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# Using Two Widespread Backbones to Increase the Lifetime of Wireless Sensor Networks

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## Abstract

Limiting energy resource in the sensor networks increases the importance of energy aware protocols. Nonexistence of fixed or predefined infrastructure in the sensor networks compared to radio and case networks, add the necessity of existence such protocols. In this paper, two energy aware rooted virtual backbone have used for collecting and transferring data toward the sink. Each backbone is built such that covers the large numbers of network nodes, so that any node is not a member of both backbones. Simulation results show that alternative usage of two mentioned backbones, have significant influence on the increasing network lifetime. Also we would show that suggested guideline, against existing methods, has not significant effectiveness of changing the size of controlled packet.

**Keywords:** Wireless sensor networks, Lifetime, Virtual backbone, Energy consumption, Backbones switching

## 1. Introduction

Each sensor network comprise of the large numbers of very small, cheap and limited processing-ability sensor node which used for supervising, collecting and processing environmental data [1].

Since in the wireless sensor networks the feed resource of a node is a battery with low energy and limited lifetime, its recharge or replacement is very difficult and in some case, it is

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impossible, thus designed algorithm for this network, as much as possible should be energy efficient.

Clustering, is one of the primary actions for designing the energy efficient and scalable protocols in the wireless sensor networks [2]. Using clusters decrease communication overhead due to data transferring, energy consumption and wave's interference between the nodes. At most applications, a natural way for grouping the closed nodes for using the related data and for removing the redundant data is cluster formation. Total volume of send data to the sink decreases significantly, through data aggregation of node in the cluster head and save the energy consumption and resources [1].

Finishing the energy of a node that we consider it as "node death" leads to fundamental changing in the network topology and the manner of protocol performance. Thus the energy consumption criteria are considered as a standard for measuring and comparing algorithm efficiency.

In the recent years, numerous protocols put forward to balance energy consumption of nodes in order to increasing the network lifetime, which among them clustering based protocols has been chosen as the best one. One of the most important of these protocols is LEACH protocol [3] which has described in section 3. Other considered protocols in the term of increasing the network lifetime, are HEED [4], LEACH-C [5]، E-LEACH [6] and H-LEACH protocols [7] which all are the improved kind of LEACH algorithm.

Wireless sensor networks are lack of fixed or predefined infrastructure compared with radio and ad hoc networks, and consequently, accessing to scalability and performance of routing protocols would be difficult [8]. Thus virtual backbone has been proposed as a promising approach for providing an efficient communication infrastructure in wireless sensor networks [9], [10], [11] and [12].

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The proposed approach is based on the idea that alternating use of two separated virtual backbone for directing data packets toward the sink, leads to monotone energy consumption between the nodes and as a result lifetime of network increases due to using the clustering based methods. In addition, it is attempted to avoid from energy loss through substituting long single hop communications to shorter multi hop communications.

The rest of paper is organized as follow: section two is devoted to providing a detailed description of energy consumption model. In section 3, clustering protocols of LEACH, LEACH-C, E-LEACH, H-LEACH are briefly discussed and some of backbone formation methods are studied. Proposed method is provided in section 4. Section 5 is dedicated to present and study simulation results and conclusion is provided in section 6.

## 2. The energy consumption model

In WSNs, the main energy consumption of the active node is made up of three parts: message sending, message receiving and data processing [13],[14]. The simplified energy consumption model for each part can be defined as equation (1):

$$\begin{aligned} P_T(K) &= E_{elec}\times K + E_{amp}\times d^{\gamma}\times K \\ P_R(K) &= E_{elec}\times K \\ P_{cpu}(K) &= E_{cpu}\times K \end{aligned} \tag{1}$$

