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Book 5
**Mathematics, Informatics and
Physics**

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RUSE

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BOOK 5

**"MATHEMATICS,
INFORMATICS AND
PHYSICS"**

VOLUME 8

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EXTENDING THE LIFETIME OF WIRELESS SENSOR NETWORKS BY USING A MODIFIED METHOD FOR HIERARCHICAL ORGANIZATION OF THE SYSTEM IN CLUSTERS WITH UNEQUAL NUMBER OF DEVICES

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Abstract: *Wireless sensor networks are a new type of telecommunication networks with many areas of implementation. These systems are known for their many advantages and few disadvantages. This paper investigates one of the biggest problems in this research field – the unequal energy dissipation and the unequal lifetime of the sensor motes. In order to solve this problem, first the standard approach for hierarchical organization of the networks is analyzed and then a solution for solving of this problem is proposed. Simulation models of wireless sensor networks are created using MatLAB, and the results of the evaluation of the new approach are compared to the results obtained by the standard one.*

Keywords: *Wireless sensor networks, clusters, hierarchical networks, sensor motes, cluster heads*

INTRODUCTION

Sensor networks are used in many aspects of modern life and are implemented for home automation, consumer electronics, military application, agriculture, environmental and health monitoring geophysical and weather measurement. Usually the sensor devices are small and inexpensive and can be produced and deployed in large numbers. Due to the requirements for their small size and low price, these devices are severely constrained in terms of energy resources, memory, computational speed and bandwidth. Therefore, it is important to design sensor networks aiming to maximize their life expectancy. There are many factors that can influence the lifetime of a sensor mote but the approach for organization of the network is probably the most critical one. This is why this research is focused exactly at them.

ANALYSIS OF THE STANDARD APPROACH FOR ORGANISATION OF THE CLUSTERS IN WSN

The standard approach for organization of the wireless sensor networks defines the division of the system into clusters, composed of equal number of devices. The algorithm that defines to which layer a device is belonging is presented in the next figure.

By analyzing the block scheme from Fig.1, a conclusion can be made, that when in the system is used the standard approach for hierarchical organization the first layer of the network will consist of the devices, which are in communication range of the base station. The devices of every other layer will communicate with the sensors from the previous one, but not with the devices from the layers before that (Fig.2).

After the conclusion of this process the total number of the clusters in the system can be divided by the number of the layers N_L , and thus obtaining the average number of clusters per layer:

$$(1) \quad N_{CL}^{avg} = N_{CL} / N_L$$

Assuming that the devices are distributed equally then the average number of devices for a layer can be calculated by:

