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Energy-Aware Virtual Backbone Tree for Increasing Wireless Sensor Network's Lifetime

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Abstract

A wireless sensor network consists of numerous tiny sensors which have small and not rechargeable batteries. These tiny sensors are intelligent devices with the ability of wireless communication. They can sense different kinds of data such as light, voice, temperature and then process them. At the end they transmit their results to other nodes or to a central station. Existence of a physical and real infrastructure in Ad-hoc wireless networks or telecommunication networks causes to design many efficient protocols, which could not be used in sensor networks because of the lack of such infrastructures in these networks. Therefore virtual backbone has been developed to prepare an efficient infrastructure in sensor wireless networks. We use two virtual backbones which are energy aware. In this paper, they collect and transmit data to the sink. Each backbone should cover many of our nodes and each node must be covered only by one backbone. Simulation results confirm that periodic use of these tow backbones increases network lifetime very much.

Keywords: Wireless sensor networks, Energy consumption, Lifetime, Guha Algorithm, Virtual backbone.

1. Introduction

A wireless sensor network is typically composed of numerous cheap and tiny nodes with limited process ability to sense the environment. Each node is equipped by a sensor unit, a radio circuit for send/receive messages, a processor, a memory set, and a battery. Our nodes

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can sense information from environment and send them to their neighbor nodes or to a base station. In most cases, sensor nodes are randomly spread in an environment. This distribution way helps us to establish network in dangerous and in accessible areas [1]. In comparison with Ad-Hoc and telecommunication networks, WSNs don't have any fixed or predefined infrastructure such as access point or BTS. Thus it is difficult to reach scalability and run the routing protocols. By establishing a virtual backbone we can create such infrastructure in WSN. This idea has been done successfully in [2] by the use of a few adjacent nodes.

A virtual backbone is a subset of network's nodes which are capable to communicate with each other and make connections between other nodes [3], [4], [5], [6], [7] and [8]. This infrastructure improves routing protocols and increases network lifetime and energy saving by the use of scheduling mechanisms and turning nodes on and off periodically. Our suggested approach based on the idea that alternate use of two fully separated virtual backbones for leading data packets to sink can uniform energy consumption among network's nodes and as a result can increase network lifetime in comparison with the previous methods. In addition, we try to replace long one hop communications with short multi hop communications that prevents loss of energy in the system. In the follow, we explain energy consumption model in section 2 in details. In section 3 Guha algorithm has been described briefly. Our suggested approach is presented in section 4. Then, in section 5 we present and consider the result of simulation. Finally the conclusion will be presented in section 6.

2. Energy Consumption Model

In WSNs, most consumption of energy for an active node is in sending, receiving and processing messages [9], [10]. Energy consumption model for each section can be described by relation (1):

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$$P_T(K) = E_{elec} \times k + E_{amp} \times d^{\gamma} \times k$$
$$P_R(K) = E_{elec} \times k \qquad (1)$$
$$P_{cpu}(K) = E_{cpu} \times k$$

In which "*k*" is packet length (bit) and "*d*" is transmission distance (meter), γ is path loss power that is related to transmission distance (*d*). E_{elec}(nJ/bit) is energy consumption for sending or receiving one bit in the electronic circuit of receiver or transmitter. Also E_{amp}(pJ/bit/m^n) energy consumption in radio amplifier circuit to send one bit of packet in a channel of length *d*, in a way that *S/N* is acceptable. E_{cpu} (nJ/bit) is the energy consumption for processing one bit in a node that senses the environment. Energy consumption of the cluster head sending or receiving a packet of length n (bit) is also defined as:

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

In relation (2), energy consumption and packet length are in direct proportion. However, when *d* is less than the optimum distance, energy consumption is in direct proportion with d^2 otherwise, energy consumption is in direct proportion with d^4 [9] and [11]. So, it is clear that replacing a one hop communication which has non-optimal transmission distance with existing multi hop communication which has optimal transmission distance, can be effective on reduction of energy consumption.

