

Wireless Sensor Networks with Temporary Cluster Head Nodes

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Abstract— The clustering in the Wireless Sensor Networks (WSN) is one of the most important investigation areas. There are many cluster head selection algorithms which were developed before today. These algorithms were developed to 2D and 3D spaces, WSN with fixed and mobile sensor nodes. The main goal of all of developed algorithms is the energy consumption decreasing and WSN life-time increasing. The new algorithms for clustering appeared during last time. These algorithms based on the idea of temporary cluster head using. The round length optimization and the impact of the temporary cluster head node moving on the network operation investigation in this paper.

Keywords— ubiquitous sensor networks (USN), LTE, mobile temporary cluster head node, round, round length

I. INTRODUCTION

Ubiquitous sensor networks (USN) [1,2,3] are now one of the most important trends in the development of communication networks.

USN consists of a plurality of sensor nodes capable to fix the environment conditions (temperature, humidity, atmosphere) or characteristics of the objects in it (size, speed of movement), save and analyze this information (within certain limits), and transmit it through wireless communication channels to USN data collectors.

USN can be refer to cooperative networks [4], in which the nodes help each other's in data transmission from/to the base station.

USN has a number of features that differentiate them from the traditional networks. Among these features the most important are:

a) Combining of a large number of sensor nodes. Most USN applications assume that within such networks will be merged sufficiently large number of sensor nodes, to several tens of thousands.

b) Low power consumption, limited hardware resources, small size and low cost of the sensor nodes.

USN concept assumes that the sensor nodes have a significant degree of autonomy. In most scenarios, the use of USN sensor nodes is planned to be located on the zone, where they cannot be supply, and maintenance can be difficult. Hence, each sensor node must be equipped with an autonomous power source, and, in addition, must have low power consumption, as consumed power source can be

replaced, i.e. the lifetime of the sensor node will equal to the lifetime of its power source.

This USN feature actually gives a new trend of development of the communication networks protocols - namely, the design of protocols, optimizing energy consumption of a particular sensor node, and improving the energy consumption uniformity of the network nodes in general [5,6,7].

c) Easy of deployment and self-organization. This feature is aimed at ensuring the USN possibility of penetration in all areas of human activity [8]. USN should be as easy to deploy and use, should be able to organize themselves into a network, do not require a centralized infrastructure, and quickly change its topology in case of failure of individual nodes.

In this paper we propose a solution to the problem, namely: an increase in the residual energy and the duration of the life cycle of a sensor network by passing the temporary status of the cluster head node to the LTE terminal crossing the sensor field, such as VANET node, flying sensor network drone [18] etc. It can be really effective since the energy reserve of LTE terminals, vehicle network nodes, flying sensor network drones, etc. is substantially greater than the energy of sensor nodes. At the same time taking into account the constraints on energy capabilities of sensor networks, the goal is achieved at the network level. For sensor node, this means invariance of his behavior as to whether cluster head is a node from its field or is temporarily element from another network crossing this sensor field. This task has been made possible primarily due to the widespread of ubiquitous sensor networks, as well as due to the presence of ZigBee network interface in the modern cellular networks, VANET, medical network, flying ubiquitous sensor network terminals [9,10]. Earlier studies in this area investigate a task of collecting data from sensor fields using specialized gateways, consequentially crosses a number of pre-defined sensory fields [1].

Generally, ubiquitous sensor networks are formed based on the cluster architecture [11,12]. It is also possible to construct 2D and 3D networks [13,14]. Sensor nodes can be fixed and mobile [15], in the latter case, we speak of a mobile sensor network. Since the proposed study, is the first in the research field of temporary granting of cluster head roles to transit nodes crossing the sensor field as a model we have chosen a typical model of the sensor network

with stationary nodes and clustering based on the basic LEACH algorithm [1].

II. NETWORK MODEL

The network model is similar investigated in the [16]. Poisson sensory field is completely located in the area of heterogeneous LTE network. Gateway is located in the center of the field, 500 m distant from the LTE base station. 100 sensor nodes are randomly distributed in the plane with the size of 200 by 200 meters. Sensor nodes are stationary. The range of the sensor node - 20 m, energy stored in each node - 2 J, the power consumption at the reception - 50 nJ/bit, at the transmission - 50 nJ/bit, and an additional 100 pJ/sq.m. All sensor nodes are homogeneous, i.e., have the same range and the initial energy characteristics. Sensor field is clustered. In accordance with the practice of using the LEACH algorithm, number of cluster heads predetermine as 5% of the total number of sensor nodes.