$$(2) \quad n^{avg} = n / N_L$$

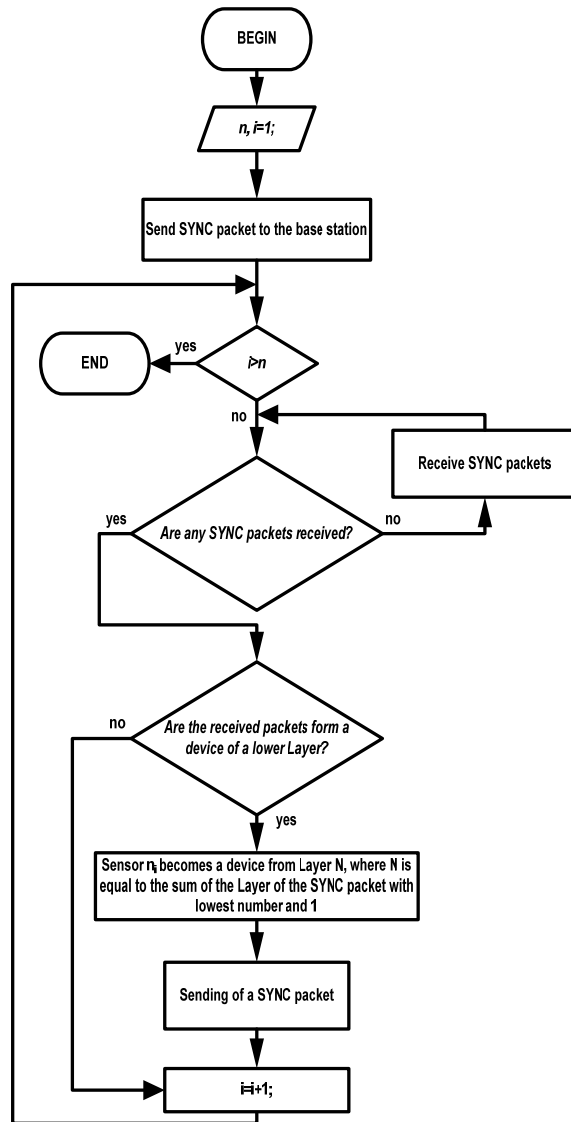


Fig.1. Block scheme of the standard approach for organization of the hierarchical WSN

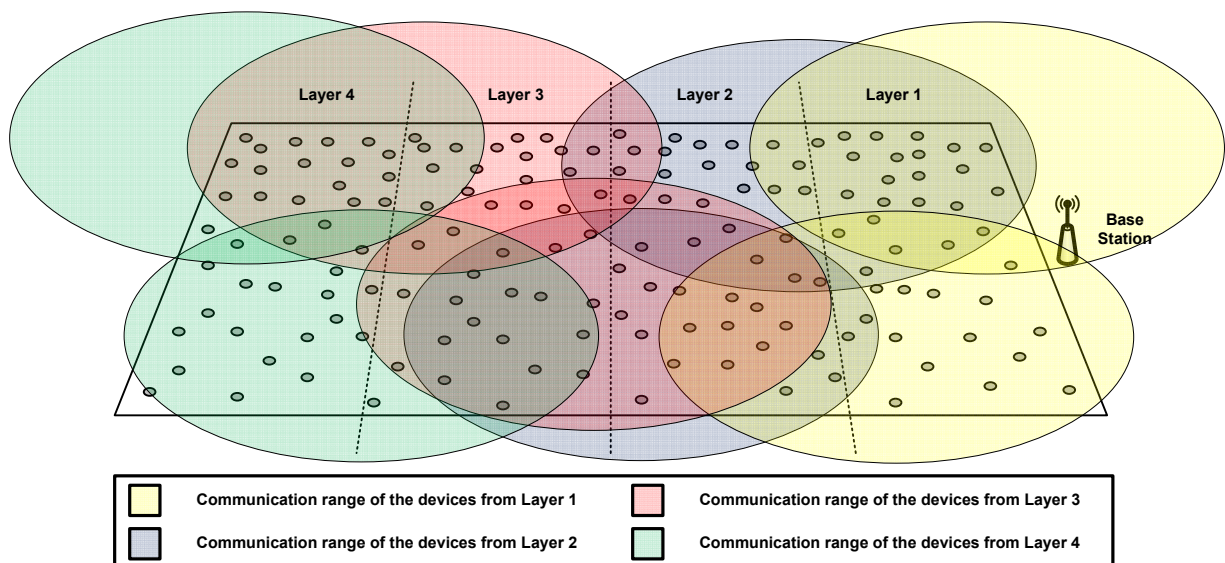


Fig.2. Organization of a hierarchical WSN using the standard approach.

After the average number of devices is determined, they are distributed equally in the corresponding clusters for every layer.

By using these rules, the possibility for a certain module from a given layer to become a cluster head can be given by:

$$(3) \quad P_{n_i}(t) \begin{cases} \frac{N_{CL}^{avg}}{n^{avg} - N_{CL}^{avg} \left(R_e \bmod \frac{n^{avg}}{N_{CL}^{avg}} \right)} & npu \quad C_{n_i}(t) = 1 \\ 0 & npu \quad C_{n_i}(t) = 0 \end{cases}$$

After the completion of the process for organization of the hierarchical wireless sensor network, the system is divided into clusters of equal number of sensor modules.

