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An Energy Efficient Three Dimensional Coverage Method for Wireless Sensor Networks

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Abstract

Wireless Sensor Networks (WSN for short) almost always try to receive the information of the region in which the wireless sensors are dispersed. This kind of information aggregation is known as coverage in WSNs. Lots of coverage methods have been proposed till now that attempted to focus on the two dimensional WSNs. In the real situation the heights of the dispersed nodes are not the same so it is better to say three dimensional (3D) regions are the real situations that should be considered as the WSN functional regions. So the three dimensional coverage methods are much better to be presented for 3D regions. Actually, a kind of 3D network platform can help to achieve at a 3D coverage method thus this would be needed to have a 3D clustering method to be used as the so-called platform. In this paper a three dimensional network coverage based on our recent proposed three dimensional clustering algorithms for wireless sensor networks is proposed. The clustering algorithm uses pyramid shapes to make the clusters over the network while the new proposed coverage method applies the mentioned clusters to achieve at network coverage. This presented idea will have a significant effect on network energy efficiency for 3D WSNs. Also this idea guaranties both the network full coverage and overlap avoidance over the network.

Keywords-wireless sensor network; 3D coverage; 3D clustering.

I. INTRODUCTION

Wireless Sensor Networks (WSN) consists of a huge number of sensors with energy resource limitation, dispersed in a region. The network nodes sense data from the region and send them to base station. We need a suitable coverage algorithm to get the entire region information. To achieve a suitable coverage scheme, we should select a set of nodes to cover whole the network. This action should overcome network overhead. The selection of covering nodes directly affects the network, especially in region covering. The actual environment in which the wireless network is dispersed is a three dimensional one. This means all the functions and algorithms presented for such networks should pay attention to this note.

Tries to mention some proposed clustering methods in wireless sensor networks and focuses on their differences in functioning. Also the others considered the objectives, advantages and disadvantages of the papers proposed for clustering in wireless sensor networks (Abbasi et. al., 2007). The others of this paper paid attention to the details of network coverage in wireless sensor networks. They estimated the factors should be achieved when a WSN being covered by its nodes (Attarzadeh et. al., 2009). The authors of this paper presented a greedy method to select some nodes via them the network coverage being performed. The algorithm begins by some calculations about the weigh existing between the nodes and their Neighbors, then the nearest nodes to other nodes are to be selected as the pivot nodes. The set of pivot nodes can cover all the network nodes such that each node in the network can achieve to at least k nodes of the pivot set. So full network coverage can be performed, as well. Also Jiang focused on network coverage in the same platform (Bein, 2008; Jiang et. al., 2005). The entitled paper is known as the paper who presents LEACH clustering algorithm in the wireless senor networks. LEACH attempts to find some nodes of the network as the managers of each segment of the network known as clusters. LEACH proposes a formula for cluster head selection: the nodes that never worked as cluster heads in some previous rounds can be selected for this operation (Heinzelman et. al., 2000).

Clustering is an approach in which all the network nodes are organized into some groups each one is known as a cluster. Every cluster has a cluster head which is to be chosen from among all the network nodes in different rounds of network implementation. Different clustering methods have been proposed until now (Mehrani et. al., 2011; Younis et. Al., 2010; Attarzadeh et. al., 2011) but because of implementing the network in the three dimensional areas, a three dimensional network clustering should be considered as the base and platform of network coverage methods for such networks.

After dividing the network nodes into some groups –clusters – region covering can be considered, as well. A very important note in network coverage is not to cover a single part of the area by more than one node; because this can lead extra covering which is against energy efficiency. This means overlapping should be avoided. In this paper we present a technique for this problem.

Each node just knows about sensing region of its own. The overlap areas will have negative impact on the energy factor. It is because of the possibility of repeating messages. Obviously, to avoid overlap areas clustering technique can be utilized. As noted before, clustering partitions nods into non-overlapping groups and some of the nodes can act as the representatives of the cluster members. In this way, the probability of creating overlapping message will be reduced and consequently energy consumption will be improved. Meanwhile, as any point of the region will be covered by using the minimum number of nodes, connectivity will also be satisfied. So the matter is: covering each part of the region by one and just one node to achieve at 3D full coverage.