In Eq. (1), $k$ is the length (in terms of bits) of packets, $d$ is the transmission distance (m) and $\gamma$ is the path loss power that is related to the transmission distance. $E_{elec}$ (nJ/bit) is an energy consumed in the electronic circuit of the receiver or transmitter for sending or receiving one bit of a data packet. $E_{amp}$ (nJ/bit/m$^2$) is also an energy consumed in a RF amplifier of the transmitter node for sending one bit of a data packet in a channel with the length of $D$ between transmitter and receiver so that the signal-to-noise energy ratio at the receiver circuit is acceptable. $E_{cpu}$ (nJ/bit) is the energy used in the processor of a sensor node

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for processing each bit. Also, the energy consumption in the cluster head for receiving and transmitting *k* bits packets can be defined as

$$P = P_T(k) + P_{cpu}(k) + P_R(k) = k(2E_{elec} + E_{cpu} + E_{amp} \times d) \quad (2)$$

In Eq. (2), energy consumption is in the direct proportion with data packet's length. So, when the transmission distance being smaller than optimal distance, energy consumption is in the direct proportion with $d^2$. Otherwise, energy consumption is in the direct proportion with $d^4$ [13] and [5]. Therefore, it is clear that substituting single hop communication by non optimal transmission distance with an existing multi hop communication by optimal transmission distance could have significant influence on decreasing energy consumption.

## 3. Related work

Many algorithms have been presented for clustering and selecting cluster heads which significantly influenced on decreasing network energy consumption and increasing network lifetime. Among them, LEACH protocol is very famous, so that it is a basis for comparing the various methods of increasing network lifetime.

LEACH [3] utilizes a repetitive distributed algorithm in the alternative performance framework of two steady-state and set-up phase for division the network environment into some cluster and then, collecting and sending data to the sink. In the set up phase, firstly, each node according to Eq. (3) calculates the probability of being cluster head, then according to calculated probability it performs one of both keeping still or claiming for being cluster head. Each node that decides on being cluster head, informs other nodes from this issue through sending a broadcast message across the network environment. Each non-cluster head node, by receiving message from cluster head nodes, finds the closest cluster head regard to received signal power, and joins to it. Then in the steady-state phase, that could include one or more time frames, each non-cluster head node, gives the surveillance data from the environment to

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cluster head. Cluster head node, after receiving and aggregating data of cluster nodes, sends the final data to cluster head. LEACH algorithm emphasizes on the dynamic selection of cluster heads in order to create a balance for data energy consumption.

$$T(n) = \begin{cases} \dfrac{P}{1 - P\left(r \bmod \frac{1}{P}\right)} & if\ \ n \in G \\ 0 & otherwise \end{cases} \tag{3}$$

In the Eq. (3), *p* is the possibility of being cluster head, *r* is the current round number and *G* is the data set which was not a cluster head in the last round. In the first round, all of the nodes could be cluster head with *p* probability, but after becoming cluster head, each node could not be cluster head for at least *1/p* number of round.

Although the proposed method for LEACH leads to significant increment of network lifetime, but this algorithm is not without problem. For example inappropriate distributing cluster head node in network environment and ignorance of residue energy of nodes in the cluster head selection process are two basic problem of this algorithm, for this reason many researchers tried to improve this algorithm with providing various methods. One of the provided improvements in the LEACH algorithm, assuming nodes are equipped, is based on Global Position finding System (GPS). This centralized algorithm which is called "LEACH-C" [5] suggests that each node sends its position to sink. Then the sink decides about determining cluster heads in the later round.

In [6], with considering residue energy of nodes for cluster head selection, new reformation provided for LEACH algorithm which improved the process of cluster-head selection. E-LEACH protocol could increase the network lifetime by this change of cluster head selection. Clustering method in H-LEACH [7] protocol is the same as LEACH, except that the measure of determining cluster head is its residue energy. Also, in the clustering process continuation,

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one cluster head is selected as MCH among the other cluster heads, which transmits data of other cluster heads beside its own data toward the sink.

Just as mentioned before, the aim of this paper is providing a new method based on using rooted energy aware backbone in order to increase the network lifetime. a backbone is a subset of the network nodes which improved the routing and organizing nodes, so that a normal node sends a data packet to a member node of backbone, then member node of backbone, based on a routing protocol, hands the data packet between together and reaches it to destination. Backbone per se could cause to decrease the communication cost and throughout energy consumption, and increase efficient bandwidth and network lifetime [15].

