

Ubiquitous sensor networks in the heterogeneous LTE network.

Abdo FUTAH^{*}, Andrey KOUCHERYAVY^{*}, Alexander PARAMONOV^{*}, Andrey PROKOPIEV^{***}

^{*}Saint-Petersburg State University of Telecommunications, Russia

^{**}UbiTel Co. LTD, Russia

aahf_84@mail.ru, akouch@mail.ru, alex-in-spb@yandex.ru, a.prokopiev@ubitel.ru

Abstract— The introduction of a broad concept of the Internet of Things, together with the development of LTE systems (Long Term Evolution) raises a number of new challenges for the integration of resources of self-organizing networks and traffic management in LTE. The article investigates the possibilities of increasing in the residual energy and the duration of the life cycle of a sensor network by providing the temporary status of the cluster head to node crossing the sensor field, such as mobile network terminal, VANET nodes, etc.

Keywords— USN, Cooperative communication, LTE, Traffic model, Mobile cluster head

I. INTRODUCTION

The imminent introduction of a broad concept of the Internet of Things [1, 2], together with the development of Long Term Evolution system (LTE) raises a number of new challenges for the integration of self-organizing networks resources [3, 4] and LTE service traffic.

On the territory of a heterogeneous zone LTE at the same time there may be a set of nodes of different networks: ubiquitous sensor [6], automobile [5], health [7], etc. Furthermore, in the same area there are a number of mobile terminals operating in a certain moment of time at different distances from the base station. Last of addressing the objective of improving the quality of service for users who are closer to the border service area, led to the creation of so-called cooperative networks [8]. In cooperative networks, quality of service of users located at the boundary of the service area, or at other disadvantageous conditions can be improved with a help of message forwarding by other users or special repeater terminal [9].

In this paper we propose a slightly different 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 [10] 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 behaviour 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 sensor network terminals [3, 5]. Earlier studies in this area investigate a task of collecting data from sensor fields using specialized gateways, sequentially crosses a number of pre-defined sensory fields [11].

Generally, ubiquitous sensor networks are formed based on the cluster architecture [12]. It is also possible to construct a three-dimensional network [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 [12].

II. NETWORK MODEL

Poisson sensory field is completely located in the area of heterogeneous LTE network. Gateway is located in the centre 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 of 2 m/s (typical speed for mobile sensor networks), 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. NETWORK CHARACTERISTICS

When using a LEACH clustering algorithm, the network structure is selected (changed) periodically. The period during which the structure of the network is unchanged, is called round. In the beginning of the round a number of head nodes are selected that define the network clusters. The number and arrangement of head units are random, determined only the mean number of cluster heads. Thus, for the network node, the probability of being in the range of cluster head is less than 1, therefore the probability of message sending is also less than 1. Mobile cluster heads temporary became additional head nodes, so an increase in the probability of message delivery in the current round should be expected.

Network nodes consume energy for receive and transmit data, and cluster heads consume the largest share of energy, since they serve as retransmitters of messages from multiple nodes - members of the cluster. With presence of the temporary mobile head nodes, such nodes "take on" the energy costs are associated with the transfer of a certain amount of messages, so a decrease in energy consumption of sensor network nodes should be expected, and hence increase its lifetime.

A. Estimation of the probability of access to the head node for an arbitrary network node

Consider one round of the sensor network operation. The probability that a sensor network node is within range of at least one cluster head, will be defined as

$$p_C = 1 - p_0^{(H)}, \quad (1)$$

where the $p_0^{(H)}$ - the probability that there are no cluster head in the area of the sensor node, which may be determined according to a Poisson distribution (property of the Poisson field):

$$p_0^{(H)} = \frac{(\pi r^2 \rho_H)^k}{k!} e^{-\pi r^2 \rho_H} \Big|_{k=0} = e^{-\pi r^2 \rho_H} \quad (2)$$

then

$$p_C = 1 - e^{-\pi r^2 \rho_H}$$

where $\rho_H = \rho \cdot \eta$ - cluster heads density;

$\rho = \frac{n}{S}$ - network nodes density (nodes/m²);

n - total number of nodes in the network;

S - area of the service field (m²);

In general, the probability that for d - rounds sensor node will be able to send a message (cluster head will be available) will be defined as

$$p_C(d) = 1 - \left(e^{-\pi r^2 \rho_H} \right)^d = 1 - e^{-\pi r^2 \rho_H d} \quad (4)$$

Equation (4) from time (with round duration equal to 5 seconds, which generally used in the papers dedicated to cluster head selection) for different proportions of cluster heads is shown in Figure 1.