The rest of this paper is as follows. Section 2 describes our last work in clustering the three dimensional wireless sensor networks. Section 3 explains the new 3D coverage method while evaluating the performance of the proposed algorithm is mentioned in section 4. Finally, section 5 is conclusion and a summary of the contributions of the proposed approach.

II. THE 3D CLUSTERING ALGORITHM

As mentioned before, to achieve at a 3D full coverage method, first network is to be clustered by a 3D clustering method. We use our last presented 3D clustering method (Benkič et. al., 2008) for grouping the network nodes. Now we mention this method, briefly. We introduce the different levels of our new designed network architecture considered for wireless sensor networks. The details of implementation are explained as follows: firstly the sensor nodes are dispersed in the region, randomly and without any consideration about place of nodes. Now, we organize all the senor nodes into three different groups and inform them about their duty according to their

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position in the 3D WSN. Assume some pyramids with square shape bottoms used for grouping the sensors before network configuration. It is the spatial form of the network we use in the proposed new 3D clustering architecture.

Beginning is the highest level which is considered as the *root*. This level has the lowest amount of nodes, so the most power full and most energy full node with most score is selected as the root. To calculate the score, each node calculates its distance from the center of the region considering symmetry. Thus the score of all the nodes can be calculated as well. After this calculation, each node sends its calculated score to its neighbors existing at the same level of the assumed pyramid. Mutually, every one of the sensor nodes receives the same messages from its neighbors. By comparing all the scores the node decides whether to be active or awaiting. If a node decides to be active it finds the position of its substitute node and sends it an activation message when necessary. Otherwise, the node switches to sleep mode (awaiting mode) and tries to listen to the received messages and looks for the activation message that maybe sent from its active node. The sensor nodes existing at the lower levels of the network are divided into four different and separate groups. They would be aware about their groups via the corresponding messages sent from the *root*. This kind of sensor node grouping is based on an assumed square where the root position is at a certain height of the crossing of the square diagonals. The root election operation is performed by sending two kinds of messages by sensor nodes; so two amounts of energy would be consumed by nodes:

1. The consumed energy caused by nodes when they send their scores to the neighbors existing at the same level, these messages are called public messages.
2. Consuming energy to inform lower level nodes for partitioning sensor nodes.

Each node placed at the next (third) level lets its neighbors existing at the same square bottom know about its score. This score can be calculated based on the distance from the node to the head of the square. The nodes with most scores in all the four explained groups would be elected and chosen as the cluster heads of that groups while others join to them but switch to sleep mode and await. Each Cluster head assumes itself as the manager of the cluster and also as the head of an assumed pyramid; then divides its member nodes into four groups by considering the square bottom of the pyramid. This operation decreases the energy level of the cluster head because of sending some very necessary messages, as follows:

1. The energy that each node consumes to send its score to its same group neighbors. Obviously the cluster head acts such before being chosen as cluster head.
2. The consumed energy during partitioning lower level sensor nodes; this action leads sending corresponding messages, too. At the lowest level sensor nodes evaluate their functionality sate (active or waiting) in the same manner. Now, the network starts to work.

At the phase of network functioning, the active nodes existing at the lowest levels cover the region and receive its data then after a few evaluations send the corresponding regional event messages to their cluster heads in the certain predefined time slices. If the active node's remaining energy falls below the threshold amount (this amount is the energy needed for sending two activation messages) it would be replaced by its waiting node. This leads network to be fault tolerant. "Fig. 1" shows the network form after clustering. We select the threshold energy equal to energy needed for sending two activation messages to make sure about receiving activation message which leads increasing the safety factor. Sensor replacement operation is same in all the levels.

