Probabilistic Selection of Cluster-head based on the nearest possible Distance of Cluster-head

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Abstract

In recent years using wireless sensor networks (WSNs) in applications, such as disaster management and security surveillance have been increased. A lot of sensors in these applications are expected to be remotely deployed in unattended environments autonomously. To support scalability, nodes are often grouped into disjointed and mostly non-overlapping clusters. Every cluster has a leader that is known as a cluster-head (CH). The CH may be selected by the sensors in the network or pre-assigned by the network designer. These networks require effective communication protocols to be energy efficient and increase network quality. In this paper, a self-organization routing protocol for wireless sensor networks is presented by using hierarchical protocols and considering the position of CHs regarding to each other which is called "Probabilistic Selection of Cluster-head based on the Nearest possible Distance of Cluster-head". In addition to increase network lifetime, it causes to increase scalability of the network, optimal use of communication bandwidth and improve some of qualitative parameters of the sensor networks. Proposed method has little overhead control and can find appropriate CHs with local information. In this paper, simulation is done by the NS-2 simulator, and simulation results show this protocol could lead to increase environment monitoring, improve network lifetime, throughput and some qualitative sensor network parameters by improving the clustering process of all the routing protocol. WSNs that aren't considered CHs distribution (LEACH protocol here).

Key words: wireless sensor networks, clustering, network lifetime, probabilistic selection

Introduction

Wireless sensor networks are typically composed of hundreds or thousands of cheap and low power sensor nodes. Sensors are scattered randomly without following a predefined infrastructure (e.g. ad hoc manner) [1-3]. These sensors are capable to collect data and transfer them to the interested nodes. There are different applications for wireless sensor networks such as disaster management, war field identification, protection of borders and hidden surveillance [4, 5].

Sensors in these applications are expected to be remotely deployed with large numbers autonomously in unattended environments. In most wireless sensor networks applications, it is possible to have damaged nodes during distribution, sensors with short battery lifetime and non-rechargeable sensors. Thus, to provide extensive coverage and increase reliability, a high number of sensors are used. Therefore, designing algorithms that are energy-aware is a necessity. By using these algorithms, not only the total energy consumption in the network decrease, but also the energy distribute uniformly among nodes to increase network lifetime. Various routing protocols are proposed for wireless sensor networks to improve the challenges of sensors such as lack of sufficient energy, communication bandwidth, reliability, delay, etc [6, 7].

Routing protocols in wireless sensor networks based on the architectural structure can be divided into three categories: flat routing networks, hierarchy routing networks and location-based routing networks.

In flat routing networks, all nodes have the same duties. Each node can collect data and act as a router. In order to achieve energy efficiency, scalability and reducing data overhead hierarchical routing protocols divide network into groups. The hierarchical networks are an efficient method to increase network lifetime and save energy. LEACH is the most popular routing protocol based on

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clustering. In location-based routing network, nodes location information is used to compute the routing path. This information can be obtained from global positioning system (GPS) [8-10]. To increase scalability of the network, sensor nodes are often grouped in clusters. Among the members of each cluster one node is chosen as CH which locally aggregates and processes received data from sensors. CH may be selected by the sensors in the network or pre-assigned by the network designer.

Routing algorithms based on clustering aggregate data in a cluster and cause to reduce data transferred and minimize the distance between nodes and servers. Clustering is an effective method to increase network lifetime. Hierarchical protocols (based on clustering) improve the energy efficiency of the network. The most important issues in these protocols are that how clusters should be formed and how CHs should be selected to increase network lifetime and reliability also decrease the number of transferred data and delay. LEACH Protocol is a hierarchical protocol (based on clustering) which is introduced for wireless sensor networks and many of the protocols are designed based on it [11]. In this protocol, clusters are formed randomly. They are adaptive and autonomous. Transferring information from cluster members to CH and from CH to the Base Station (BS) is performed with local control. There is no need to an external agent or a particular node in the network for data transmission. LEACH like other clustering protocols aggregates data in each cluster and transmits them to BS. Thus, the number of sending and receiving in the network are decreased.

