has been done to partition the network into clusters with limited land area by which the network environment could be covered in such a way that intra cluster and inter cluster communications are associated with minimum energy consumption. Also, in order to prevent waste and balancing the energy consumption among all network nodes (both nodes far from the sink or near the sink) some chains of interconnected nodes are used to send data to the sink.

More in this paper is organized as follows: The second part is devoted to the study of energy model. In the third part, a detailed description of the GUHA method and LEACH as two examples of previous work will be presented. The fourth part is devoted to describing the proposed approach, and simulation results are presented in the fifth part. As well, the final evaluation in the form of sixth part is given as a conclusion.

2. Energy Consumption Model

As noted earlier, the energy consumption is one of the most important challenges facing protocol designers of wireless sensor networks. The nature of sensor networks which tends to smaller and cheaper nodes prevents a permanent solution to this challenge. Hence, researchers are always looking for ways to reduce the energy consumption of nodes in performing different protocols.

Energy consumed in an active node is composed of three parts, the energy consumed for sending a message (P_T), the energy consumed for receiving a message (P_R) and the energy consumed for augmenting or processing a message (P_{cpu}). It is worth noting that an active node is a node which is involved in performing network operations and protocols, and it is responsible for a part of performing network activities. If we assume that a transmitter requires to consume energy with an amount of E_{elec} (in terms of joules) to set up its radio circuit for sending one bit, then the amount of energy consumed in transmitter radio circuit for sending data with an amount of k bit, it needs a receptor in d meter which is shown with $P_T(k)$. This is calculated according to Eq.(1).

$$P_T(k)=E_{elec}\times k+E_{amp}\times d^{\gamma}\times k \quad (1)$$

In Eq. (1) E_{amp} is energy consumed in amplifier to boost sending signal so that the received signal can be decoded at the receiver. Dissipation power of the distance has also been shown by γ.

Accordingly, the energy consumed at the receiver to receive a k-bit data packet which is shown by $P_R(k)$, can be calculated by Eq. (2).

$$P_R(k)=E_{elec}\times k \quad (2)$$

Also, if we show the energy consumed in the processor of a sensor node for processing one bit by E_{cpu}, then the energy consumed in sensor node for processing a k -bit packet which is shown by $P_{cpu}(k)$ can be calculated according to Eq. (3):

$$P_{cpu}(k)=E_{cpu}\times k \quad (3)$$

3. Related Works

In this part we are going to describe algorithm of LEACH as the representative of clustering algorithms, and algorithm of GUHA as the representative of algorithms of producing a backbone.

3.1 LEACH Algorithm

In LEACH [3] which is a two-level hierarchical protocol, clusters are formed in distributed and self-configured forms in the networks. This will increase the scalability of the protocol. In LEACH, discrete time is considered. It means that the time is divided into small parts called time frames. LEACH algorithm is used alternatively in terms of numbers of rounds(each round consists of a number of time frames). This algorithm consists of setup phase and steady state phase which run in turns.

At the setup phase, some nodes are chosen randomly as cluster heads. Cluster head selection algorithms are different and some of them have been described in [4, 5, 6]. The optimum number of cluster heads is calculated according to Eq. (4).

$$k_{opt}=\sqrt{\frac{N}{2\pi}}\sqrt{\frac{E_{fs}}{E_{amp}}}\frac{M}{d_{toBS}^2} \quad (4)$$

In Eq. 4, E_{amp} and E_{fs} are amplifies energy that depend on the distance to the receiver and acceptable bit-error rate [7]. LEACH does not make any assumptions about selecting cluster heads, but it makes a balance between power consumption in the network nodes by establishing the equality in the number of being cluster heads. In other words, in LEACH, the probability of changing a node into a cluster head increases by passing the time (over the rounds of the algorithm run). LEACH tries to do it in order for all nodes to be selected as cluster heads equally.
LEACH is a very energy efficient but it is not an optimal algorithm and many enhancements on it have been investigated in [8], [9], [10].

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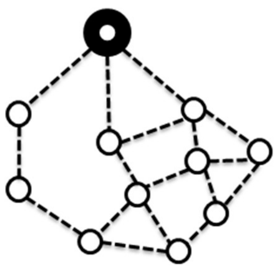
3.2GUHA Algorithm

The first phase of GUHA algorithm [11] is performed by identifying neighboring nodes. In this phase, each node by sending a message containing its ID within the specified territory as a neighboring range makes adjacent nodes informed from its presence. Each node will receive a similar message from neighboring nodes, and it will estimate the distance between itself and its neighbor based on the existed ID in received packs and received signal strength, and it will provide a list of this information. Later we will talk about how to determine the neighboring territory or range.