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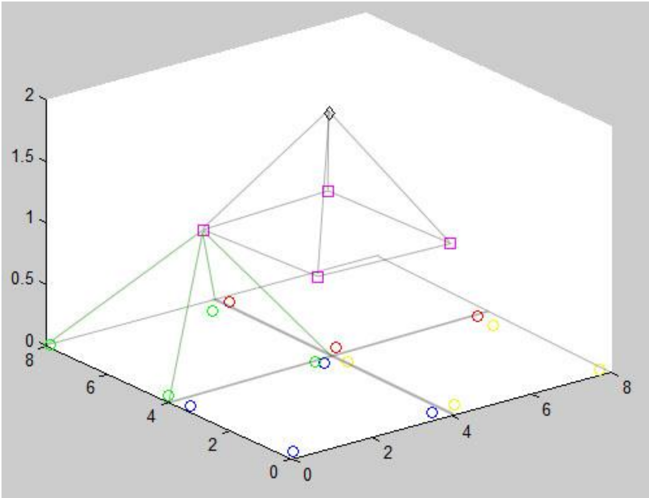

Figure 1. Network Form after Configuration

Now, we estimate three dimensional network clustering method performance. “Fig .2” shows the column chart of network lifetime for different number of sensors. As can be seen in “Fig .2”, in parallel with increasing number of network nodes, network lifetime increases. It is natural because when the number of network nodes increases then the number of substitute nodes increases, consequently. In this situation when a node dies a substitute node will

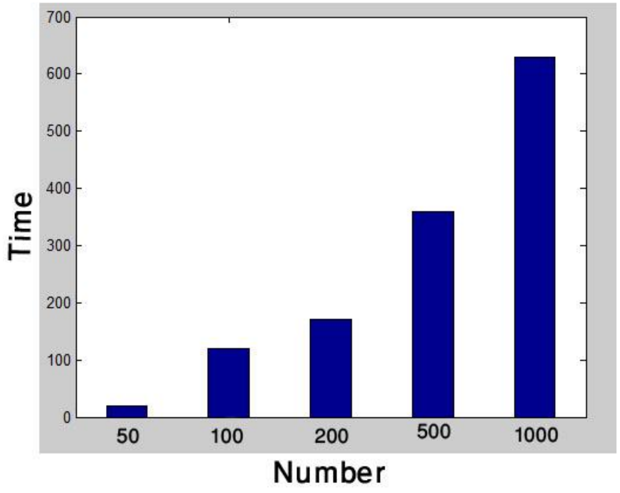

Figure 2. Network Lifetime for Different Number of Sensors

replace it quickly. The most important factor of the proposed architecture shown in “Fig .2” is that similar to raising the number of sensors, network lifetime raises, too.

III. THE ENERGY EFFICIENT 3D COVERAGE METHOD

After clustering, all the sensor nodes ate organized into some groups in different levels of the assumed pyramid. This is a good shape for three dimensional wireless sensor networks. The purpose of clustering is to help managing network functioning. Receiving the region information

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and forwarding them to the base station is the most important duty of the wireless network; meaning region coverage. As mentioned in the previous section the sensor nodes are placed in an assumed pyramid shape; thus all the parts of the pyramid have to be completely covered to achieve at network full coverage. The mentioned 3D clustering method in each level assumes a group manager plus some other active nodes existing at the square bottom of the pyramid. Now, two important factors should be considered to achieve at energy efficient full coverage in each small pyramid and consequently to achieve at energy efficient full coverage in whole the big pyramid:

1- Overlapping shouldn't happen as possible. This means just one single node is enough to cover a single piece of area; otherwise some pieces would be covered by more than one node, so the same messages will be sent for the information of that area which leads extra energy consuming by nodes and also making overhead in the network.
2- The coverage radius of all the active nodes has to be dependent to their remaining energy. This means minimum and maximum coverage radius should be denoted for active nodes.

We consider the mentioned notes to present the new energy efficient 3D coverage method. Assume the "Fig. 3" as a small pyramid in which five nodes are the router nodes: root and four other active nodes at the bottom. The problem is denoting some active nodes with different coverage radius in the small pyramid in different time slices such that whole the small pyramid is covered, completely.

In "Fig. 3" there are five nodes on the corners of the small pyramid. Also some other nodes are placed at the inner space of the pyramid. Every small pyramid should be covered; this is the duty of its nodes in different time slices. Each small pyramid should be covered so all its four different parts shown in "Fig. 3" have to be covered, completely. In the pyramid based clustered network, in normal distribution, by assuming each side of the bottom square equaling to *a*, the covering radius of active nodes would be equal to *0.25a*. This is considered as the normal coverage range of active nodes such that having bigger coverage radius leads extra energy consumption by active nodes. We pay attention to such notes in evaluating our proposed method.