An important point in designing wireless sensor networks is to balance energy among nodes. One of the main factors that causes imbalance in energy level of nodes is selection of CHs in positions which is not useful. Clustering-based protocols such as LEACH, TEEN, APTEEN and PEGASIS use central control methods to avoid creating large differences in energy level between nodes which makes impose high latency to network and violation of network scalability or don't consider the effect of the distance parameter (distribution of CHs) in energy level difference of sensors [11-15]. Designing energy efficiency routing protocols is required to maintain scalability and energy balance between energy levels in different nodes to increase network lifetime. These protocols must reduce the total energy consumption of the network and cause to distribute energy between the nodes to avoid creation of dead areas.

The method presented in this paper is a random and distributed algorithm which uses hierarchical protocols and considers the location of CHs relative to each other in clustering mechanism. It is a self - organization hierarchical routing protocol for wireless sensor networks and in addition to increase network lifetime, it causes to increase scalability of the network, optimal use of communication bandwidth and improve some of qualitative parameters of the sensor networks. Furthermore, it aggregates collected data in the cluster by sensors so it decreases a number of relayed packets.

The paper is organized as follows. Section 2 survey related work, in section 3 gives sensor network model and formulates the proposed protocol, presents the protocol in section 4.

Section 5 shows the performance of this protocol and provides extensive simulation experiments for evaluating protocol and validating the analysis. Finally, section 6 gives concluding remarks.

1. RELATED WORK

In this section, LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol is generally introduced. LEACH is one of the first hierarchical routing protocols for WSNs. LEACH protocol is the base of the most hierarchical routing protocols. In this protocol, time is divided into parts called round. Each round includes two phases. The first phase is called setup phase which is the cluster formation phase and the second phase is related to the normal operation of the network and is called the steady-state phase.

In the first phase, CHs are selected. In each round a random number is assigned to any node between zero and one. This number is compared with threshold $T(i)$. If this number be smaller than $T(i)$, the node will be selected as CH during the round. r is the number of current round. G is the set of nodes have not been chosen as CH in previous rounds. n is the number of network nodes. k is the average number of CHs in each round [11, 12].

$$f(x)=\begin{cases}\frac{k}{n-k*\left(r \bmod \frac{n}{k}\right)} & if\ i\in G\\ 0 & otherwise\end{cases} \qquad (2.1)$$

2. Sensor Network Model

2.1. System Model

Wireless sensor network that is considered in this paper is homogeneous and has similar nodes. It is assumed that all sensors have the same energy. Moreover, the position of nodes can be obtained by GPS or each sensor can estimate the relative location information to nearby nodes by using signal strength, time delay in direct communication or detecting the relative distance and angle [16-18]. Nodes decide themselves and in order to coordinate activities, they do not need any infrastructure or BS. This protocol is assumed that all nodes are static and have the same level of transmission power, so they have the same transmission range. The communication area is assumed to be error-free. Thus, there is no data resend in sensors. MAC layer protocols such as DSSS, CSMA and TDMA are used for scheduling and preventing collision.

2.2. Definitions and Notations

Sensor networks can be modeled as $G=(E,V)$ graph, so that sensors form the graph vertices $V=\{x_1, x_2, \dots, x_n\}$ the connection between two nodes is an edge of the graph $E=\{(x_i, x_j)\}$, $1\le i\le n$, $1\le j\le n$. (n is a number of nodes in network).

- $|e|$ is the length of an edge, $e=(x_i, x_j)\in E$ and it is equal to the Euclidean distance from x_i to x_j, $|e|=|x_i-x_j|$.
- Network size (n) is a number of nodes are deployed in area, $n=|V|$. Because the area is fixed the changes in network size cause the change of network density $\mu={n}/{l^2}$. (The area is a square with the length side of l)
- k_{opt} is an optimum number of clusters in the network.
- Cluster radius(R) is the largest radius of a cluster and it can be the maximum possible distance between each node in the cluster and its CH(the cluster is a circle with area πR^2).
- Probability of getting cluster-head $(p(CH))$: The probability for a node to get CH. The average number of CHs is $np(CH)$. By increasing p, the number of cluster would be increased too.
- Overlapping clusters (o $|area_{ch_i}-area_{ch_j}|$) is the share area between clusters.