3. Creating a Rooted Backbone by Using the Guha Algorithm

In [12] a centralized algorithm has been suggested to create CDS for general graphs. In this algorithm a WCDS is created and then the central nodes are chosen to make a CDS. In the follow we will explain the algorithm. In the first phase of implementing Guha, all nodes are marked with white color. Then the sink node and all its neighbors are marked with

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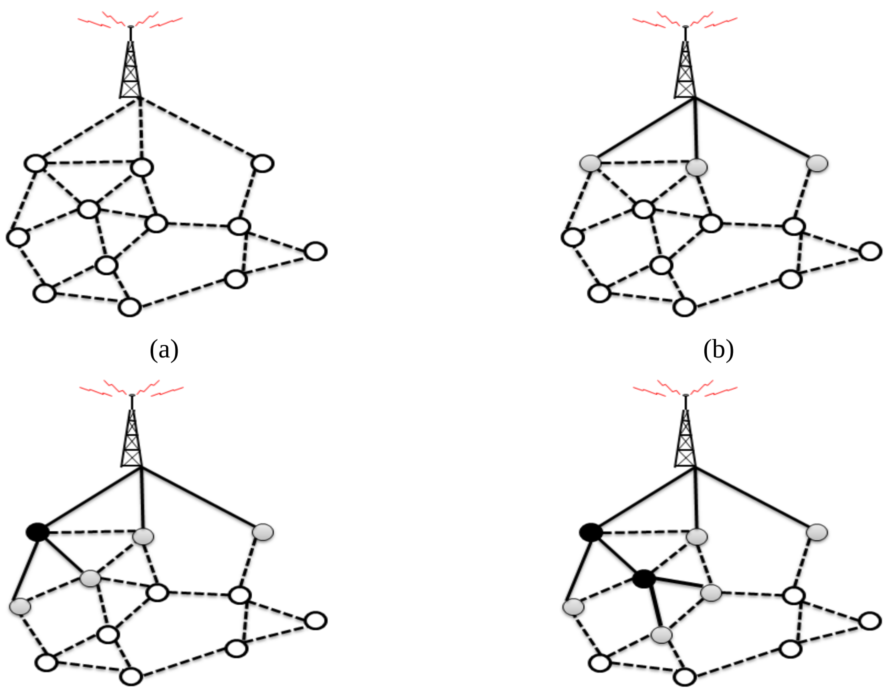
black and gray color respectively. After that, the algorithm enters to an iteration phase in which a gray node that has most white neighbors is chosen and marked with black color, then all of its white neighbors will be changed to gray. This iteration phase continues until there is no white node left. After completing this process, the nodes which have been painted black, create the backbone. These steps shown in figure 1 for an example of network that its graph is presented in (a). It should be noted that the created backbone of this algorithm isn't unique but it ensures that the backbone will have the minimum nodes.



(a) (b)

(c) (d)

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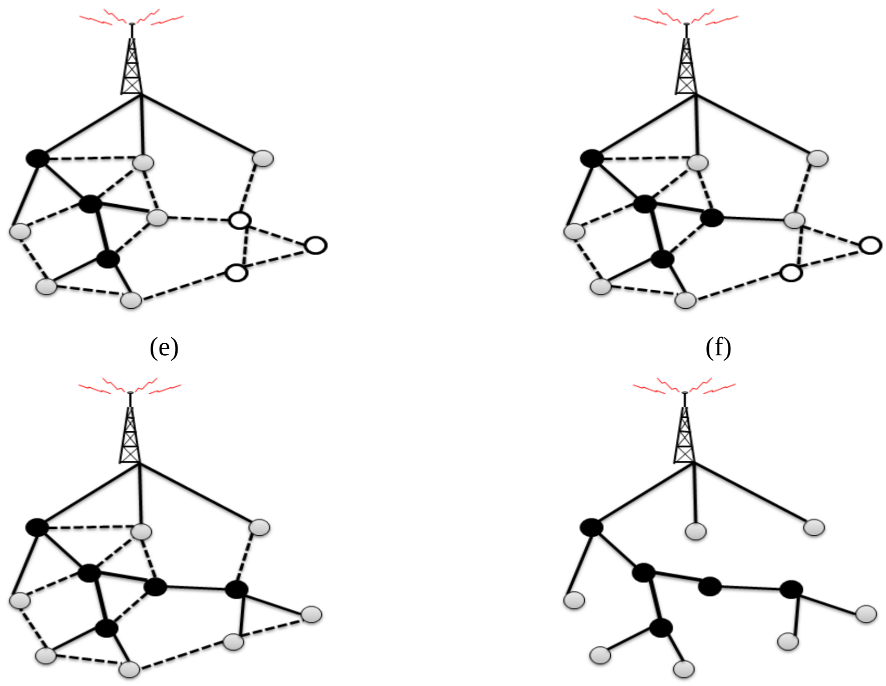