A maximum sensing range (1) and also a minimum sensing range (2) would be denoted for active nodes. This also can be seen in (3). Denoting sensing range bigger than *0.35a* isn't necessary and also leads overlapping in coverage area. Furthermore, having sensing range smaller than *0.25a* leads making some uncovered holes between coverage areas.

This algorithm presents a way by which almost whole the region is to be covered completely. Moreover each node has a sensing range corresponding to its remaining energy: more energy results in a bigger sensing range and vice versa. If the energy of the node is more than a threshold it contributes in covering. Each node of the each small part of the small pyramid informs its manager about its energy. The threshold amount is according to maximum initial energy. Thus, if the energy of the node is more than this threshold (assume: threshold = 0.05*initial energy), manager decides to

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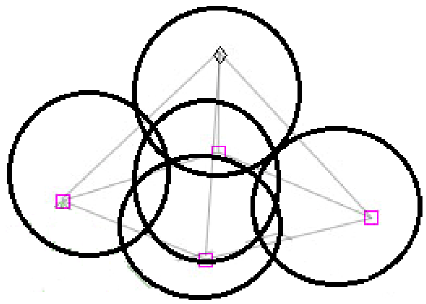

Figure 3. A Small Pyramid of the Big Pyramid

contribute it in covering by giving a sensing range between *MaxSensingR* and *MinSensingR* to that node. The manager selects covering range of every one of its member based on (4).

$$MaxSen\sin gR \quad \alpha \quad 0.35 * a \tag{1}$$

$$MinSen\sin gR \quad \alpha \quad 0.25 * a \tag{2}$$

$$MinSen\sin gR <= Sen\sin gRange <= MaxSen\sin gR \tag{3}$$

In (4), *sr*, *node.energy*, *a* and *MaxSensingR* are the sensing range of a node, the percentage of the remained energy of a node, the side length of the bottom square and the maximum sensing range of the node, respectively. According to (4) each node will be aware of its covering range. Furthermore, it gets its turn on time slice from its manager.

$$sr = \begin{cases} 0\,, & node.energy < threshold \\ \left[\max\left[\left(0.25 + 0.001 * (100 * node.energy - 5)\right) * a\,, (MinSensin\ gR)\right], \right], & O.W. \end{cases} \tag{4}$$

By using this equation if the energy of a node is less than the threshold it will have no contribution in covering and its sensing range would be equal to zero, but when a nodes' energy is more than the threshold, its sensing range will be between *0.25a* and *0.35a*. When the node has the minimum required energy for contributing in covering, its sensing range would be equal to *0.25a* and it will have a sensing range equals to *0.35a* when it is full of energy. By doing such, some active nodes may have extra energy consumption but some other may still have the normal radius coverage (*0.25a*). Also the numbers of network nodes affect the functionality of the proposed method. This means whatever the number of network nodes is bigger the chance of each node of being active will reduce so the number of sleep nodes increases and consequently the percentage of network overall energy saving will increase, too. Note that increasing the size of the network would affect the functionality of the coverage method. We consider all the mentioned notes to evaluate our work.

IV. METHOD PERFORMANCE EVALUATING

In this section the functionality of the new 3D coverage method is to be evaluated. We use some tables and charts to show the results. First, we consider the normal network implementation in which the normal coverage radius of the active nodes is equal to *0.25a* and 100, 150, 200 or

250 nodes are dispersed in a 100*100*100 region. In this case the network overall energy saving (*NES*) will be calculated by considering this note that slept nodes can save energy while active sensors may have extra energy consumption. So there are a *best case* and a *worst case* for *NES*.