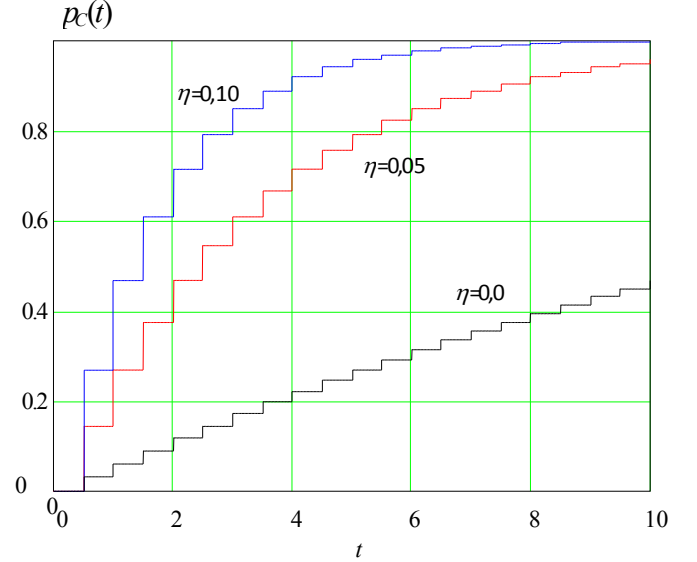


Figure 1. Probability of node connectivity on the number of rounds for different proportions of cluster heads

B. Estimation of the probability of availability of the mobile node (which serves as the head node) for an arbitrary network node

After entering the service area of the sensor network a mobile node from other network in the first whole round becomes cluster head. In this case, the nodes of a sensor network in its range become child nodes and can send messages through the head (parent) node. When the temporary cluster head is moved during the round number of the nodes at a distance L may become out of range of its service. The nodes of the cluster, which is available to a temporary mobile head node, will be in the region of the intersection of two circles, represent coverage of the cluster head at the beginning of the round and at the distance L from that point.

Thus, at the beginning of the round, temporary mobile head with a probability equal to 1 will be available to all nodes in the cluster, and a time t probability of availability of temporary mobile head decreases. The probability of availability of temporary mobile head can be defined as the ratio of the area of intersection of the discussed circles and area of the coverage zone (for the duration of the round):

$$p_a(t) = \frac{\tilde{S}(L(t))}{\pi r^2} = \begin{cases} \frac{\tilde{S}(vt)}{\pi r^2} & t < T_0 \\ 0 & \text{other} \end{cases} \quad (5)$$

Figure 2 shows a model illustrating the movement of temporary mobile cluster head.

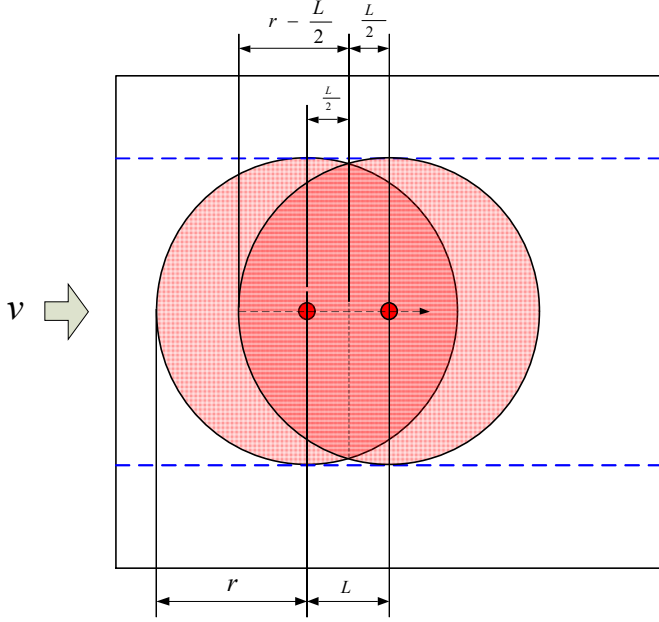


Figure 2. Moving of the temporary mobile cluster head

From the drawing the area of intersection of the coverage zones can be defined by the formula:

$$\tilde{S}(L) = 2 \left(r^2 \arccos\left(\frac{L}{2r}\right) - \left(\frac{L}{2}\right) \sqrt{r^2 - \left(\frac{L}{2}\right)^2} \right) \quad (6)$$

Figure 3 shows the dependence of the probability of availability of mobile head from a time with the different speed of movement at the beginning of the round (excluding the duration of the round).

Then the dependence of the probability of availability of temporary mobile cluster head node for the cluster nodes it from a time will be determined as

$$p_A(t) = \begin{cases} \frac{\tilde{S}(vt)}{\pi r^2} & vt < r \\ 0 & other \end{cases}$$

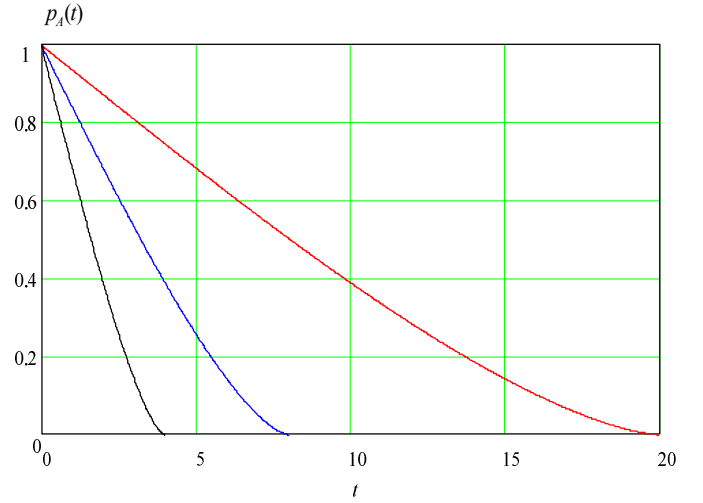


Figure 3. Change in the probability of availability of temporary cluster head from a time for different speeds of the movement

Given that the rounds occur periodically and their duration constant and equal to T_0 , the probability of availability of temporary mobile head will be a periodic function with a period equal to the duration of the round

$$p_a(t) = \begin{cases} \frac{\tilde{S}(vt)}{\pi r^2} & (T_0 z < t < T_0(z+1)) \wedge (vt < r), \quad z \in \mathbb{N} \\ 0 & other \end{cases} \quad (7)$$

where the $\tilde{S}(v \cdot t)$ - determined in accordance to (4);

T_0 - the duration of the round (s);

v - the speed of movement of the head (m/s);

r - the radius of the cluster head coverage;

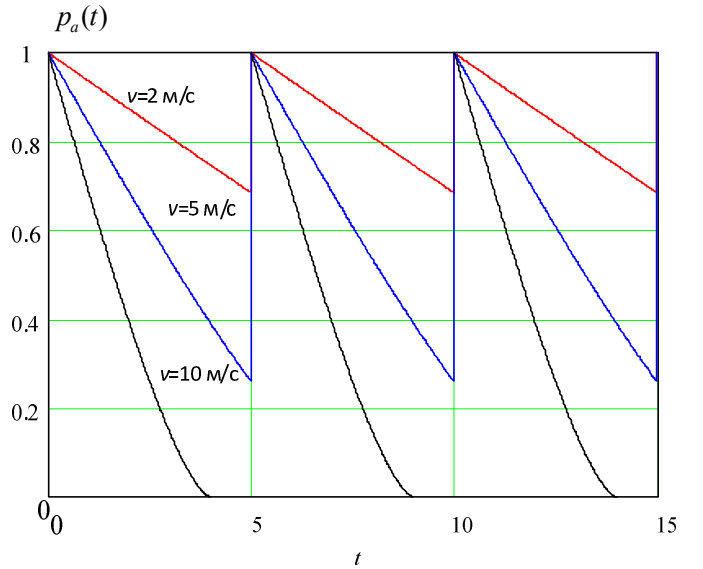


Figure 4. Changes in the probability of availability of temporary mobile head from a time for different speeds for a few rounds