Multiple methods have been introduced to instruct the backbone, so far. In [16], a distributed algorithm called “EVBT” has been proposed to create a backbone in the wireless sensor network. EVBT introduced a concept of energy threshold level for the members of backbone, in which just the nodes with higher level of predefined threshold place in the backbone. In [17], ViBES algorithm, through creating a connected backbone, facilitates the routing and causes to decrease energy consumption in the routing process. In [18], a heuristic algorithm based on pruning is suggested in which the selection measure for pruning is a node with lowest degree. In [19] a greedy algorithm is introduced to find the minimum connected dominating set in the unit disk graph. In [20] two distributed heuristic algorithm based on maximal independent set is provided to determine the connected dominating set. In this method, the maximal independent set is determined by the help of nodes labeling strategy, and then connected through instructing rooted spanning tree [21]. In [22] a local algorithm is proposed to determine the connected dominating set in the general graphs. In this algorithm, firstly, each vertex which has two non-connected neighbors, is added to a dominating set and a connected dominating set is created, then using two pruning law, some nodes deleted from the connected dominating set. In [15] an algorithm is suggested to determine the minimum connected dominating set using introduced dominating set. This algorithm includes 3 phases.

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In the first phase, dominating set determines by defining maximum nodes degree for most covering. In the second phase, nodes are connected in the dominating set using Steiner tree. In the third phase, a tree prunes to create minimal connected dominating set.

## 4. Proposed method

In the proposed method, instead of clustering, two separated virtual backbone are alternatively used for directing data packets toward the sink. In the clustering based approaches, the alternative process of constructing clusters causes high energy consumption, thus it has efficiently been tried to save the energy consumption through removing this repetitive process.

### 4.1. Optimal distance

As it is described in the section 2, in wireless sensor networks, energy consumption of active node composes of three parts: message sending, message receiving and data processing. According to Eq.(1), increasing the receiver and sender distance leads to increase the energy consumption of sender. If this distance be less than a threshold which we called it “optimal distance” the distance effect in the Eq. (1) will set with second power and otherwise it will set with fourth power. Transmission threshold (optimal distance) of Eq.(4) is calculable.

$$D_{opt}=\sqrt[\gamma]{\frac{(2E_{elec}+E_{cpu})}{E_{amp}\times(\gamma-1)}} \quad (4)$$

### 4.2. Using backbone instead of clustering

This method is based on using backbone instead of clustering. Making a compressed and concentrated backbone in the form that most nodes become its member could be energy efficient. If there is a backbone in the network, such that each node is either a member of this backbone or is neighbor of its member, then it is sufficient that each non-member node

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delivers heard data to the nearest member node in the backbone. Also, it is sufficient that each member node of backbone instead of sending its data toward the sink directly, delivers it to the upstream node in the backbone , and this process will continue until delivering data to the sink by one of the member node of backbone which is near the sink. It is clear that task of a member node of backbone is a little more than a normal node because it should hear the data of downstream and non-member node, in addition to sending data toward upstream node and also should aggregates them (Eq. (2)). Thus workload of half of nodes will be charged to other half of nodes.

A logical approach for dominating such injustice is creating second backbone using nodes which are not members of first backbone. In other words, a second backbone could be constructed along with the first one in order to avoiding centralization of energy consumption, so that it has not any similarity with the first backbone. Then while the network performance, two mentioned backbone would be used alternatively. Figure 1 show typical constructed backbone by this method. Just as you can see, member nodes of the first backbone have shown with blue color and that of the second backbone with red color.