SYNTEZIS OF A ADVANCED APPROACH FOR HIERARCHICAL ORGANIZATION OF WSN IN CLUSTERS OF UNEQUAL NUMBER OF SENSOR MOTES

As discussed in the literature [1], the cluster heads are using out their energy reserves mainly for communication purposes in their own cluster and between their cluster and other clusters in the network. In the first case the amount of energy, necessary for receiving of the information is proportional to the number of devices, which are transmitting to the cluster head, while in the second case this amount can be expressed as a function of the expected amount of data, which this device is transmitting toward the base station. If it is assumed that the cluster heads can be positioned precisely in the sensor field, than by changing the size of the clusters (and by that changing also the number of the sensor nodes in the cluster) we can change the amount of energy that every cluster head is going to need for the communication processes. The implementation of this approach will lead to a situation, where for all communication rounds in a epoch the average amount of energy in the cluster heads will be almost equal and by that one of the major problems of the WSN will be solved – the early depletion of the energy of some of the network devices, and by that the reduction of the network lifetime. The main reason for this study of the parameters of the cluster heads is the fact, that these modules have the largest impact on the network performance, and the depletion of the energy of even a single cluster head can lead to the loss of data from the whole cluster under its management. To study the above mentioned parameters a WSN, which consists of n sensor nodes can be investigated. These sensor motes are equally distributed on a circle with radius of R_{SF} . The cluster heads for every layer are placed in this sensor field at an equal distance one from another. By placing them is such a matter, the coordinates of these devices will match the coordinates of points on the internally concentric circles of the given circular sensor area. The base station, which will receive the data of the sensor field, is placed in the center of the area (Fig.3). The data received by all sensors in the clusters is transmitted to the corresponding cluster head, which aggregates the information, and forwards it to the base station. The transmission of the aggregated packets is completed by forwarding the packets to the closest cluster head in direction toward the base station.

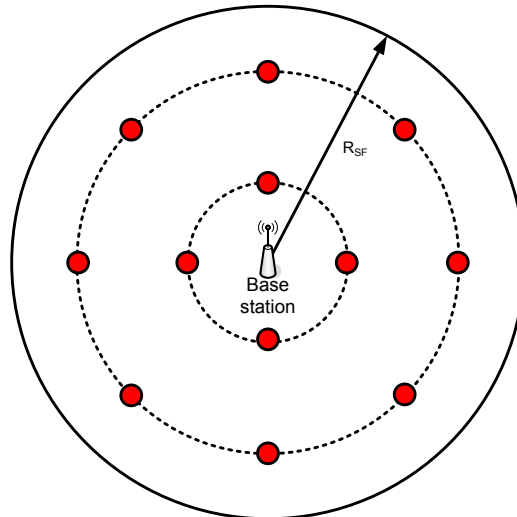


Fig.3. Deterministic distribution of the cluster heads in internally concentric circles around the base station.

Assuming the distribution of the cluster heads as shown in Fig.3, every of the clusters can be represented by a Voronoi tessellation with center the cluster head. By doing this a multilayer hierarchical structure of a sensor network can be created. Fig.4 (a) shows a two layered network, with the internal layer (Layer 1) consisting of N_{CLL1} clusters, and the external layer (Layer 2) consisting of N_{CLL2} cluster. In order to simplify the analysis of this model the Voronoi tessellations will be presented as parts of circles as shown on Fig. 4 (b).

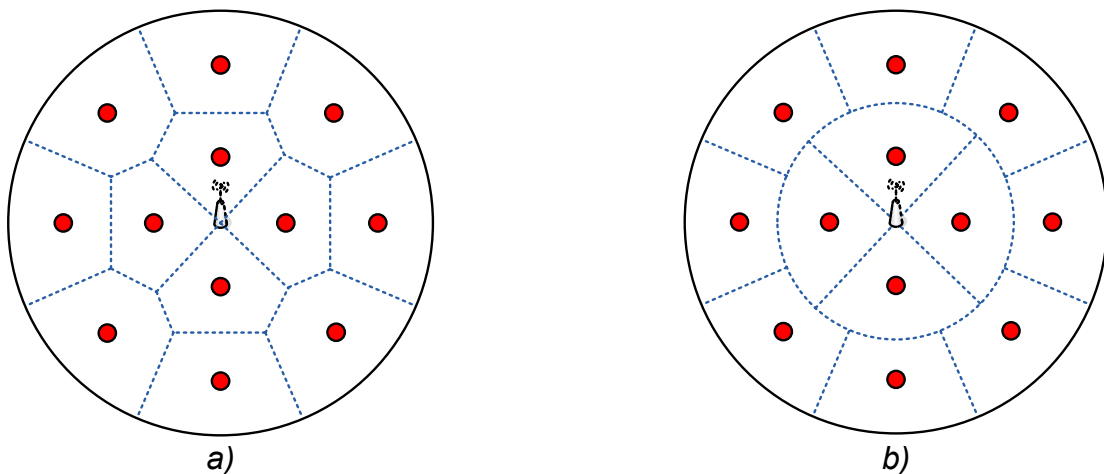


Fig.4. Wireless sensor network with the clusters represented as Voronoi tessellations (a) and parts of circles (b).