Suppose *n* as the number of sensor nodes, *k* as the number of active nodes, *(n-k)* as the number of slept nodes, *NCR* the normal coverage range (which equals to *0.25a*), *OCR* the over coverage range and *OEC* as the over energy consumption of active nodes. So:

$$\mathrm{OEC} = \left(\frac{\mathrm{OCR}}{\mathrm{NCR}}\right)^2 - 1 \qquad (5)$$

$$\mathrm{NES} = \frac{n-k}{n} - \frac{k}{n} * OEC \qquad (6)$$

"Fig .4" shows the percentage of energy reduction by sensor nodes in the best and worst cases when 100, 150, 200 or 250 nodes are dispersed in a 100*100*100 area. Based on this figure, using the new proposed 3D coverage method leads between 59% to 89% energy saving for whole the network which a satisfying outcome.

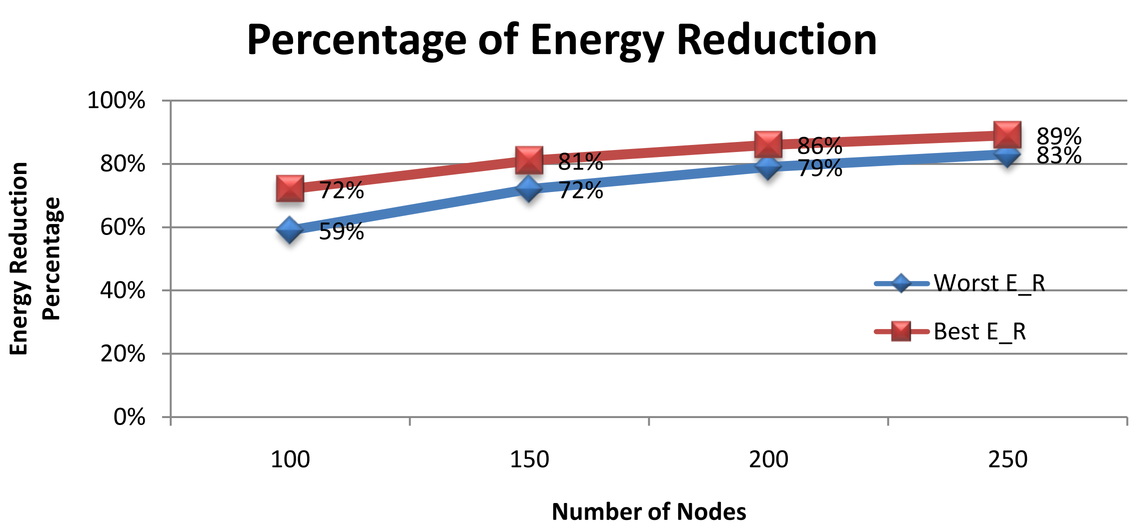

Figure 4. Percentage of Energy Reduction

By considering "Fig .1" a hidden pyramid between other five pyramids can be seen. In usual implementation of the network whole this pyramid would completely be covered by active nodes of other small pyramids. But, by increasing the size of the network the size of the mentioned hidden pyramid increases, too. To solve this problem, the coverage radius of all active nodes is assumed as *0.35a* where *a* is the length side of the bottom square. In this condition, *worst case* and *best case* are the same. Thus, the functionality of the method would be affected by two factors: *n* as the number of the sensor nodes and *a* as the length side of the bottom square. Assume *a'* as the new length side of the bottom square in resized network. So:

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$$\frac{a'}{a} = b \qquad (7)$$

In (7), *b* shows how much the network has been resized. Thus, sensing range (*sr*) and over energy consumption (*OEC*) will be dependent to *b* as follows:

$$\text{sr} = 0.35a' = 0.35ab \qquad (8)$$

$$\text{OEC}\ \alpha\ (\frac{0.35ab}{0.25a})^2 - 1 = 1.96b^2 - 1 \qquad (9)$$

Table I shows the relation between *OEC* and *b*. According to this table in parallel with increasing the network size, active nodes will have over energy consumption in comparison with usual network size. So, the functionality of the network would be affected by these changes meaning that energy saving will change.