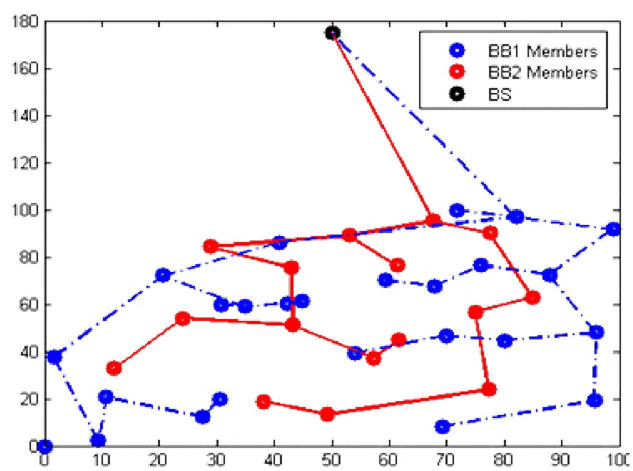


**Figure 1: First and second backbone**

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After constructing both backbones, except the nodes which connect directly with the sink, each node of network has a parent of the first backbone and a parent of the second. Thus in the time of activity, each backbone sends the data resulted of hearing the environment to its parent in the active backbone. Proposed algorithm for creating each of both backbones is shown in the figure 2.

1- Each node broadcasts an identification message to identify neighboring nodes with transmission radius of *R*.
2- A list called "list of contended nodes for becoming parent" is made and initially the ID of sink node is inserted into it.
3- If the "list of contended nodes for becoming parent" is empty, then the algorithm ends, otherwise step 4 is executed.
4- Every node whose ID is in the "list of contended nodes for becoming parent" inserts its ID to BB-Construction message and broadcasts it with transmission radius of *R*.
5- Each node that receives the BB-Construction message, chooses the sender of this message as its parent provided that:
   5-1 it has not a parent.
   Or
   5-2 the sender is closer than its current parent.
6- If the sender is approved by at least one of its neighbors as a parent, it becomes member of the backbone.
7- Each node that chooses the sender as its parent in step 5 will set a counter which is inversely proportional to the distance from the parent node and start counting.
8- Each node finished counting, joins to the "list of contended nodes for becoming parent" and goes to step 3.

**Figure 2: the proposed algorithm for constructing a backbone**

Now the question is that how should be the order of using backbone for balancing energy consumption? The proposed algorithm takes advantage of using the average residue energy of the member nodes at each backbone as a measure for backbone switching. In other words, the proportion of average residue energy of active backbone's member nodes to the average of

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residue energy of passive backbone's member nodes calculates the possibility of backbone switching (Eq. (5)).

$$P_{switch} = 1 - \frac{E_{avg-active\ backbone}}{E_{avg-passive\ backbone}} \qquad (5)$$

In this equation, $P_{switch}$ shows the possibility of backbone switching, $E_{avg\text{-}active\ backbone}$ is the average residue energy of member nodes of active backbone and $E_{avg\text{-}passive\ backbone}$ is the average residue energy of member nodes of passive backbone. Active backbone is a backbone that is used in the current time slot and thus the other backbone will be a passive backbone. Eq. (5) shows that simultaneous with decreasing the value of residue energy of active backbone, the possibility of its switching will be increased. $P_{switch}$ value is calculated by the sink and at the end of each time slot. After calculating $P_{switch}$ value, the sink with the possibility of $P_{switch}$ decides on switching backbone. On this basis, if the sink decides to change backbone, it will inform the node by sending a message in the form of broadcast.

Also at the end of transmitted data packet, a separated field is considered for inserting residue energy, such that each member node of backbone collects its residue energy with existing number on this field while delivering data to the parent node. Thus the second field would be considered for counting the backbone member nodes, such that each member node of backbone, during sending data packet toward the parent node, increases the value of this counter by one unit. Lastly, the sink, with receiving data and studying both above fields, will easily be capable to calculate average residue energy of backbone member nodes.

### 4.3. Repairing backbone

Backbone member nodes consume more energy other than normal nodes which are not members of any backbone. Even the rate of energy consumption between the backbone member nodes has not similar speed, because distance of the member node is different with their parents. Also, the children number of each member node is not necessarily equal to other

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member nodes. By this reason, death time of the member nodes is different from each other and causes to creating cavities on the backbone. For example, in the figure 3, the death of node A in the backbone interrupts the communication of nodes B, C, and D.