Once in 100 rounds a mobile node from other network passes the sensor field with a speed v m/s, which becomes the head node for the intersected clusters. The entry point of the node in the sensor field is random. Number of the first round for a temporary mobile head is also random. After entrance, mobile cluster head crosses sensor field parallel to the sides of a square. This mobile unit has become temporary head in the first whole round after his appearance in the sensor field. Mobile head node is considered to be moved out of the sensor field at a time when begins another round, and time until crossing the border of the sensor field is less than the duration of the round. In this case, he cannot be elected as temporary cluster head. If there is a temporary cluster head in the sensor field, the number of selectable cluster heads is reduced by one. Information, which is collected by mobile cluster head during his time as the head, is transmitted to the gateway or base station.

III. ROUND LENGTH OPTIMIZATION

A. Network Parameters and Round Length Impact

One of the main parameters that characterize the quality of USN operation is the data delivery time, which in turn depends on the network connectivity. As shown in [16] the time of data delivery decreases with the length of the round. However, reducing the round length can affect to other network parameters.

Network elements (USN nodes) perform some work on the network reconfiguration (defining new clusters) periodically with a period equal to the round length. This work is related to energy consumption. Thus, the shorter the duration of the round, the higher the frequency of the network performance and higher power consumption should be analyzed. It should also be noted that the USN node, in order to save energy it is advisable to change node mode into a low consumption mode "sleep" when USN node does not perform any action. The state of "sleep" can be changed automatically, by the timer at the end of the predetermined time period (timeout), and for

example, if there is some external event, such as a sensor node activation. Therefore, it is appropriate to combine the majority of the work done by the node, if possible, with node interval "awake". Using of clustering algorithms, such as LEACH it is necessary to determine the clustering interval i.e. round length. It is advisable to define this interval as the interval through which the sensor node becomes "active" for performing clustering functions and data transmission. Thus, the length of the round is the parameter determining the power consumption of the nodes, and consequently, the network lifetime. This parameter also impact on the delivery time if data transmission functionality is combined with network clustering on the "awake" periods.

B. Energy Consumption Minimization

To implement the reconfiguration i.e. selecting the head node at the beginning of each round, the network elements transmit and receive signaling messages. Thus a number of nodes selected as head exchange data with neighboring nodes. We assume that the average number of nodes in the cluster is

$$n_c = \pi \cdot r^2 \cdot \rho \quad (1)$$

We assume that at the beginning of each round, one message is transmitted by each head node, which is received by all the nodes of the future clusters. Then, each of the future members of the cluster, also sends one message, an request for membership in the cluster to its head node. These messages are received by head nodes. We assume that after this update, the structure of the network is ready for operation. Thus, at the beginning of each round will be spent energy:

- on the transmission of messages in the direction of the head node - cluster members

$$E_{Tx}^{(H-M)} = n \cdot \eta \cdot E_{Tx}^{(C)} \quad (2)$$

- on the receiving these messages by cluster members

$$E_{Rx}^{(M)} = \pi \cdot r^2 \cdot \rho \cdot E_{Rx}^{(C)} \quad (3)$$

- on the transmission of messages in the direction of the cluster member - the head node

$$E_{Tx}^{(M-H)} = \pi \cdot r^2 \cdot \rho \cdot E_{Tx}^{(C)} \quad (4)$$

- on the receiving these messages by cluster head nodes

$$E_{Rx}^{(H)} = \pi \cdot r^2 \cdot \rho \cdot E_{Rx}^{(C)} \quad (5)$$

where

$$E_{Tx}^{(C)} = E_{elec} \cdot k + \varepsilon_{amp} \cdot k \cdot d^2 \quad (6)$$

$$E_{Rx}^{(C)} = E_{elec} \cdot k \quad (7)$$

E_{elec} - energy consumed on the processing of the message by controller node (J);

ε_{amp} - energy consumed on transmission by node transmitter (J);

d - distance between nodes (m);

k - amount of bits in a transmitted message.