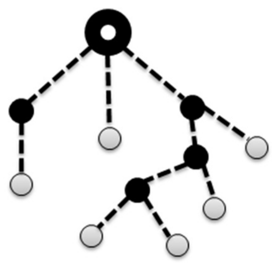
This algorithm has the following steps:

1. Initially the color white is assigned to all nodes.
2. The color of sink is set to black.
3. The color of white neighbors of a black node is set to gray.
4. Among gray nodes, the color of each node which has more white neighbors is set to black.
5. If any white node still remains, steps 3 to 5 are executed again.

This algorithm will last until the color of all nodes turn into black or gray. Fig. 1-a, illustrates an example of a hypothetical graph, and in Fig. 1-b, backbone resulted from GUHA algorithm is observed. It should be noted that the backbone created by GUHA algorithm is not unique, but this algorithm ensures that this backbone will include a minimum number of nodes.



(a): Network Graph



(b): The obtained infrastructure of the algorithm

Fig. 1 An example of performing GUHA algorithm on the graph of a given network.

4. Proposed Solution

In this section, we will explain the proposed solution in detail. As previously mentioned, the proposed solution tries to combine clustering methods with methods based on creating backbone. Therefore, in the proposed solution, we first attempted to use the method GUHA to create an identification infrastructure.

An example of this infrastructure is given in Fig. 2. It should be noted we assumed that the sink is located in position or coordinates of (50, 100).

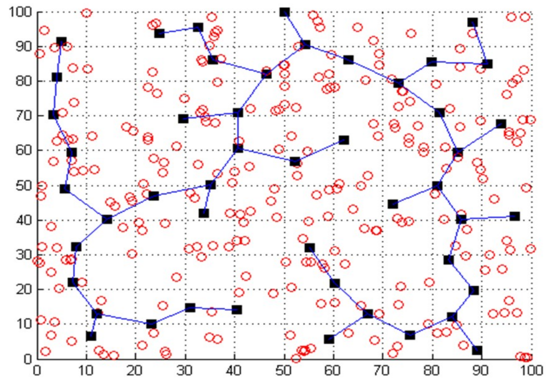


Fig. 2 Backbone made by GUHA algorithm in a network with 300 nodes.

In the second stage, every black node (node of the backbone member) by sending a message to its neighboring gray nodes, asks them about their remaining amount of energy and also every gray node by sending a message to black nodes, announces its remaining amount of energy. Among its nodes and adjacent gray and black nodes, the black node selects a node which has the highest residual energy as a final cluster head for the current round (steady state phase), then announces it to the adjacent nodes by sending a message.
After announcing the names of cluster heads by nodes which are members of the identification infrastructure, every non-cluster head node decides to join its intended head cluster. In proposed solution, after assigning the cluster heads, each node joins the cluster of a cluster head which is closer to it.

The amount of used neighboring radius has a great effect on the quality of performing the algorithm since it affects inter- and intra-cluster communication distance. As you know, if the transmitting distance between the transmitter and the receiver of the message is less than optimal neighboring radius (Eq. 5), energy consumption in transmitting node drastically reduces [12]. Thus, this question arises as how the neighboring radius should be to make this feature (i.e. inter-and intra-cluster communication with a distance less than optimal neighboring radius).

$$d_{opt} = \sqrt{\frac{(2E_{elec} + E_{cpu})}{E_{amp}}} \quad (5)$$

As you have seen, the primary clusters surrounding member nodes of identification infrastructure are formed. Then, among these nodes, the nodes of highest residual energy are selected as cluster heads and the final clusters are formed. Consequently, the amount of neighboring radius should be enough so that the communication of member nodes of identification infrastructure with each other and with member nodes of primary cluster is less than maximum neighboring radius.

Thus, the first constraint is stated as follows: the amount of neighboring radius must be less than or equal to the maximum optimal neighboring radius in order to provide a communication between member nodes of primary clusters and the member nodes of identification infrastructure as well as member nodes of identification infrastructure with each other within a limited transmitting radius. Moreover, to establish the first feature, i.e. inter-cluster communication with the mentioned constraint, the amount of the neighboring radius of a member node of identification infrastructure should be enough so that the distance between any two member nodes of the primary cluster in any location of the cluster, is less than the maximum optimal neighboring radius.

Consider Fig. 3. Due to dynamic selection of cluster heads, it is possible that node A by a period of time can be introduced as a cluster heads by the black node (the member of identification infrastructure). To ensure that node B can find at least one cluster head with distance less than the maximum optimal neighboring radius around itself, the amount of the cluster should be adjusted so that the maximum possible distance between A and B is not more than d_{opt}.