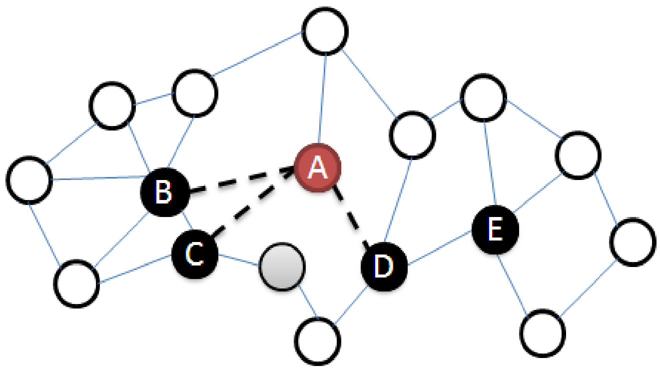


**Figure 3: Disrupting in backbone after the death of member nodes**

The proposed approach for avoiding such problem emphasizes on the substituting dying node with a neighbor node which preferably is not the member of any backbone. In this situation, whenever the amount of residue energy of a member node is being less than a threshold (equal to 10% of initial node energy), the process of repairing backbone starts. In this process, dying nodes, first tries to find a node which is not a member of backbone and has more residue energy, by broadcasting a message with *R* radius of neighbor. Each neighbor, if it isn't member of any backbone, by receiving this message determines whether it could be substituted with a dying node or not. Condition of substituting is such that firstly substituted node should covers all children of dying node, secondly it should make a relationship between the child of dying node which is member of backbone and the parent of dying node in the active backbone. Thus a node which has competency for substituting condition, becomes a member of active backbone nodes and dying node removed from the membership of backbone. Then substituted node is selected as a parent of the dying node's children and then selects the parent of dying node as its parent. According to simulation results we consider the

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threshold value of residue energy for performing the process of backbone repair, equal to 10% of initial energy of node. Thus whenever residue energy of a backbone member node reaches to 0.1 of its initial value, the process of repairing the backbone is accomplished.

Also, it is always possible that if a dying node doesn't find a substitution for itself, it realizes this issue by failure of receiving messages from neighbors. In this case, dying node asks its child nodes to change their parent through broadcasting a message, and lastly the parent of dying node will be their new parent.

## 5. Simulation result

In order to evaluate the proposed approach, simulation of a sample network which is referred to in [23], with characterized conditions has been implemented using MATLAB software. These conditions are shown in Table 1. The considered network includes 300 nodes with exact similar structural characteristics that are distributed evenly throughout the network.

**Table 1: Simulation parameters**

| | |
|---|---|
| Network grid | A square area of 100×100 |
| Initial energy | 0.5 J |
| Data-packet-size | 1000 |
| Control-packet-size | 200 |
| $E_{DA}$ | 5nJ/bit |
| $E_{elec}$ | 50nJ/bit |
| $E_{amp}$ | 0.0013pJ/bit/m$^4$ |
| $E_{cpu}$ | 7nJ/bit |
| $E_{fs}$ | 10pJ/bit/m$^2$ |
| Threshold distance | 87.7m |
| Sink | (50,175) |

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The simulation process has repeated 10000 times, and in the same condition and its results have been depicted in Figure 4. As you can see, the proposed method has been compared with LEACH, E-LEACH and H-LEACH algorithms, for the value of α = 0.05J. Clearly, our proposed approach has achieved great success in comparison with other algorithms.