2.3. Problem Formulation

G graph defined in the previous section shows the sensor network. The method presented in this paper is modeled as a graph $M=(V_{CH},E_{CH})$. M graph is a subset of G graph($M\subset G$).

Vertices or nodes in the M graph can have different levels of transmission power between $P_{min}\le P\le P_{max}$. In this protocol, it is assumed that initially all nodes have the same power level. Vertices set of M graph is equal to CHs and candidate nodes(nodes which are being examined in order to become CH), $V_{CH}=\{ch_1, ch_2, \dots, ch_i, \dots, ch_n\}$.

Edge set of M graph is equal to the Euclidean distance from ch_i to ch_j, $|E_{CH}|=|ch_i-ch_j|$.

The aim of this paper is an efficient method for optimal distribution of CHs in the area. In this method, each CH is selected as it wasn't located in the forbidden area of the other clusters.

The Forbidden area of a cluster is an area that if the other CHs locate in it, it will lead to congest and interfere between data signals and sends useless data to the interested node. Moreover, it makes the qualitative parameters of the sensor networks such as lifetime and reliability decrease. Determining the forbidden area of clusters to select CH is complex and it requires global information.

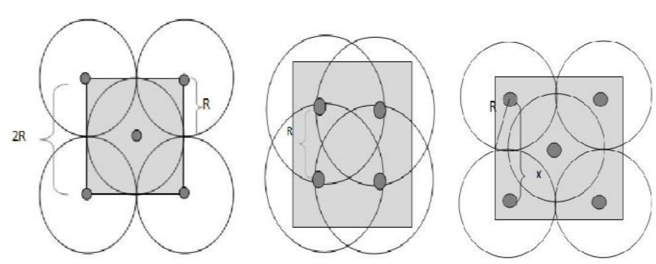


Figure 1: The nodes are deployed in square area with side length of 1. The gray circles are CHs. *R* is the largest radius of the cluster,(a) shows the maximum distance between CHs. (b) shows the minimum distance between CHs. (c) CHs can be selected in the range of (*R, 2R*) to cover the total square area with 5 CHs.

For example in figure 1 CHs must be selected in special position of square area with side length of 1. As they don't locate in forbidden area of other cluster and cover total square area with minimum overlapping between them.
In figure 1(a), 5 CHs are selected to cover total area in the vertex and center of the square area but there is overlapping between clusters. To decrease overlapping, 4 CHs are selected in the vertex of the square but there are some uncovered areas. So CHs are selected inside the square along the diagonal to cover the total area, figure 1(b). Overlapping in figure 1 (b) is increased more than figure 1 (a). So in figure 1 (a), CHs are selected by decreasing the range of clusters and putting them in the square along the diagonal as in figure 1 (c). In this figure, the distance between two CHs is assumed *x*.
The maximum distance between CHs with no overlapping between clusters is *2R* and the minimum distance between CHs is *R*.

$$x = |ch_i - ch_j|$$
$$d_{maxCH} = 2R \quad \Longrightarrow \quad R \le x \le 2R$$
$$d_{minCH} = R$$

$$if\ x > 2R\ then\quad o\ \left|area_{ch_i} - area_{ch_j}\right| = 0$$
$$if\ x < 2R\ then\quad o\ \left|area_{ch_i} - area_{ch_j}\right| \neq 0$$

In formula (3.3.1) the selection range of CHs based on different value of R can be choosen as clusters have the minimum overlapping and the maximum covering.