(e) (f) (g) (h)

Figure 1: an Example of Guha algorithm

4. Proposed Method

In our proposed method, instead of using the clustering, we periodically use two perfectly distinct virtual backbones to lead data packets to the sink. In methods based on clustering, the periodic process of creating clusters consumes considerable energy. Hence, we tried to omit this periodical process to save the energy.

4.1. Optimal Distance

As mentioned in section 2, in wireless sensor networks, most of energy that an active node consumes is for transmitting and receiving messages and processing data. According to relation (1), increase in the distance between transmitter and receiver causes to increase

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the energy consumption in transmitter. If this distance is less than threshold energy level namely optimal distance, the effect of distance in relation (1) will be squared otherwise it will be biquadratic. We can obtain this threshold from (3).

$$D_{opt}=\sqrt[\gamma]{\frac{(2E_{elec}+E_{cpu})}{E_{amp}\times(\gamma-1)}} \quad (3)$$

4.2. the Effect of Increasing Radius of the Neighborhood (*R*) on Network Connectivity Probability

The proposed algorithm for creating virtual backbone would run if the network is connected. A connected network is a network where every two distinct nodes are linked by at least one path. The *R* parameter indicates the radius of a node's neighborhood. Obviously, by increasing *R* value, the network connectivity probability will increase. To explain more precisely, we will describe one cycle of this simulation. Our considered area is a square and its dimensions are 100 meter where 200 nodes have been distributed with uniform distribution. Then the network connectivity probability is assessed by changing radius of the neighborhood. The result of this simulation is shown in figure 2. The horizontal axis represents radius of the neighborhood and vertical axis represents the network connectivity probability. In this simulation, we postulate that radius of the neighborhood can increase gradually from 0 to 120. In a way that for example we repeat the simulation 1000 times for *R*=1 meter. In the other words, we randomly distribute nodes in network 1000 times and we assess the network connectivity probability for this radius of the neighborhood, each time. If we divide number of times that the network is connected (with this radius of the neighborhood) by total times, the result will be the network connectivity probability. As you can see in the figure, the network connectivity probability has risen from one point to the next and the network connectivity probability received to 1

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very soon before radius of the neighborhood grew more than 40. In this chart, the network is divided into three parts. On the left side, radius of the neighborhood is changed from 0 to 38. In this area, the network connectivity probability is less than %99. In the middle, radius of the neighborhood is changed from 38 to 42 and the network connectivity probability is %100. On the right side, radius of the neighborhood is changed from 42 to 120 and the network connectivity probability didn't changed and is %100. It should be noted here that after the network was connected with probability 1.0, increasing radius of the neighborhood won't affect on the network connectivity probability. Thus in such cases, increasing radius of the neighborhood (*R*) only causes to increase power consumption, so in all of the simulations, we assume that radius of the neighborhood (*R*) is approximately 42.

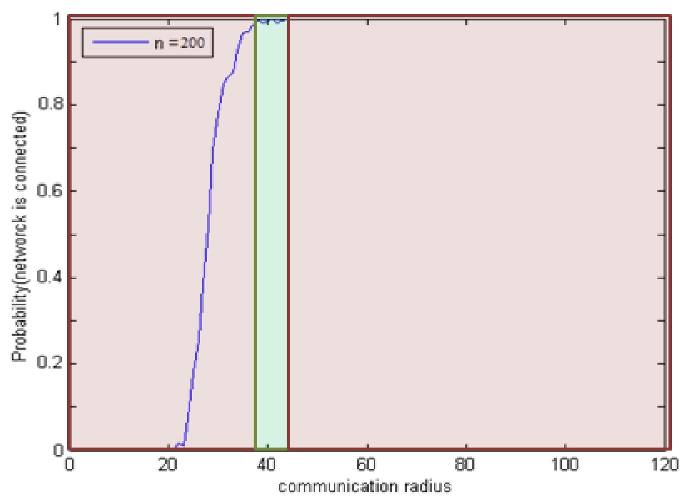

Figure 2: the Impact of increasing radius of neighborhood on connected network probability