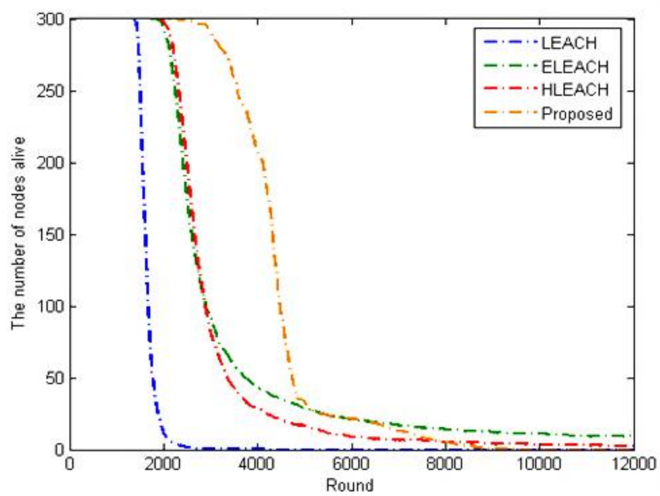


**Figure 4: Comparing network lifetime in the proposed method and clustering based algorithms (n=300)**

The above simulation has also been performed for a network with 100 and 200 nodes. Simulation results are shown in Figures 5 and 6 show that in networks with higher density, the proposed method is more efficient. Reducing network density (in the case that the number of network nodes is equal to 100) our method still has better performance than the LEACH algorithm, but a significant drop is observed relative to the E-LEACH and H-LEACH algorithms.

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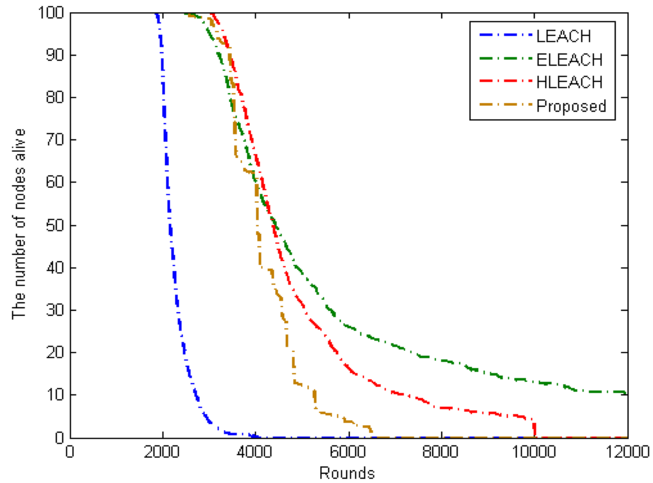


**Figure 5: comparing network lifetime in the proposed method and clustering based algorithms (n=100)**

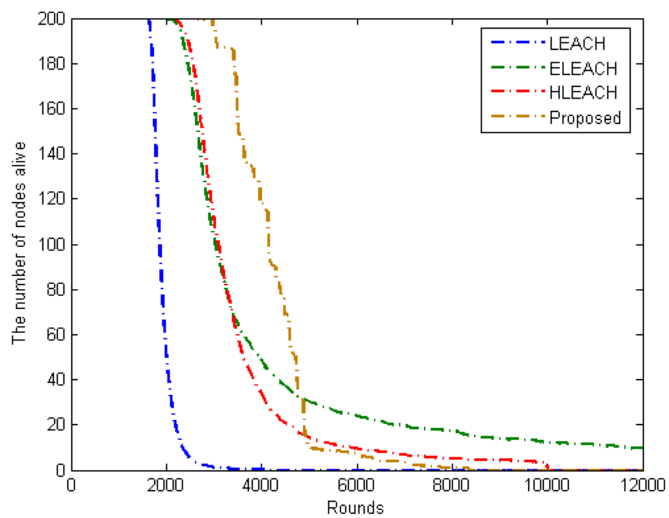


**Figure 6: Comparing network lifetime in the proposed method and clustering based algorithms (n=200)**

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Inefficiency of the proposed method in areas with lower density is the result of increasing the distance between nodes. For constructing backbone in the proposed algorithm, we saw that the made backbone is compact because of the short distance of nodes in a dense environment. We also know that diminishing the distance between sender and receiver nodes is a factor in reducing energy consumption.