$$R^2 = y^2 + \frac{x^2}{4}$$
$$\Rightarrow y^2 = R^2 - \frac{x^2}{4} \Rightarrow y = \sqrt{R^2 - \frac{x^2}{4}}$$
$$2R + 2y \ge 1 \Rightarrow 2R + 2\sqrt{R^2 - \frac{x^2}{4}} \ge 1 \qquad (3.3.1)$$

So in square area without any obstacle with same CHs(equal radius) there are lots of calculations for finding the distance between CHs. Thus, PSCDN protocol suggests the probable function, formula (3.3.2) that it doesn't need many calculations.

$$p_i(t) = \begin{cases} \left(\frac{k}{n - k \times \left(r \bmod \frac{n}{k}\right)}\right) * \left(\frac{min_{j\in V_{CH}} dist(i,j)}{dist_{max}}\right)^a & C_i(t) = 1 \\ 0 & C_i(t) = 0 \end{cases} \qquad (3.3.2))$$

$$d_{max} = \sqrt{(x_B - x_A)^2 - (Y_B - Y_A)^2} \qquad (3.3.3)$$

$$d_{min} = min_{j\in V_{CH}} dist(i,j) \qquad (3.3.4)$$

$r \bmod {}^{n}/_{k}$ is a number of nodes have been selected as CHs previously. A number of nodes were CHs in all previous k clusters and a number of nodes weren't CHs is $k \times (r \bmod {}^{n}/_{k})$ and $(n - k \times (r \bmod {}^{n}/_{k}))$ respectively.
If node i is CH in $r \bmod {}^{n}/_{k}$ it will be $C_i(t) = 0$. If the node isn't CH previously, it will be $C_i(t) = 1$. After ${}^{n}/_{k}$ round expected all nodes have been role of CH once. a parameter is the positive real number ($\Re^+$).
which is based on analysis and simulations $0 \le a \le 0.5$. It indicates the extent of intention of selecting CH based on distance. Distance parameter is inefficient in selecting CH when a is equal with zero and vice-versa.

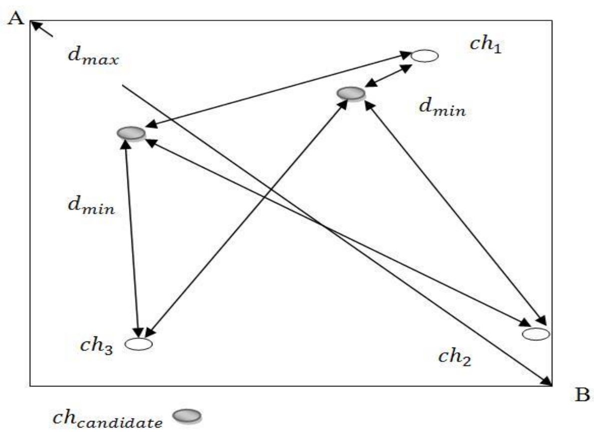


Figure 2: *dist*$dist_{max}$ is the maximum possible Euclidean distance between two nodes in the network. d_{min} is the minimum distance among candidate CH node and the existent CH nodes in that round.

The maximum possible Euclidean distance between two nodes in the network is $dist_{max}$. (In the rectangle or square area, the diagonal is as $dist_{max}$). d_{min} is the minimum distance among candidate CH node and the existent CH nodes in that round.
In figure 2, it is assumed that the nodes A and B with the coordinates of (X_A, Y_A) , and (X_B, Y_B), respectively have the maximum Euclidean distance to each other and locate in the two sides of diagonal of square area with side length of l .

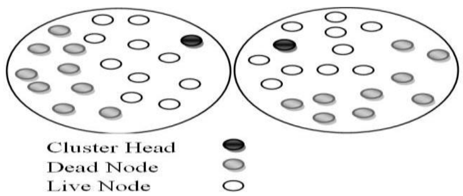


Figure 3: The network is divided into dead area and living area. Dead areas include dead nodes. Live areas include live nodes.