Due to the symmetrical distribution of the cluster heads in concentric circles, all clusters for a given layer will be characterized by a common shape, size and area, but will be different, compared to the clusters of the other layers like in Fig.4 (b). If R_{SFL1} is the radius of the circle, which contains the given number of clusters from the first layer of the system, then by changing this parameter the area of coverage of the circle will change, and by that the number of the sensor notes in every of the clusters will change.

If it is assumed, that all cluster heads are equally effective in the implementation of the data aggregation mechanism, and that this effectiveness is represented by the aggregation coefficient – γ , than the amount of data send to the base station by every of the cluster heads for a communication round is γn_c , where n_c is the sum of the sensor notes in the cluster and the devices sending data to the investigated cluster head, and γ is

changing the limits between 1 and $1/n_c$. This means that when $\gamma=1/n_c$, then we have a system with full aggregation of the data, and if $\gamma=1$ the cluster head is not performing any aggregation at all. By assuming the model for distribution of the information given in [2] and by using a data delivery approach with retransmission of the information as the one in [3], then the amount of energy, which is used for the transmission of a packet with the size of b bits at a distance of d meters is given by the following equation:

$$(4) \quad E_{TX} = b(E_{elect} + E_{fs}d^k).$$

The amount of energy used for the reception of a packet with the same size is given with:

$$(5) \quad E_{RX} = bE_{elect}.$$

For the studies of the approaches for organization of hierarchical wireless sensor networks is assumed the model for distribution of the information in free space, which means that the fading coefficient k is equal to 2. Additionally it is assumed that there are ideal conditions for the network (there are no transmission errors and the data overhead for system messages is not investigated).

For every cluster in the network the total amount of energy of the devices is determined by the location of the cluster head. In order to achieve constant value for the amount of energy used for every communication round in the cluster, every cluster head has to be static and not movable. In this case if it is assumed that the cluster heads are in the center of the clusters, as in Fig.4, then the distances between the cluster heads from both Layers of the system and the base station can be expressed by the following equations:

$$(6) \quad d_{CH1BS} = \frac{\int_0^{R_{SFL1}} r 2r \sin\left(\frac{\beta_1}{2}\right) dr}{R_{SFL1}^2 \frac{\beta_1}{2}} = \frac{2}{3} R_{SFL1} \frac{\sin\left(\frac{\beta_1}{2}\right)}{\frac{\beta_1}{2}}$$

$$(7) \quad d_{CH2BS} = \frac{\int_{R_{SFL1}}^{R_{SF}} r 2r \sin\left(\frac{\beta_2}{2}\right) dr}{\left(R_{SF}^2 - R_{SFL1}^2\right) \frac{\beta_2}{2}} = \frac{2}{3} \frac{R_{SF}^3 - R_{SFL1}^3}{R_{SF}^2 - R_{SFL1}^2} \frac{\sin\left(\frac{\beta_2}{2}\right)}{\frac{\beta_2}{2}}$$

where β_1 and β_2 are the angles defined by the number of clusters in every layer of the system and are equal to:

$$(8) \quad \beta_i = \frac{2\pi}{N_{CLL_i}}, i \in [1,2]$$

Analyzing the model above, one can conclude that the system is organized during the network convergence phase, and the formed clusters remain untouched for the lifetime of the WSN. Considering this, the lifetime of the network can be defined as the time interval from the beginning of the exploitation of the system till the depletion of the energy of any sensor mote. In this way the situations in which the cluster heads are depleting their energy and are having impact on the total system performance are ruled out.