In the proposed method, it has been tried to replace long single-hop connections with an existing multi-hop connection. In the case that a network's density is low, situations usually occur in which it is impossible to find short-range communications. Therefore, the probability of success of the proposed algorithm decreases in environments with less density.

Most of dynamic clustering algorithms, due to repeated clustering process, require exchanging a lot of control packets that their size has a significant impact on increasing and decreasing of network life time. Figure 7 represents a comparison of four mentioned algorithms against increasing the control packet's size. In this comparison, viability of at least 80% of nodes is considered as a measure for determining network's lifetime. In the proposed method, the control packets are used considerably in two stages: 1) the stage of constructing a backbone and 2) the stage of restoration of a backbone.

Given that the construction of a backbone is only performed at the beginning of a network operation and it is not repeated, control packets do not have much use. So, this has caused that an enhancement in the size of the control packets, unlike existing algorithms, have no significant effect in reducing the network lifetime.

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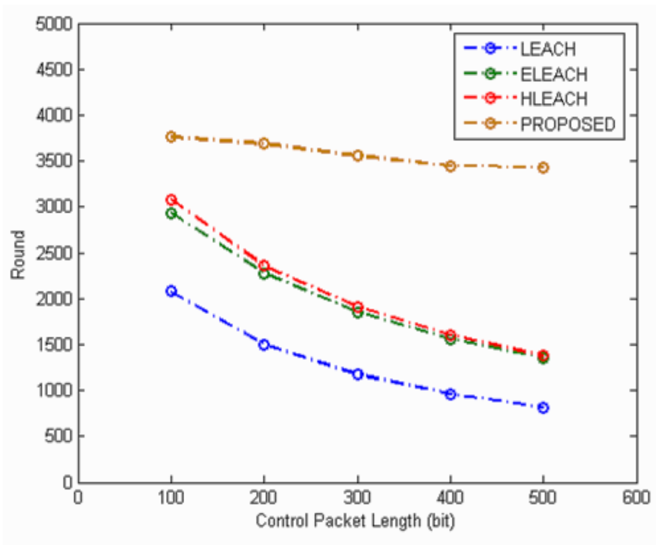


**Figure 7: checking the effect of increasing the length of control packets on the network lifetime in different algorithms (n=300)**

## Conclusions and future work

Constructing a connected dominating set as a virtual backbone and with this feature that each node of a network is a member of a virtual network or is neighbor with one of its members helps to replace all of single hop connections with the existing multi hop ones. In order to construct such a backbone, the proposed algorithm is based on the principle that as much as possible additional nodes are joined, because it helps to distribute the network's load over a larger number of nodes. A comprehensive backbone with mentioned conditions could have significant impacts on decreasing energy consumption of nodes which are away from the sink.

The proposed approach for constructing a backbone would eliminate the need for routing from cluster heads to sink. Also, the algorithm is designed so that half of network's nodes become member of any backbone of the network. Distribution of network's workload needs

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more nodes to cooperate. In order to achieve this goal, we have tried to construct two distinct backbones with no subscriptions. According to the experimental and simulation results, we can claim that half of nodes join the first backbone and half of them join the second backbone.

We have suggested that these two backbones could be used alternatively. In this way, each backbone that the average energy of its members is more, more likely will operate as an active backbone. Accordingly, members of an active backbone will deliver the surveillance data to their parent node in the active backbone. Then, members of each active backbone aggregate the incoming data from its child nodes with the surveillance data from the environment and deliver it to its upstream node (parent node) in the backbone.

The simulation results presented in section 5 that compare the proposed algorithm with a number of algorithms based on clustering shows that the proposed approach leads to a significant improvement in increasing network lifetime. The main feature of this paper is the new and innovative approach to the problem of increasing the lifetime of network's nodes. Using virtual backbones in wireless sensor networks have been applied in the implementation of routing and data aggregation protocols, while using it for increasing the lifetime of sensor networks still needs more researches. Utilization of clustering besides virtual backbone construction could be considered as our future work.

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