For an arbitrary node probability that will be at least one cluster head from other network in node's range, will be determined similarly to (3) and equal to

$$p_C^{(T)} = 1 - e^{-\pi^2 \rho_T} \quad (8)$$

where the ρ_T - density of mobile nodes from other networks range.

In the case of availability of a mobile node from other network, it certainly is selected as cluster head, considering (7) dependence of the probability of its availability from a time is defined as

$$\tilde{p}_a(t) = p_C^{(T)} p_a(t) \quad (9)$$

This dependence with $\rho_T = \rho_H = \rho$ is shown on Figure 5.

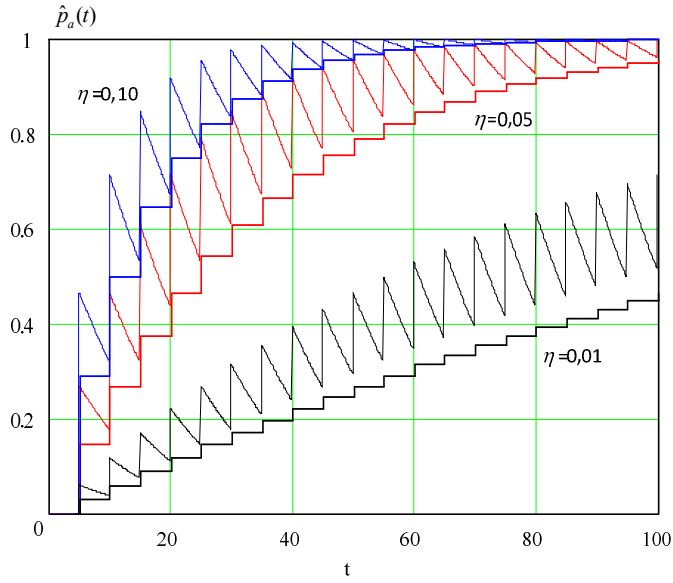


Figure 5. Changes of the probability of availability of temporary mobile head from a time for different densities for 20 rounds

C. Estimation of the probability of availability of any of the cluster head, including temporary mobile head

The probability of availability of any of the cluster head is defined as

$$\hat{p}_a = p_C^{(T)}(t) + p_C(t)(1 - p_C^{(T)}(t)) \quad (10)$$

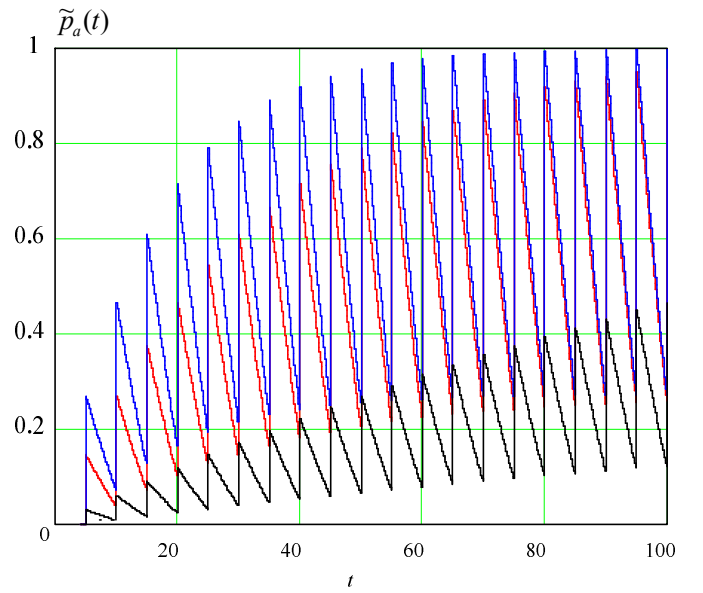


Figure 6. Changes of the probability of access to any of the cluster head for different densities for 20 rounds with the presence and absence of temporary mobile cluster heads

Figure 6 shows that the use of mobile nodes from other networks as temporary cluster heads for sensor network probability of availability of cluster head increases significantly, and hence the duration of the life cycle of a wireless sensor network.