The total amount of energy, necessary by the cluster heads at Layer 1 and Layer 2 for the communication processes can be obtained by using:

$$(9) \quad E_{CH1} = \left(\begin{aligned} & bE_{elect}(n_{SM_{CL1}} - 1) + \\ & bE_{DA}n_{SM_{CL1}} + \gamma bn_{SM_{CL2}} \frac{N_{CLL2}}{N_{CLL1}} E_{elect} + \\ & + b\gamma \left(n_{SM_{CL2}} \frac{N_{CLL2}}{N_{CLL1}} + n_{SM_{CL1}} \right) (E_{elect} + E_{fs}d_{CH1BS}^2) \end{aligned} \right)$$

$$(10) \quad E_{CH2} = \left(\begin{aligned} & bE_{elect}(n_{SM_{CL2}} - 1) + \\ & bE_{DA}n_{SM_{CL2}} + \\ & \gamma bn_{SM_{CL2}} (E_{elect} + E_{fs}d_{CH2CH1}^2) \end{aligned} \right)$$

where d_{CH2CH1} and d_{CH1BS} are correspondingly the distance between the cluster head at Layer 2 and its neighbor at Layer 1 and the distance between the base station and the cluster head at Layer 1. The total amount of energy used to aggregate the data is given by the parameter E_{DA} , and $n_{SM_{CL1}}$ and $n_{SM_{CL2}}$ are the numbers of the sensor nodes for the clusters in Layer 1 and 2 of the system. The last two parameters are proportional to the area covered by the clusters and can be calculated with:

$$(11) \quad n_{SM_{CL1}} = n \frac{R_{SFL1}^2}{R_{SFL2}^2 N_{CLL1}}$$

$$(12) \quad n_{SM_{CL2}} = n \frac{R_{SFL2}^2 - R_{SFL1}^2}{R_{SFL2}^2 N_{CLL2}}$$

The ratio N_{CLL2} / N_{CLL1} in (9) and (10) is used to show that the packets generated by the cluster heads at Layer 2 of the system are equally distributed among the cluster heads in Layer 1 of the network. Organization of a hierarchical WSN using the modified approach is presented on Fig. 5.

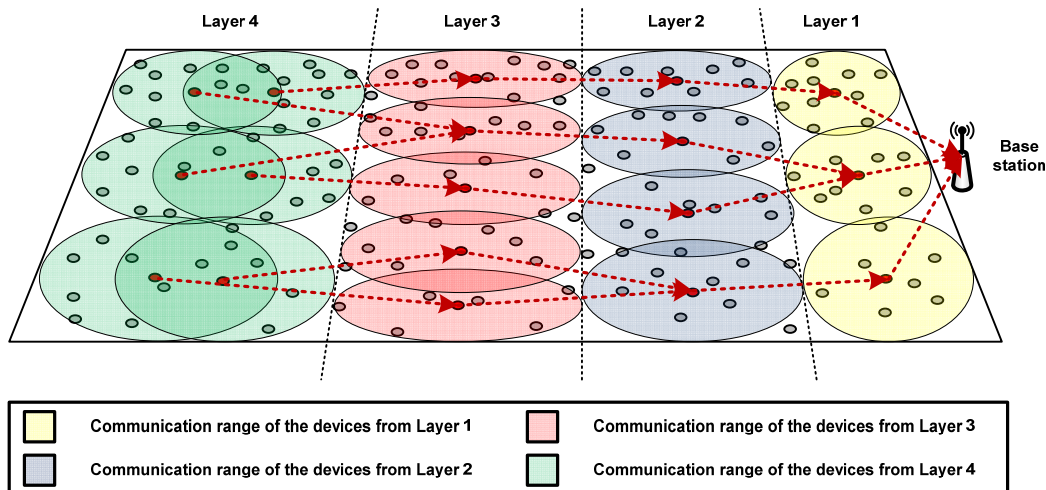


Fig.5. Organization of a hierarchical WSN using clusters with unequal number of sensor

SIMULATION EVALUATION OF THE METHODS FOR HIERARCHICAL ORGANIZATION OF WSN

In order to evaluate the consumption of energy it is necessary to study the results obtained by the simulation experiments of both approaches. For those purposes two simulation models were created using MatLab. For the simulations we assume all simulation and system parameters as in [4].

The first of the conducted simulations is done with a sensor field of 100x100 meters and with the base station at the center of this field. The initial energy of all 100 sensor devices and cluster heads is equal to 0.5 J. Results of devices the conducted simulation are shown in Fig.6.