Then, the total energy required for clustering equals

$$\begin{aligned}
E_C &= E_{Tx}^{(H-M)} + E_{Rx}^{(M)} + E_{Tx}^{(M-H)} + E_{Rx}^{(H)} = \\
&= n \cdot \eta \cdot E_{Tx}^{(C)} + \pi \cdot r^2 \cdot \rho \cdot E_{Rx}^{(C)} + \\
&+ \pi \cdot r^2 \cdot \rho \cdot E_{Tx}^{(C)} + \pi \cdot r^2 \cdot \rho \cdot E_{Rx}^{(C)} = \\
&= n \cdot \eta \cdot E_{Tx}^{(C)} + \pi \cdot r^2 \cdot \rho \cdot (2 \cdot E_{Rx}^{(C)} + E_{Tx}^{(C)})
\end{aligned} \quad (8)$$

If the total initial energy equal $E_0^{(E)}$, the share of energy consumed on clustering for k rounds

$$\xi_C = \frac{E_C}{E_0^{(E)}} k \quad (9)$$

Time and energy indicators of the network are determined by the ratio of a given message delivery time value T_D , the probability α that the delivery time will not exceed a predetermined value, the duration of the round T_0 , and the share of head nodes.

We assume that the energy consumed on the transmission of useful information (payload) is constant.

$$E_I = \lambda t (E_{Tx}^{(M-H)} + E_{Rx}^{(H)} + E_{Tx}^{(H-S)}) \quad (10)$$

Total energy is

$$E_\Sigma = t \lambda (E_{Tx}^{(M-H)} + E_{Rx}^{(H)} + E_{Tx}^{(H-S)}) + \left\lceil \frac{t}{T_0} \right\rceil E_C \quad (11)$$

In the Figure 1, we can see the total network energy consumption on time.

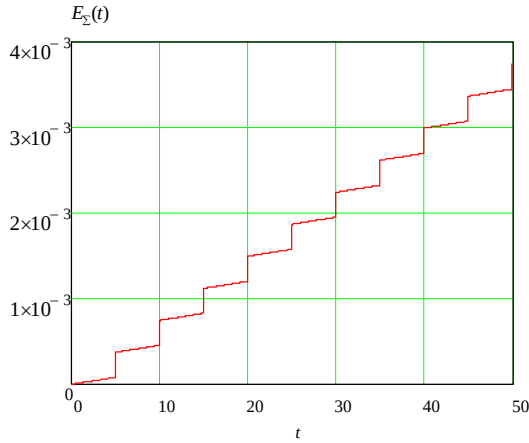


Figure 1. Total network energy consumption on time

If the energy consumed on the transmission of useful information depends only on the intensity of information messages, and may in this case be considered as a constant, then the minimum of consumed energy will be determined by the minimum of energy consumed on clustering. Then the minimum consumed energy is achieved by minimizing the value $\left\lceil \frac{t}{T_0} \right\rceil E_C$ obviously, that at a

constant value E_C , this minimum is achieved at the maximum value T_0 . By limiting the messages delivery time T_D for a given probability α is:

$$T_D = d \cdot T_0 \quad (12)$$

Where d - the number of rounds

$$\alpha = F_C \left(\frac{T_D}{T_0} < d \right) = 1 - e^{-\pi^2 \cdot \rho (\eta + \eta_M) \frac{T_D}{T_0}} \quad (13)$$

$$\min_{T_0} \left(\left\lceil \frac{t}{T_0} \right\rceil E_C \right) \quad (14)$$

for

$$T_0 \leq \frac{\pi^2 \cdot \rho (\eta + \eta_M)}{-\ln(1 - \alpha)} T_D \quad (15)$$

From (14) it is clear that the minimum of consumed energy for clustering takes place at the maximum allowable value T_0 on the expression (15).

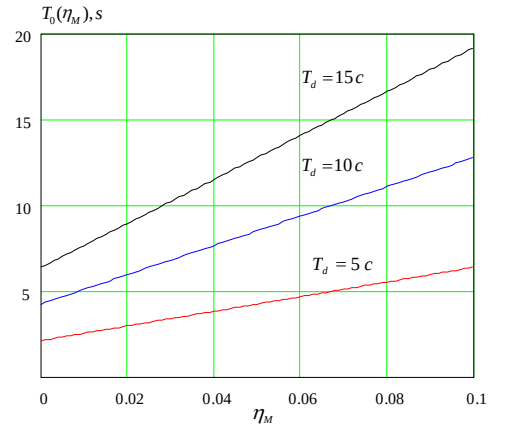


Figure 2. Dependence of the maximum round duration on the share of mobile head nodes

As seen from the Figure 2, the increase in the proportion of mobile head nodes leads to the possibility of increasing the round duration, with a given probability and message delivery time. This, in turn, reduces the amount of energy consumed for operations of clustering.