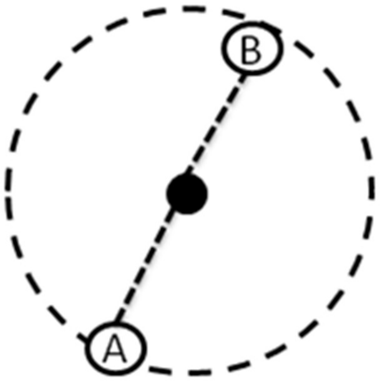


Fig. 3 A view of the status of primary clusters in the proposed solution.

The maximum distance between nodes A and B, is respectively equal with the node diameter. As a result, the second constraint is stated as follows: the amount of neighboring radius should be as half as d_{opt} so that the relationship of the two primary inter-cluster nodes, with respect to the mentioned constraint, is possible.

However, considering this amount for neighboring radius ensures only that if node A is introduced as the cluster head, node B will have a maximum distance as far as d_{opt} away from it.

Now consider another case. Suppose two nodes A and B are adjacent in the two primary clusters, and both as cluster heads at a period of current time, are selected by black nodes (member nodes of identification infrastructure) (Fig. 4).

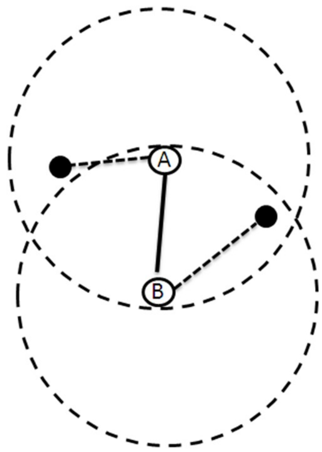


Fig. 4 An illustration of the status of two adjacent cluster heads in final clusters.

As we explained earlier, node B after collecting data from its cluster, should deliver the aggregated data to the upstream cluster head, i.e. node A. In order for the intra-cluster relationship to consider the above restrictions, neighboring radius should be set so that the maximum distance between A and B is not more than d_{opt}. The maximum distance between A and B is obtained when the two nodes A and B and member nodes of the identification infrastructure are parallel and located along the same line. Since the two black nodes of the identification infrastructure members nodes are in each other's neighboring district, the distance of A and B will be at least up to three times of the neighboring radius, and as we said, this distance should be as the same as d_{opt}.

Thus the third constraint is stated as follows: For establishing relationship between the two final cluster heads, the amount of neighboring radius should be one third of d_{opt}. With a meticulous attention to the three above mentioned constraints, we will find that with respect to the third constraint, the first and second constraints will be provided by themselves. So it is enough to consider the amount of neighboring radius equals to $\frac{d_{opt}}{3}$.

After forming the clusters, the steady state phase will begin. In this phase, like the steady state phase of LEACH algorithm, each non- cluster heads node send its data to cluster heads node, and then after aggregating received data, the cluster head sends final data to the upstream cluster head.

5. Simulation Results

To evaluate the performance of the proposed method, a course of simulation has been arranged by MATLAB software, and the results of it will be reviewed in this section. For this purpose, two hundred sensor nodes scattered with a random and uniform distribution in a square-like network with the side of 120 meters. All nodes are considered to have the same hardware and software properties. In the other words the network is a homogeneous one. Table (1) has shown Physical properties of nodes and simulation environment.

TABLE 5-1: Simulation parameters

Network Grid	A square area of 120 ×120 m
Initial Energy	0.5 j
Data Packet Size	1000 bit
Control Packet Size	200 bit
E_{cpu}	7 nj
E_{elec}	50 nj/bit
E_{mp}	0.0013 pj
E_{fs}	10 pj
d_{opt}	75 m
Sink	(60, 175)

The simulation process has been repeated 10,000 times in the same condition of repetition, and after averaging the results, it has been presented in Fig. 5. In this diagram, the horizontal axis shows passing time in terms of time periods, and the vertical axis presents the number of live nodes at any time. The length of the steady state phase for both algorithms has been considered as long as on period of time.

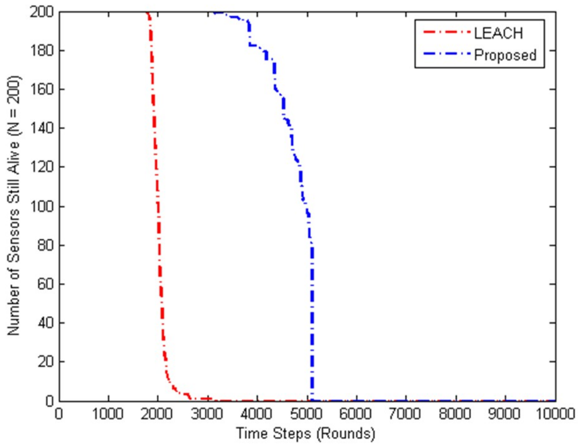


Fig. 5 Comparison of network lifetime in the proposed algorithm and LEACH algorithm (N = 200)

For better study of performance of the proposed solution, the above mentioned simulation has been performed for networks with different densities. Since it is necessary for the proposed algorithm to be performed (in accordance with the restrictions mentioned) by being connected to the network, its performance in low-density networks has better results.