4.3. Using backbone instead of clustering

The proposed approach is on this basis that we use backbone instead of clustering. Creating a compressed backbone that most of the nodes are its member can reduce energy consumption considerably. If there is only one backbone in the network so that every node

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is a member of this backbone or is neighbor with a member of it, then it is sufficient that each non-member node sends captured data to the nearest member node. Instead of sending data to the sink directly, every member of the backbone sends its data to an upper node in the backbone and this routine repeats until one member of backbone that is nearest node to the sink delivers data to the sink. It is clear that duty of every members of the backbone is little more than other non-member nodes because in addition to transmit data to a upper node, it should sense data from lower nodes and adjacent non-member nodes and integrate them (relation 2). So, half of the workload of the nodes will be assigned to other half of the nodes. A rational solution for this problem is creating another backbone with the nodes that is not member of the first backbone. In the other words we can use another separated backbone to prevent centralized energy consumption so that it has nothing in common with the first one. A sample backbone that created by this way is shown in figure 3. As you can see, the members of first backbone are blue and the members of second backbone are red.

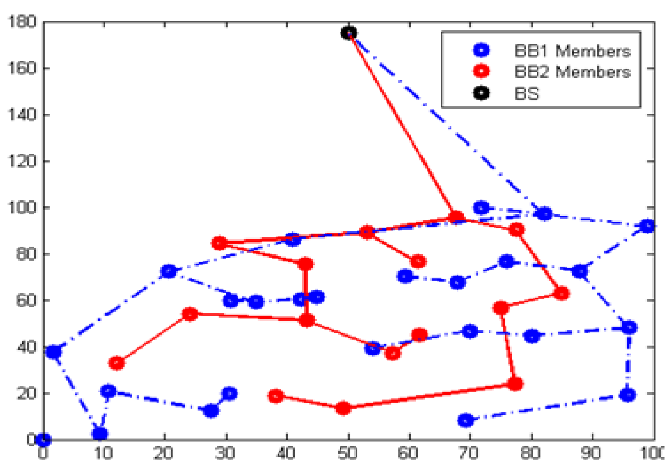

Figure 3: First and second backbone

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After constructing both backbones, the nodes that aren't directly connected to the sink have got two parents, one from the first backbone and one from the second backbone. So in the time of acting of each backbone, sensed data is sent to a parent in the active backbone. Proposed algorithm for creating each of both backbones is shown in the figure 4.

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 4: the proposed algorithm for constructing a backbone

But what is the order of using backbones to divide energy consumption between them in a justice manner? The proposed method is that the average of the remaining energy for each backbone can be a good criterion to change active backbone. In the other words, the probability of changing backbone can be computed with dividing average of the remaining

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energy of the nodes that are active backbone's members by average of the remaining energy of the nodes that are passive backbone members (Relation 4).

$$P_{switch} = 1 - \frac{E_{avg-activebackbone}}{E_{avg-Passive\ backbone}} \quad (4)$$

In this relation, P_{switch} indicates changing backbone probability and $E_{avg\text{-}active\ backbone}$ indicates average of the remaining energy of the nodes that are active backbone members and $E_{avg\text{-}passive\ backbone}$ indicates average of the remaining energy of the nodes that are passive backbone members. The purpose of the active backbone is the backbone that is being used in current time slot and as a result the other one is passive backbone. The relation (4) shows that by remaining energy of the active backbone is reduced, changing backbone probability is increased simultaneity. Value of the P_{switch} is calculated by sink at the end of each time slot. After this calculation, the sink by probability of P_{switch} decides to change the backbone. If the sink wants to change the active backbone, it broadcasts a message and announces this change to all nodes.

Also, one separated field is assigned at the end of data packet for storing the value of the remaining energy so that each member of backbone adds value of its own remaining energy with this field's value when it wants to transmit the packet toward its parent. Similarly, the second field is assigned for counting the nodes that are member of the backbone and each member increases it by 1 while transmitting the packet toward its parent. Finally after considering both fields in the received packet by the sink, it can calculate average of remaining energy for all member of backbone easily.