IV. ANALYSIS OF THE IMPACT OF THE HEAD NODE MOVING ON THE NETWORK OPERATION

A. Analysis of the Mobile Cluster Head Residence (staying, holding) Time in the Sensor Area

Let us estimate the head node residence time in the sensor area. For this we consider the following model. Consider a random USN node, which communication radius is equal to R . The mobile head node enters the considered node connection zone at a random point a , and moves lineal out of the communication area at a random point b , Figure 3.

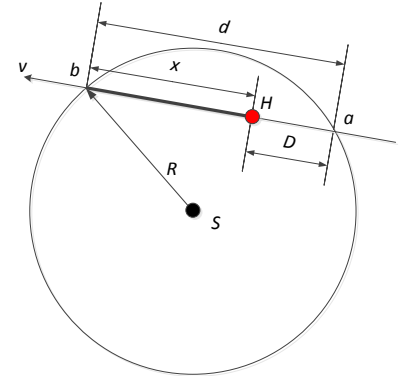


Figure 3. The head node moving model in the sensor node communication area

1. This head node passes a path d . If the speed of the head node is constant and equal to v , then its

residence duration in the communication area will be.

$$t_A = \frac{d}{v} \quad (16)$$

The length of the segment ab is random, its probability density function is defined as the length of a random chord by expression and figure 4.

$$g(d) = \frac{1}{\pi R \sqrt{1 - \left(\frac{d}{2R}\right)^2}} \quad (17)$$

The mathematical expectation is

$$M[d] = \bar{d} = \frac{4}{\pi} R \quad (18)$$

Then, the mobile node residence time in the communication area is a random value with distribution function

$$q(t) = \frac{1}{\pi R \sqrt{1 - \left(\frac{v}{2R} t\right)^2}} \quad (19)$$

Whereas its mathematical expectation is defined as

$$M[t] = \bar{t} = \frac{4}{\pi} \frac{R}{v} \quad (20)$$

Where v – mobile node speed.

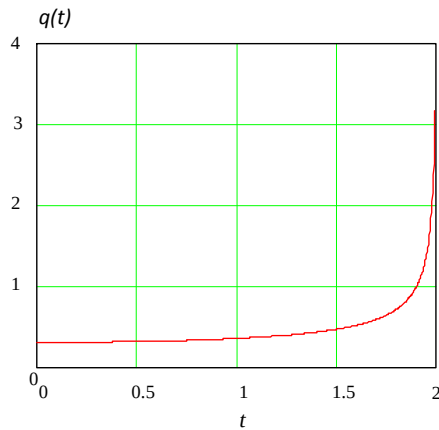


Figure 4. The node path length probability density ($R=50$ m, $v=25$ m)

2. Assume that a node that could potentially be a head node moving along this path in the sensor network node area S , becomes the head node at some random time, i.e. in random point H of the segment ab . Since the point H takes a random position on the segment ab , then the length of the segment x , is equal to

$$x = \begin{cases} d - D & D < d \\ 0 & D \geq d \end{cases} \quad (21)$$

where D – random value with uniform distribution law with the probability density

$$h(x) = \frac{1}{M} \quad (22)$$

where M – the period of network configuration change (clustering). The range of values taken by D is from 0 to M . Then the random variable x is from 0 to $2R$.

The probability density of the random variable $x = d - D$ can be estimated as the probability density of

the composition of random variables and will have the form shown in Figure 5 obtained by simulation for different values of D .