3. Overview of the Proposed Protocol

3.1. Necessity of Introducing Protocol

In most clustering protocols the difference between consumed energy base on role of nodes and distance each other aren't considered, while CHs use more energy than non-CHs and on the base of radio energy model, energy dissipation depends on the distance between transmitter and receiver [19]. Consequently, required energy of a CH which is highly distant from its cluster's nodes might be too much to communicate while a CH which is closer to its cluster's nodes has more chances to communicate with the same amount of energy. So after several rounds of network performance, there are large differences between energy levels of close nodes and far nodes from CH. If all nodes start work with the same energy level, the energy of far nodes will run out earlier than near nodes, thus the network is divided into dead areas (areas of the network not being monitored due to premature death of nodes) and alive areas, so the network doesn't work properly. This is shown in figure 3.

The quality in each network has its own definition. It is depended on the application and data type. A method of determining the quality is measurement of the amount of data received in the BS (a number of real data signals). The more the BS receives data, the more precise its control will be. If all nodes of a cluster sense the same event, the real data and the effective data (data resulted from combination of real data) are the same. The quality reduction would not happen for the network with transmission of effective data. On the other hand, if the nodes of a cluster sense different events, CHs will select the strongest event (the strongest signal among the received signals) and send it to the BS. In this case, because of transforming different signals into a representative signal, the network will have quality loss. Due to the characteristic of radio signals, transmission of signals is with quality loss, because the signal transmission depends on the factors such as the signal nature, the distance between the event, the sensor node and sensitivity of sensor. If the distance between nodes in a cluster is less than the distance of events, or if the distance between events is large, the probability that nodes of a cluster will sense the same event is high. Thus, if the CHs locate in a proper distance from each other, it will cause a more optimal network quality. The method presented in this paper uses previous works in clustering based protocol with adaptive clusters, so that in clustering politics, the location of CHs relative to each other is considered.

Proposed protocol considering this parameter causes a fair distribution of CHs among network nodes. The main idea of this protocol is that CHs are selected in the position of the network to ensure that there won't be a large difference between energy levels of a close node and a far node. P SCND protocol leads to distribute uniformly the energy consumption among network nodes in comparison to other clustering protocol like LEACH. So it increases the energy efficiency and the network scalability with network lifetime.

3.2. Assumptions

The assumption used to model proposed protocol is the same as those used in LEACH that includes:

- All nodes are the same and have the same homogeneous energy.
- All network nodes have the required energy to directly communicate with other nodes in the network even with the BS and to be able to perform signal processing to combine data.
- Symmetric radio communication model (energy required for transmission of a message from node (a) to node (b) exactly equals the energy needed to transmit a message from node (b) to node (a).
- Nodes always have data to send to the BS and neighboring nodes have correlated data.
- Nodes are always synchronized.
- The BS is a node with a high initial energy.

3.3. Cluster formation on Proposed protocol

In this protocol, time is divided into equal length parts called round. Each round includes two phases. The first phase is called setup phase which is the cluster formation phase and the second phase is called the steady-state phase.

The normal operations in the network and data transfer are done in the second phase. This phase is composed of some timing frame in which the member of cluster send their data to CH, so CH transfer data to the BS at the end of the frame. setup phase selects CHs based on the probable function, formula (3.3.2).

To select CHs in each round the candidate node compares its position to the all CH. The ratio of the minimum distance between CHs and candidate node to the possible maximum distance between nodes is calculated by formulas (3.3.3), (3.3.4).

The effect of distance to select CH in This protocol is by parameter. If is equal to zero, the distance parameter will not be effective and vice-versa. Figure (2) shows how CH is selected.

For $ch_{candidate}$ gets the role of CH it should compute the minimum distance ($d_{\min}$) between $ch_{candidate}$ and other CHs in the same round by formula (3.3.4) and the maximum distance possible ($d_{\max}$) between two networks by formula (3.3.3). By formula (3.3.2) the probability of selection of $ch_{candidate}$ is compute (the amount of a parameter is already designated) and it is compared to the random number which is designated to $ch_{candidate}$. If the number is less than $p_i(t)$, it will get the role of CH in that round.

The clusters are made in this protocol without any external agent or special node in the network so it causes to be scalability.