5. Simulation Results

In this section we want to evaluate proposed approach. For this purpose we have prepared the conditions of a WSN that is described in [13] by using MATLAB software. These conditions have been shown in table 1. This sample network includes 100 to 500

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sensor nodes and the size of control packet is 100 bit with same structures that have been distributed uniformly 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	**100**
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)**

The simulation has been repeated 10000 times in the same condition and the results have been shown in figure 5. As you can see, our proposed approach has been compared with Guha algorithm for α= 0.05 and the horizontal axis indicates time slots and the vertical axis indicates number of alive nodes. In this comparison the network lifetime is calculated until the first death of a backbone's node occurs, because the first death disturbs the use of the backbone. It's clear that proposed approach has been more successful than the Guha algorithm.

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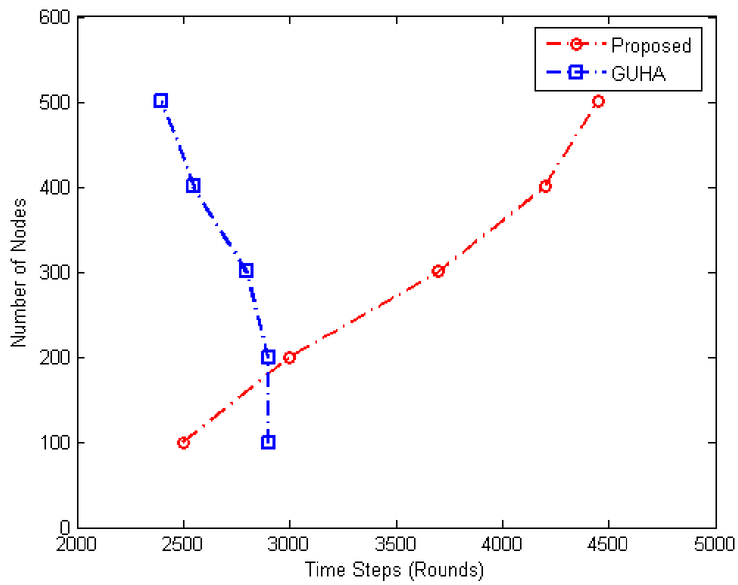

Figure 5: Comparing time of death of the first node in the proposed and Guha methods (control packet size=100)

This simulation has been implemented in several networks with control packets of length 200, 300, 400 and 500 bit. The simulation results in figures 6, 7, 8, 9 shows that our proposed method has got better efficiency in networks with high density. Because with increasing density of the network in Guha method, first death for the node happen very fast while in proposed approach this first death happen with delay.

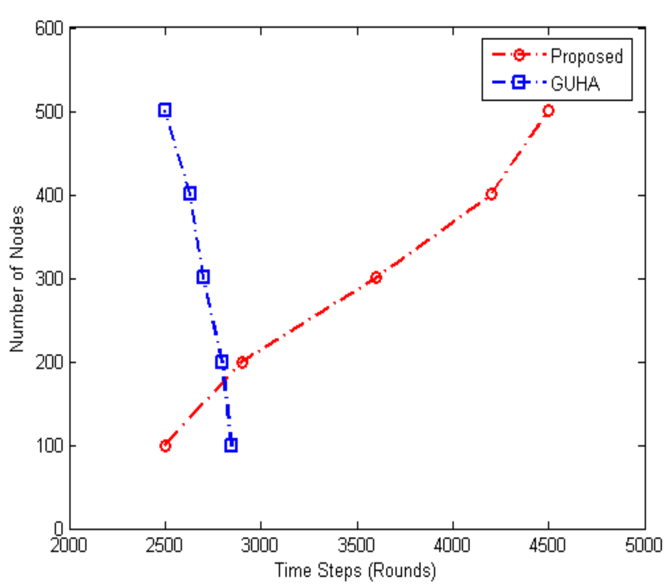

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Figure 6: comparing time of death of the first node in the proposed and Guha methods (control packet size=200)