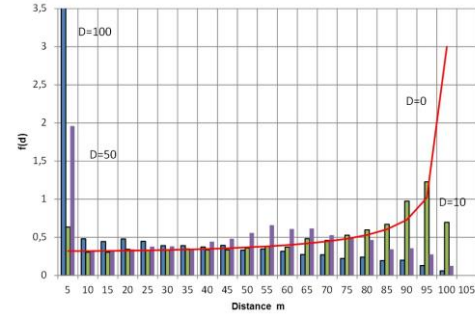


Figure 5. The probability density $f(d)$ obtained by simulation modelling

B. The Impact of Mobile Nodes Speed on the Network Operation

Let us consider the process of data transmission by mobile node. We assume that the node moves within the WSN service area, which nodes form a Poisson field of points. R is the communication radius of the mobile node, each of the sensor network nodes, entering the communication range can transmit data through the mobile node. Assuming an exponential service duration, the process of data transmission, as shown in [17] can be described by the model of a mass service system $M/M/1/k$, the input of which enter an elementary stream of requests. Requests loss occurs when the network node leaves the communication area of the mobile node before it is served. Increasing the moving speed of the mobile node leads to increasing the number of the serviced nodes, i.e. to increase the data flow intensity on the input, and increase the intensity of the serviced traffic, but it also leads to increasing the loss probability (share of unserved nodes). The loss probability in the $M/M/1/k$ system can be described by the expression,

$$p_L = \frac{(1-a)a^K}{1-a^{K+1}} \quad (23)$$

where K is buffer size

$$a = \frac{\lambda(v)}{\mu} \text{ - load intensity (Erlang);}$$

μ - service intensity (node/time unit).

As shown in [18]

$$\lambda(v) = 2R\rho v \quad (24)$$

Then, the probability that WSN sensor node, entering in the coverage area of the mobile node will be served,

$$p_S = 1 - \frac{(1-a)a^K}{1-a^{K+1}} \quad (25)$$

In this case, the buffer size K specifies the number of WSN nodes in the connection zone of the mobile node, which will be serviced or "be denied", when leaving the communication area. Thus, the buffer size is actually equivalent to the node residence time in the zone of connection. According to (18), the average value of the time determined by the speed of movement and the average length of the path (chord).

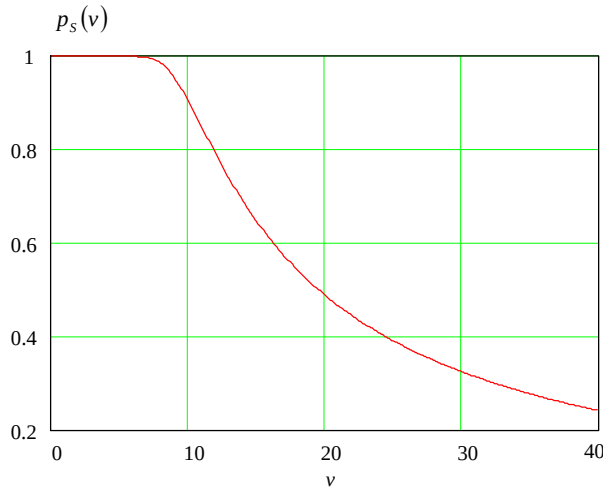


Figure 6. Service probability dependence on the speed (m/s)

Assume

$$K = k \frac{4R}{\pi v} \quad (26)$$

where k is a constant coefficient, determined empirically.

The number of nodes in the mobile node service area at the time t equals

$$n_s = S(t) \cdot \rho \cdot p_s(v) \quad (27)$$

where ρ is density of nodes (nodes / square unit);

$S(t) = 2Rvt$ - The zone, covered by the mobile node for the time t .

We characterize the mobile node efficiency by number of the WSN nodes, served during the interval t which given as

$$n_s(t) = 2Rvt \cdot \rho \cdot \left(1 - \frac{\left(1 - \frac{2R\rho v}{\mu} \right) \left(\frac{2R\rho v}{\mu} \right)^{\frac{4R}{\pi v}}}{1 - \left(\frac{2R\rho v}{\mu} \right)^{\frac{4R}{\pi v} + 1}} \right) \quad (28)$$

This function is shown in Figure 7.