TABLE I. RELATION BETWEEN OEC & NETWORK RESIZE

b	**OEC**
1.5	3.41
2	6.86
2.5	11.25

"Fig .5" shows the percentage of energy reduction after network resizing. In this figure sometimes the columns have negative amounts which show the negative effect of the new method that shouldn't be used. But, usually using the new three dimensional network coverage method has positive effects on the functionality of the network meaning 14% to 75% reduction in overall network energy consumption which is a very good outcome. The best condition happens when the network has 50% increasing in its size and 250 nodes are dispersed in the network;

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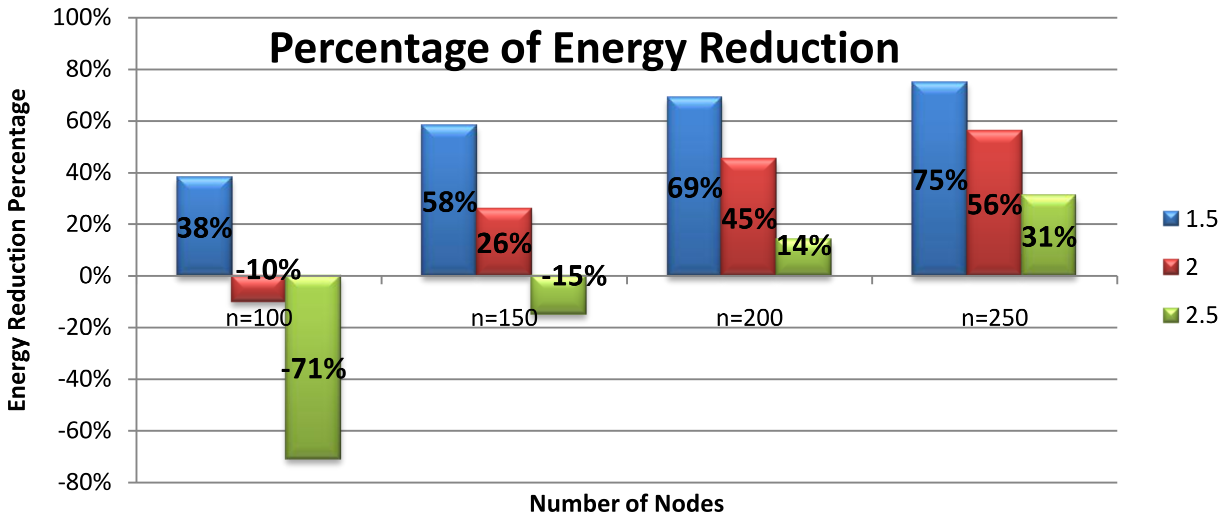

Figure 5. Energy Reduction Percentage

In this situation using the new method leads 75% energy saving for the network. As can be seen in the "Fig. 5" the proposed method may have some non positive effects in practice but this should be noted that the negative effects are also mentioned in the chart to show using the related situations should be avoided. For example when 100 nodes are dispersed in the network the factor *n* can be 1.5 to achieve at positive results (+38%) while the value 2 for *n* will harm the network's remaining energy (-10%) and also the value 2.5 for *n* will make a destructive situation for the network (-71%). Thus, the situations that make the positive effects for the network can be applied: when the number of nodes is 150, *n* can be 1.5 or 2; when the number of nodes is 200, *n* can be 1.5, 2 or 2.5; as the best state 250 nodes can be dispersed in the network and the values 1.5, 2 and 2.5 cause +75%, +56% and +31% energy reduction, respectively.

The proposed method is designed not for all the wireless sensor networks because this can be used for two dimensional wireless sensor networks: the nodes are dispersed in a region with non equal heights of surface meaning two dimensional considerations for node dispersing. In fact, proposing two dimensional ideas is close to real situation and the presented method considers this fact. Thus, as a little limitation, the method presented in this paper is used more for two dimensional regions and has a better functionality in two dimensional wireless sensor networks.

Conclusion

In this paper we presented a new three dimensional coverage algorithm for three dimensional wireless sensor networks. This algorithm is based on our new presented tree dimensional clustering algorithm. On the platform of the mentioned clustering method we focused on covering the region of the network. Full coverage and overlap avoidance are two important factors of the proposed coverage method. Each part of the small pyramids has been completely covered by active nodes while other nodes are slept and save energy until they receive activation messages from their manager in later time slices. In the usual network implementation 59% to 89% energy

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saving has been achieved by network nodes after performing new method. After changing the size of network and also changing the number of sensor nodes, the proposed coverage algorithm showed different affects: 14% to 75% energy saving by whole the network.

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