As you can observe in Fig. 6, increasing the number of network nodes increases the death rate of the first nodes, but in turn it increases the operating time of the algorithm. To justify this, it must be said that the reason for premature death of some of nodes in high density is because of an increase in workloads of identification infrastructure. In other words, in a high density, each node of identification infrastructure is in charge of interacting with a lot of other nodes and it should find the most energetic node among all. In other words, as the network density is increased, the amount of initial clusters increases, and thus the responsibility of member nodes of identification infrastructure increases, and consequently their deaths come quickly. In turn, with an increase in density of the network and the death of member nodes of identification infrastructure, and due to high density of nodes, identification infrastructure will be restored immediately. Thus the proposed algorithm can continue its activity.

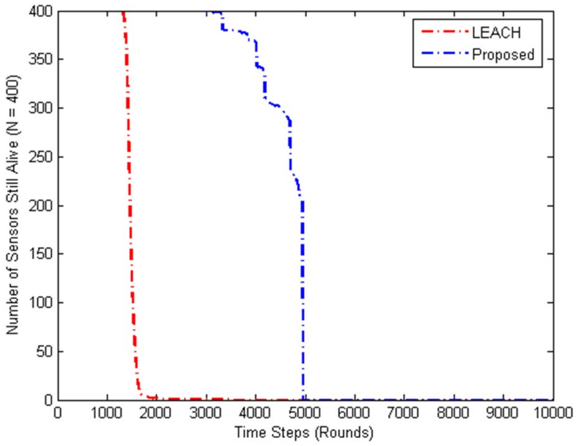


Fig. 6 Comparison of network lifetime, the proposed algorithm and LEACH (N = 400)

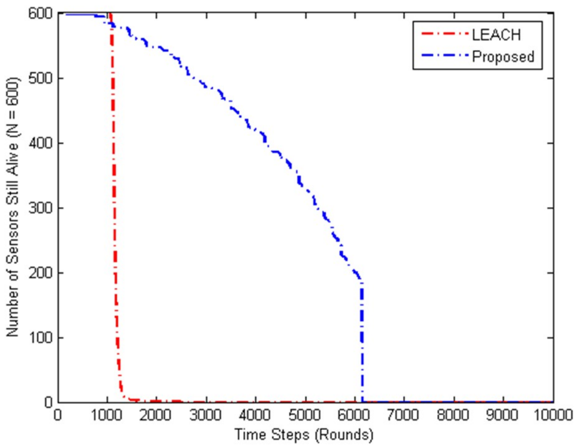


Fig.7 Comparison of network lifetime, the proposed algorithm and LEACH (N = 600)

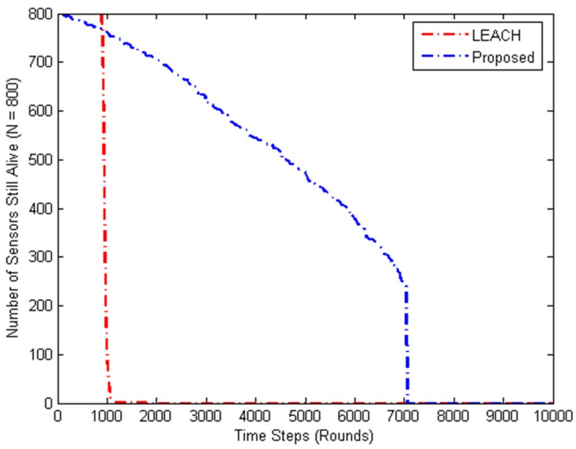


Fig. 8 Comparison of network lifetime, the proposed algorithm and LEACH (N = 800)

6. Conclusion

The increase in the distance between the transmitter and receiver in wireless communications is a major factor in the increase in energy consumption of nodes.
Therefore, in this paper we have tried to combine methods of creating backbones known as GUHA method and the two-level clustering method of LEACH to create a series of clusters connected together to create a multi-step relationship between each cluster head and the sink.

The amount of nodes, i.e. the neighboring radius has an important effect on the amount of energy consumption of network nodes, so by assigning proper neighboring radius some conditions could be provided for nodes of each cluster with neighboring radius less than d_{opt} to make a relationship with its own cluster head. As simulation results have shown, the proposed solution has achieved significant success in increasing the network lifetime.

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