The formula (3.3.2) cause following notes in protocol:

- The Nodes which recently were not CH get the role of CH in the next round, because in comparison to the recently CHs (which consume high energy, have more energy) these nodes have more energy.
- In average, each node at the end of $n/_{kopt}$ round becomes CH one time.
- The proper distribution of CHs in network cause to distribute the energy in the network. (It prevents to locate CH in the closest distance from each other).

3.4. Self-configuring cluster formation

When the nodes have selected themselves to be CHs using the formula (3.3.2), the CH nodes must let the other nodes in the network to know them. To do this, each CH node broadcasts an advertisement message using (CSMA) MAC protocol in the entire network [11].

Each non-CH node determines to which cluster it belongs by choosing the CH that requires the minimum communication energy, based on the received signal strength of the advertisement from each CH. When each node has decided to which cluster it belongs, it must inform the CH node that it will be a member of that cluster. Each node transmits a join-request message to the chosen CH using (CSMA) MAC protocol. The CHs in this protocol act as a local control center to coordinate the data transmissions in their clusters. The CH node sets up a TDMA schedule and transmits this schedule to the nodes in the cluster. As the set-up phase is completed, the steady-state operation can begin. Steady-state phase of this protocol is the same as LEACH. In spite of CHs is distributed better.

In this phase if CHs node relative position doesn't consider, it may non-CHs need to a high transmission power in order to transmit larger data message far from CH. Since sending power has reverse relation with square of the distance of sender and receiver, the more distance between sender and receiver, the more decrease the reliability of the network for sending data without error.

4. Analysis

In this section, performance of protocol is evaluated by simulation. It is assumed that sensors are uniformly deployed in a square area side length of l. The maximum radius of cluster is R. In addition, all sensors initially have the same energy. The sensor network is homogeneous. Simulation environment of this clustering algorithm has been implemented by using NS-2. Nodes are spread uniformly over a square area of 100×100 unit area. Experiment for each scenario is repeated 20 times. All experiments are done on different topologies with different amounts of α ($\Re^+$). A number of network nodes are in the range 50 to 200. Each packet size is 500 bytes. Five percent of the nodes in the network accept the role of CH (there is no guarantee for the number of CHs). Consumption energy of Eelec and εamp is 50 nJ/bit and 0.0013pJ/bit/m4 respectively. BS is in (50,175).

4.1. Performance Metrics

- The effect of α parameter and n parameter on the network lifetime and the amount of data transferred to the BS.

The quality in each network has its own definition. It is depended on the applications and data type. A method of determining the quality is measurement of the amount of data received in the BS (a number of real data signals). The more the BS receives data, the more precise its control will be.

Network lifetime is also one of the quality parameters of the network. Based on the applications, there are different definitions in different networks [20, 21].

In this scenario the network lifetime is equal to the minimum number of alive nodes required to continue its activities.

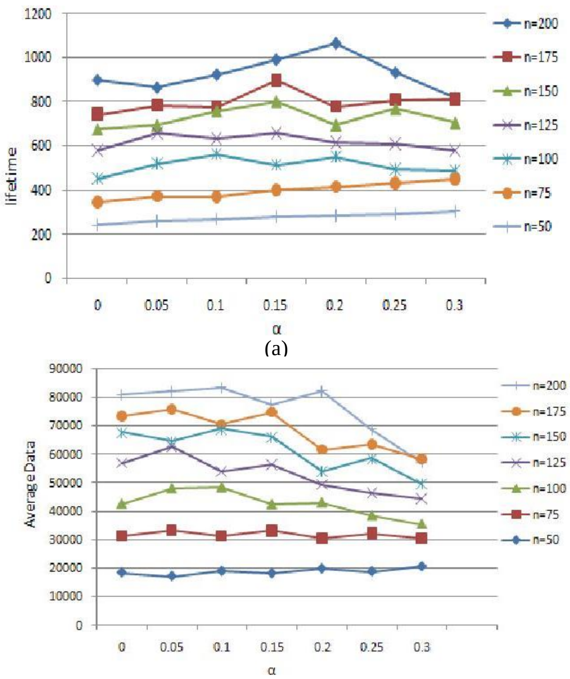


Figure 4: (a) Network lifetime when α and n are different. (b) The average packet received at the BS when α and n are different.