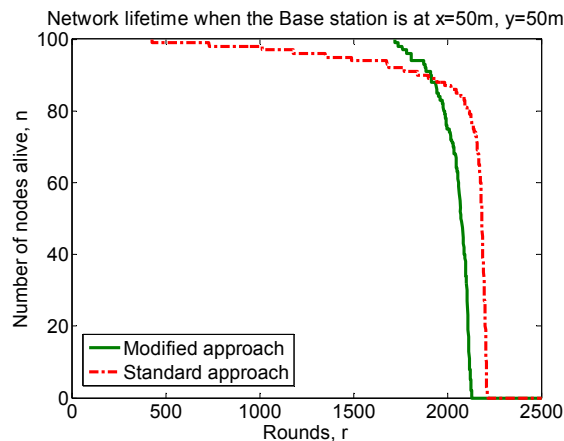


Fig.6. Network lifetime for 100 sensor nodes using both approaches

As shown in the figure the total lifetime of the modified approach is less than the one of the system with the standard approach, but the modified approach provides a longer and stable operation of the system and the first sensor node depletes its energy around the 1650 round compared to the 450 round in the system running with the standard approach.

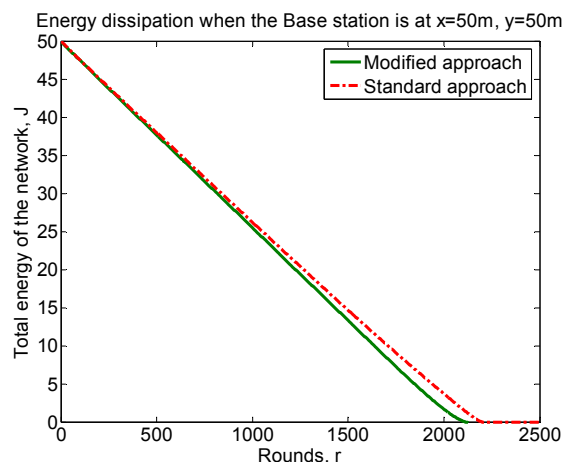


Fig.7. Organization of a hierarchical WSN using clusters with unequal number of sensor devices

Fig.7. presents the total amount of energy in the network for the systems running on both approaches. As seen from the figure the modified approach is consuming more energy than the standard approach. This is explaining the shorter total network lifetime of this approach.

CONCLUSION

From the conducted analysis and the realized simulation experiments it is obvious that the modified approach is better in terms of system lifetime. One of the directions for further improvement of this approach will be to increase the total lifetime of the systems, which use this approach by reducing the increased energy usage. Despite this the modified approach is showing significant improvement in terms of stability of the systems compared to the standard one.

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УВЕЛИЧАВАНЕ ЕКСПЛОАТАЦИОННАТА ПРОДЪЛЖИТЕЛНОСТ НА БЕЗЖИЧНИ СЕНЗОРНИ МРЕЖИ ЧРЕЗ МОДИФИЦИРАН МЕТОД ЗА ЙЕРАРХИЧНА ОРГАНИЗАЦИЯ НА СИСТЕМАТА В КЛЪСТЕРИ ОТ РАЗЛИЧЕН БРОЙ УСТРОЙСТВА

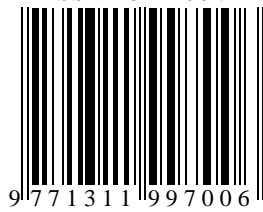
Михаил Илиев

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Резюме: Безжичните сензорни мрежи са нов тип телекомуникационни системи с много области на приложение. Тези системи са известни с многото си предимства и разнообразни приложения. В тази статия е разгледан един от най-значимите проблеми на тези мрежи – неравномерното изразходване на количеството енергия от сензорните устройства и тяхната различна експлоатационна продължителност. За да се реши този проблем, първоначално е анализиран стандартния подход за йерархична организация на мрежите, след което е предложен алтернативен вариант на този процес. Симулационните модели на безжичните сензорни мрежи са създадени с MatLAB, като резултатите от подходите са анализирани и сравнени.

Ключови думи: Безжични сензорни мрежи, клъстери, йерархични мрежи, сензорни модули, устройства за управление на клъстери.

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