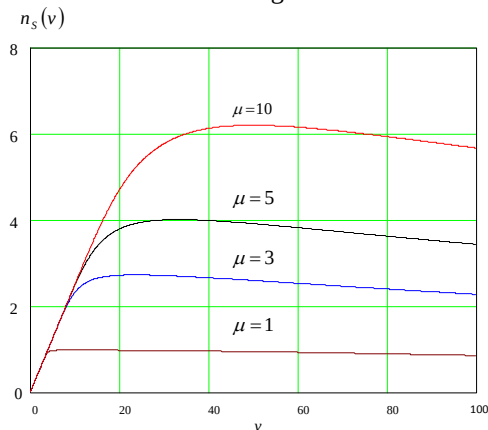


Figure 7. The dependence of served nodes number during time interval on movement speed

To study this dependence, there was developed a simulation model of WSN nodes service process by mobile node. The model is a single phase MSS (Mass Service System) with the expectation, the input of which receives the Poisson stream of requests with intensity, determined by the expression (24). Time,

assigned to the request service is obeyed an exponential law of distribution with an average intensity of service $\mu=1$. The mobile node has communication radius $R = 20$ m. This mobile node is moving in the service area, where the WSN nodes density is 0.0025 nodes/m². The discipline of service suggests that the request may expect service in the queue for a random time τ . After this time, if the request has not been serviced, it leaves the system and is considered lost. The value of τ determines by the length WSN node path in the zone of the mobile node and by the speed of its movement, in accordance with (19). When this path length is random and distributed defines in according to (17). The simulation results are shown in Figure 8.

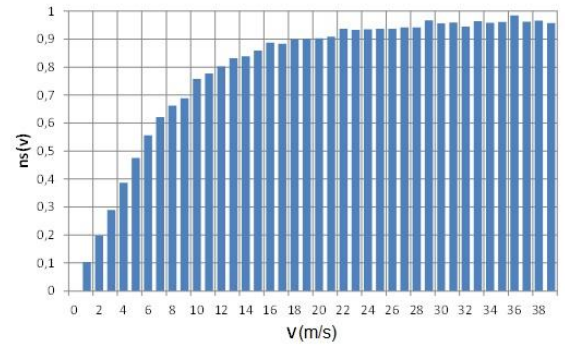


Figure 8. Dependence of the number of nodes served per unit time on the speed of the mobile node for the exponential service time

In Figure 9 are shown simulation results for the case of constant service time.

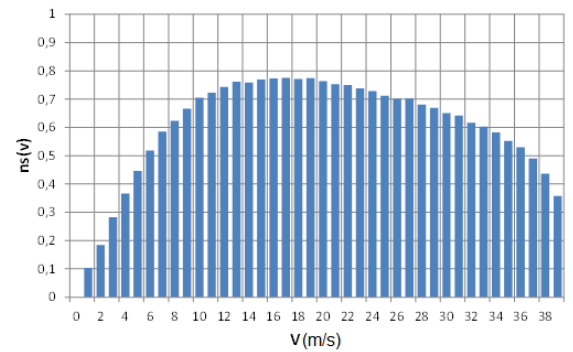


Figure 9. Dependence of the number of nodes served per unit time on the speed of the mobile node for constant service time.

At constant service time there is a maximum percentage of serviced nodes. This difference in results can be explained by the fact that in the first case, when the speed increases, the probability of node service is saved, because the time of service of a certain percentage of the nodes can be quite small or even close to zero. For the constant service time, when node speed is increasing, the probability of node service decreases. It occurs, when speed is numerically equal to or greater than

$$v_0 = 2R \cdot \mu \quad (29)$$

For current case (40 m/s) the probability of service is equal to zero.

V. CONCLUSIONS

1. The process of clustering in wireless sensor networks is related with consumption of energy, which, in its turn, is related with transmission of the service data. The length selection of the clustering interval (round) impacts on the data delivery time in the network and on the energy consumption. The optimum value of the round length, determined by the minimum energy consumption for clustering can be found from the condition of ensuring the required data delivery time.

2. The presence of communication mobile nodes, which has renewable sources of energy can increase the lifetime of the network and improve the access of network nodes. Number of WSN nodes serviced by mobile nodes depends on the speed of the mobile nodes. The process of service WSN nodes by mobile node can be described by MSS model. The proportion of serviced WSN nodes depends on the speed of the mobile node.

3. The method of simulation modeling shows that the number of served nodes per time interval depends on the nature of the service time distribution and the speed of the mobile node. For the constant service time there is a maximum number of serviced nodes, i.e. an optimal value of the node speed.

VI. ACKNOWLEDGMENT

The reported study was supported by RFBR, research project No15 07-09431a "Development of the principles of construction and methods of self-organization for Flying Ubiquitous Sensor Networks".

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