Figures 4(a), (b) show that for different *n* and *α*, the network lifetime and transferred data to the BS are different.

Each diagram has a maximum value that shows the effect of *α* parameter in the clustering process on the qualitative parameters of network.

One may conclude that to improve the network lifetime and the amount of data transferred to the BS, *α* parameter partly have to increase and on the other hand, the value of the *α* parameter is dependent to the number of network nodes. Obviously, these are probable values and more repeats may be needed.

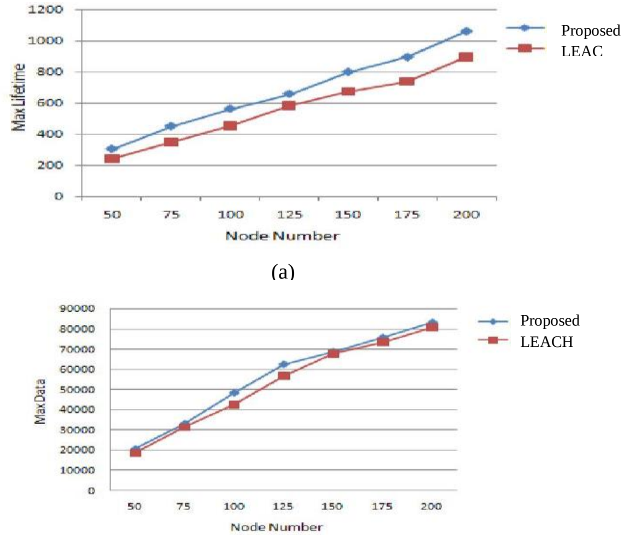


Figure 5: (a) The maximum network lifetime for different *n* (b) The maximum transferred data to BS for different *n*

Figures 5(a), (b) show that by increasing a number of network nodes, the amount of transferred data to the BS and also the network lifetime of proposed protocol would be increased compared to LEACH protocol. In the other words, in this protocol proper distribution of CHs in denser network caused to improve performance.

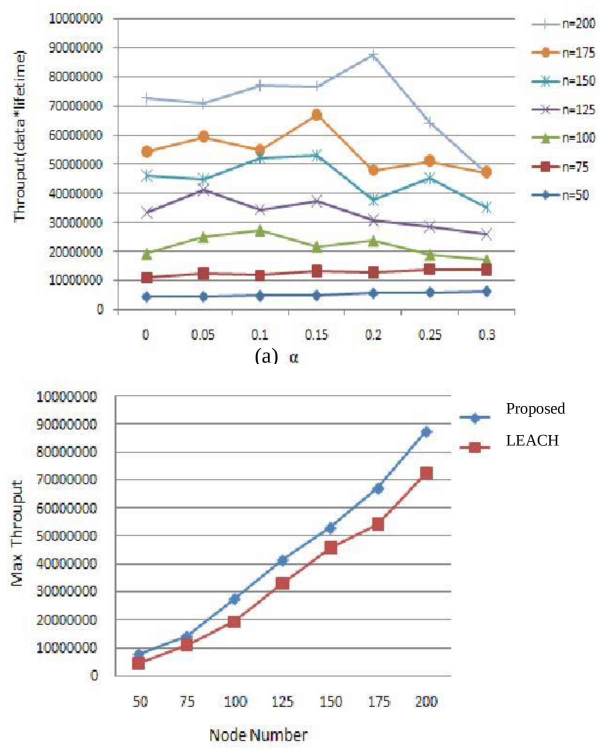


Figure 6: (a) network throughput for different n and *α* (b) The maximum network throughput for different *n*.