IV. CONCLUSIONS

A new class of problems is suggested for ubiquitous sensor networks - clustering with the use of temporary mobile nodes as a cluster head in heterogeneous areas of a long term evolution networks. LTE terminals, VANET nodes, flying sensor networks drones can act as a temporary mobile cluster heads.

The probabilities of availability of the cluster head node and temporary mobile cluster head are determined. It is proved that with the use of temporary mobile heads the availability of the cluster head node increases significantly, and thus the duration of the life cycle of a ubiquitous sensor network.

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"

REFERENCES

- [1] Recommendation Y.2060. Overview of Internet of Things. ITU-T, February 2012, Geneva.
- [2] A.Iera, C.Floerkemeier, J.Mitsugi, G.Morabito. "The Internet of Things." IEEE Wireless Communications. Dec. 2010, v.17, N6.
- [3] A. Koucheryavy, State of the Art and Research Challenges for USN Traffic Flow Models, 2014. ICACT 2014. Phoenix Park, Korea.

- [4] A. Koucheryavy, I. Bogdanov, A. Paramonov, The mobile sensor network life-time under different spurious flows intrusion, Lecture Notes in Computer Science. 2013. 8121 LNCS
- [5] Y.Koucheryavy, J. Jakubiak. Research Challenges in Vehicular Ad hoc Networks. Proceedings, IEEE CCNC 2008, January 10-12, 2008. Las Vegas, USA.
- [6] A. Koucheryavy, A. Prokopiev, Quality of Service (QoS) classes for ubiquitous sensor networks, ICACT 2009. Phoenix Park, Korea
- [7] A. Vybornova, A. Koucheryavy, Ubiquitous sensor networks traffic models for medical and tracking applications, Lecture Notes in Computer Science. 2012. 7469 LNCS.
- [8] C.Hoymann, W.Chen, H.Montojo, A.Coltschek, C.Koutsimanis, X.Chen. Relaying Operation in 3GPP LTE: Challenges and Solutions. IEEE Communications Magazine, v.50, n.2, February 2012.
- [9] А.Е.Кучерявый, А.Г.Владыко, Р.В.Киричек, А.И.Парамонов, А.В.Прокопьев, И.А.Богданов, А.А.Дорт-Гольц. Летающие сенсорные сети. Электросвязь, №9, 2014. (Russian)
- [10] V.P.Kafle, Y.Fukushima, H.Harai. Dynamic Mobile Sensor Network Platform for ID-based Communication. ITU-T Kaleidoscope-2014, Proceedings. St.Petersburg, SUT, 3-5 June, 2014.
- [11] W. Heinzelman, A. Chandrakasan, H. Balakrishnan. Energy-efficient communication protocol for wireless microsensor networks. Proceedings 33rd Hawaii International Conference on System Sciences (HICSS), Wailea Maui, Hawaii, USA, Jan. 2000.
- [12] A. Koucheryavy, A. Salim. Cluster head selection for homogeneous Wireless Sensor Networks. Proceedings, International Conference on Advanced Communication Technology, 2009. ICACT 2009. Phoenix Park, Korea.
- [13] P. Abakumov, A. Koucheryavy. The Cluster Head Selection Algorithm in the 3D USN. Proceedings, International Conference on Advanced Communication Technology, 2014. ICACT 2014. Phoenix Park, Korea.
- [14] O. Younis, M. Krunz, S. Ramasubramanian. Node clustering in wireless sensor networks: Recent developments and deployment challenges. IEEE Network, vol. 20, no. 3, 2006.
- [15] A. Koucheryavy, A. Salim. Prediction-based Clustering Algorithm for Mobile Wireless Sensor Networks. Proceedings, International Conference on Advanced Communication Technology, 2010. ICACT 2010. Phoenix Park, Korea.