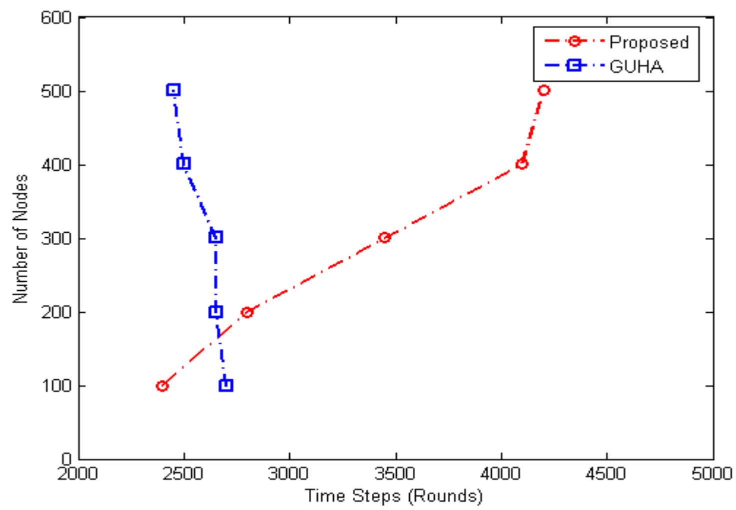

Figure 7: Comparing time of death of the first node in the proposed and Guha methods (control packet size=300)

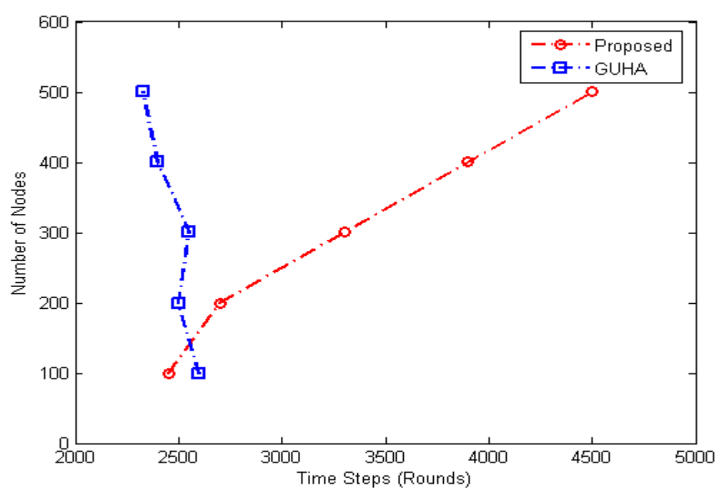

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Figure 8: Comparing time of death of the first node in the proposed and Guha methods (control packet size=400)

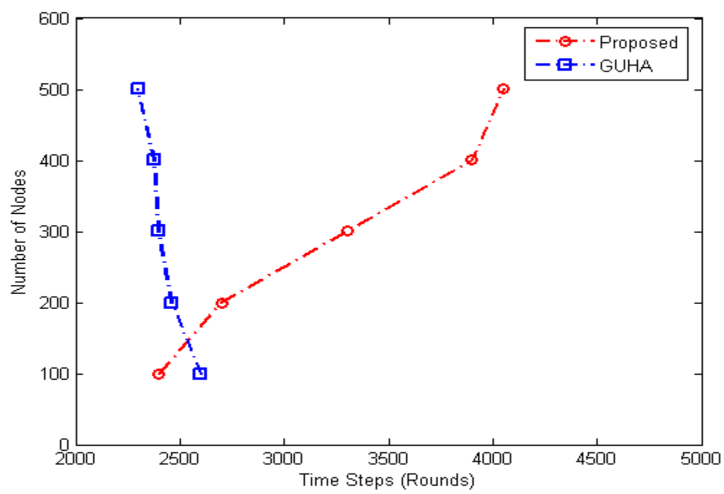

Figure 9: Comparing time of death of the first node in the proposed and Guha methods (control packet size=500)

Conclusion and Future Work

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Increasing lifetime is one of the most important issues in the sensor network area and many researchers have a good attention to it. By the use of clustering and virtual backbone concepts, many approaches have been proposed to increase the lifetime of sensor networks. In this paper, we tried to use two virtual backbones periodically to decrease energy consumption in wireless sensor networks. we use these two virtual backbones to prevent centralized consuming energy in a few nodes and to prevent untimely death for them. Our proposed method for creating the backbone designed in the way that it keeps the connectivity of the network and decreases the consumed energy in communication between backbone's nodes simultaneity. The simulation result has shown the improvement of our proposed approach. Also the use of more than two backbones can be studied.

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