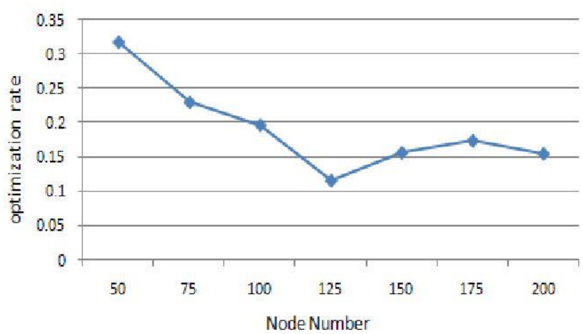
- The impact of throughput of proposed protocol.

The network throughput or digital bandwidth consumption is the sum of the data rates that are delivered to all terminals in a network. The throughput is usually measured data packets per second.

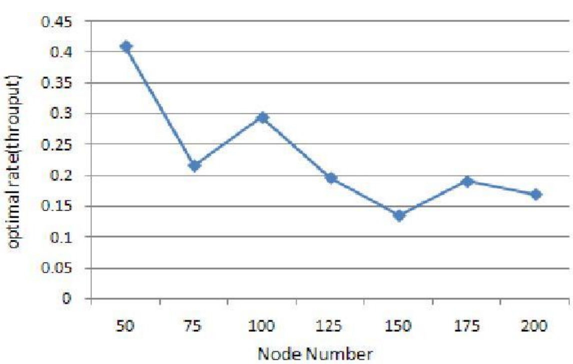
Figure 6(a) shows the effect of α parameter and the number of nodes on the network throughput, and it has a maximum value for different n.

As a result, to improve these quality parameters, α parameter partly have to increase and on the other hand, the value of the α parameter is dependent to the number of network nodes. Obviously, these are probable values and more repeats may be needed.

Figure 6(b) shows that by increasing the number of network nodes, network throughput would be increased. This protocol makes increasing network throughput with proper distributed CHs in high density network.



(a)



(b)

Figure 7: (a) The optimization rate of the network lifetime for different *n*. (b) The optimization rate of network throughput for different *n*.

• Effect of lifetime and throughput optimization rate on proposed protocol.

Figure 7(a) shows the optimization rate of lifetime proposed protocol in comparison with LEACH protocol by formula (5.1.1).

$$\text{MaxOptimization} = \frac{\text{lifetime}_{proposed} - \text{lifetime}_{leach}}{\text{lifetime}_{proposed}}$$

lifetime_{leach} shows the network lifetime in position that CH location is ineffective on clustering process.

$\text{lifetime}_{proposed}$ shows the best network lifetime when CH position is effective on clustering process.

Figure 7(b) shows the optimization rate of throughput this protocol in comparison with LEACH protocol by formula (5.1.2).

$$\text{MaxOptimization} = \frac{\text{throughput}_{proposed} - \text{throughput}_{leach}}{\text{throughput}_{proposed}}$$

$\text{throughput}_{leach}$ shows the network throughput in position that CH location is ineffective on clustering process.

$\text{throughput}_{proposed}$ shows the best network throughput when CH position is effective on clustering process.

Figure7(a),(b) show that this protocol the network throughput and the network lifetime in the low density networks. According to these diagrams, by increasing a number of nodes in comparison to conditions that the number of nodes in the network is low, the network optimality is reduced. As a result by sleeping inactivate nodes in denser networks, network density will decrease. It makes better optimality and energy saving in the network (sleeping sensors consume less energy) [22].

5. Conclusion

In this paper, a self-organization routing protocol for wireless sensor networks is presented by using hierarchical protocols and considering the position of CH regarding each other in clustering mechanism. Simulation results show proposed protocol could lead to increase environment monitoring, improve network lifetime, throughput and some qualitative sensor network parameters by improving the clustering process of all the routing protocol WSNs that aren't considered CH distribution (LEACH protocol here).

The optimization rate of proposed protocol in low density network is increased. As a result by sleeping inactivate nodes in denser networks, network density will decrease. It makes better optimality and energy saving in the network.

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