UDC 004.7

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ENERGY EFFICIENCY IN WIRELESS NETWORKS OF INTERNET OF THINGS

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ЕНЕРГОЗБЕРЕЖЕННЯ В БЕЗДРОТОВИХ МЕРЕЖАХ ПРИСТРОЇВ ІНТЕРНЕТУ РЕЧЕЙ

Annotation. This article is devoted to the analysis and design of energy-efficient work and communication model of Internet of Things devices, which connected by a wireless network. The sleep-wakeup cycles taken as a base of the energy efficiency. The degree of filling node`s buffer and the number of sleep-wakeup cycles without data transmission are taken as correction metrics of node sleep duration. The routing performed by considering the shortest paths and node loading.

Keywords: energy efficiency, wireless asynchronous networks, scaling, Internet of Things, routing.

Fig.: 0. Tabl.: 0. Bibl.: 3.

Анотація. Дана стаття присвячена аналізу та проектуванню енергоефективної моделі роботи та комунікації пристроїв інтернету речей, що поєднані бездротовою мережею. За основу енергозбереження взято цикли переходу пристроїв у режими сну та пробудження. В якості метрик корекції тривалості сну використовується ступінь заповнення буферу вузла та кількість циклів сну-пробудження без передачі даних. Маршрутизація відбувається по найкоротшим шляхам з врахуванням завантаженості.

Ключові слова: енергозбереження, бездротові асинхронні мережі, масштабування, інтернет речей, маршрутизація.

Рис.: 0. Табл.: 0. Бібл.: 3.

Relevance of research topic. Due to rapid development of mobile devices of internet of things, the topic of energy efficiency becomes very important to the spheres of life, where autonomous lifetime and scalability are the critical characteristics. Because of the limitations in these characteristics, there is a slowdown of implementation in certain spheres of life, for example, agricultural industry.

Analysis of resent research and publications. There are plenty of methods of work lifetime prolongation of wireless sensors – radio optimisation, aggregation and intermediate data processing, duty cycles schemes, energy-efficient routing and charging methods [1]. Only one of these methods is the most energy-effective and which configured by a software – duty cycles schemes. In [2] clusterization method is used along with duty cycle schemes where a duty node is chosen in each cluster, which receives messages from other nodes within the cluster for some period of time and then sends this data further to the sink and control node (base station). The disadvantage of this method is low scalability because with node distance increase the clusterization ability decreases.

Target setting. The best method of energy saving in wireless networks of internet of things devices is switching nodes to a sleep state which is characterized by ultra-low power consumption. The switching to a sleep state means disconnect from the network, which makes the further communication impossible. Thus, a periodical wakeup is required for reconnection. In this case, each node with a certain periodicity can generate data retrieved from the connected sensors. Thus, this scheme of work nodes communication includes sleep/wakeup cycles with asynchronous communication, which ensured by buffer presence and work duty cycling.

The statement of basic materials

The determination of cycle duration. Immediately after awakening, the node activates the radio channel and broadcasts the beacon message so the other nodes in the covered region can find out about its presence and active status in the network. The time needed for beacon message transmission is denoted as T_B. So for receiving of the beacon message, an interval of time T_{ACK} is needed to eliminate the possibility of missing a reply to a message and which is 2-3 times bigger than T_B correspondingly. Besides that, the active mode also involves the work with connected sensors which takes T_W and communication time T_{RTX} itself. Since the process of sensing is periodical, its frequency can be denoted as ω and the maximum sleep time will be $T_{Smax} = 1/\omega$ correspondingly. Hence, we get a formula of effective time of sleep:

$$T_S = \frac{1}{\omega} - (T_B + T_{ACK} + T_W + T_{RTX}) \quad (1)$$

The given formula (1) doesn't resolve the synchronization problem (the presence of 2 and more nodes in access zone for the same time slot). So, with a long time work there's a high probability of local buffer overflow and hence the unavailability to transmit the data. Thus, (1) is suitable only for the initial setting sleep/wakeup cycles right after routing tables initialization on each node. So it means that it's required to change sleep duration dynamically depending on nodes state. As such metric the node`s buffer filling degree was taken. The more data in the buffer, the faster this data should be transmitted to the subsequent nodes in order to avoid data accumulation and buffer overflow. This can be expressed as follows:

$$T_{S_i} = T_S * \left(1 - \frac{n}{c}\right) \quad (2)$$

Where, n – data size in buffer, c – buffer capacity, T_S – maximum sleep duration, T_{S_i}- sleep duration for the next cycle. Due to (2) the problem with buffer overflow was resolved but the same time may be a case where buffer is not replenished by new messages (for example, because of sensors failure or their complete absence) and the condition of decreasing of sleep time never happens. Therefore, a new metric should be presented, such as the number of cycles m during which the message was stuck at the buffer without being transmitted. Let's introduce the K_i coefficient for which value the next sleep duration will be divided:

$$T_{S_i} = \frac{T_S * \left(1 - \frac{n}{c}\right)}{K_i} \quad (3)$$

Where K_i is determined as:

$$\begin{cases} K_0 = 1, \text{для } m = 0 \\ K_i = K_{i-1} * (1 + m * k_b), \ \text{для } m \ \geq 1 \end{cases} \quad (4)$$

In (4) the k_b defines the coefficient of message importance (priority) and is constrained: $0 < \ k_b \leq 1$. Thus, the longer message stays in the buffer the less time the node will sleep so there's bigger probability to detect ready for transmission neighbor nodes in access range.

Routing. At the first glance, routing in asynchronous networks with periodically sleeping nodes is a difficult problem. Since duty cycles guarantees with delay though, the existence of connection between two and more nodes the problem can be simplified for finding the shortest path. During network initialization, there is construction of routing tables for each V_i node from the W set. In this case each node calculates and saves in memory the cheaper path cost to each node in the netwok which can be achieved using Dijkstra's algorithm. Taking into account asynchrony, the same time receiving node choice algorithm requires adjustments in both selection principle itself and the routing table. So each node stores the information about paths costs from itself to other nodes, but the same time it has similar records for neighboring nodes that are available. This is due to the fact that during the optimal path selection, the node through which the path lies can be in a sleeping state. And in fact the routing is as follows: select the available nodes, which have path cost less than the transmitting node and select the less costing node taking into account load balancing.

Balancing. In order to avoid nodes overhead which make an optimal path it's a normal practice to balance the loading by the mean of these nodes which are less involved in data transmission. The node load can be expressed through the degree of buffer filling:

$$\beta = \frac{n}{c} \quad (5)$$

Correspondingly, the receiver node selection will be as follows:

$$N_i = \min\left(h_i + \sqrt{h_i} * \beta\right) \quad (6)$$

Where, h_i – path cost from i-neighbor node to the destination node and N_i – is a number of the selected receiver node during the routing task.

Conclusions. Using the proposed integration method of nodes operation mode the significant reduced energy consumption can be achieved due to a sleep mode. In spite of the periodicity of wakeup state, the nodes data transmission ability was saved by dynamic sleep/wakeup cycles reconfiguration. This method allows you to reduce node density on some area, improve the coverage correspondingly without increasing energy consumption, and improve the scalability of the system.

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EXTENDED ANNOTATION

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Relevance of research topic. Due to rapid development of mobile devices of internet of things, the topic of energy efficiency becomes very important to the spheres of life, where autonomous lifetime and scalability are the critical characteristics. Because of the limitations in these characteristics, there is a slowdown of implementation in certain spheres of life.

Analysis of resent research and publications. There are plenty of methods of work lifetime prolongation of wireless sensors – radio optimisation, aggregation and intermediate data processing, duty cycles schemes, energy-efficient routing, charging methods and clusterization method.

Uninvestigated parts of general matters defining. The requirements in hardware change configuration for most of methods which result in more costs of the system. The methods that can be implemented with a software have problems with data integrity, delivery and scalability.

Target setting. The best method of energy saving in wireless networks of internet of things devices is switching nodes to a sleep state which is characterized by ultra-low power consumption. Thus, this scheme of work nodes communication includes sleep/wakeup cycles with asynchronous communication, which ensured by buffer presence and work duty cycling.

Найкращим можливим способом збереження енергії в бездротових мережах пристроїв інтернету речей є переведення вузлів у режим сну, який характеризується наднизьким енергоспоживанням. Таким чином, дана схема роботи та комунікації вузлів передбачає чергування циклів сну та робочого стану вузлів з асинхронною комунікацією, яка забезпечується наявністю буфера у вузлів та циклічністю роботи.

The statement of basic materials. The sleep cycle duration is determined dynamically depending on the node and the network state. The required data sensing rate, time required for sending the beacon message, time requeired for listening for incoming messages, data transmission time and sensors work time are taken into account. In this case, the sleep duration is adjusted depending on buffer load as well as the time messages spent in the buffer in the dimension of cycles sizes and importance of these messages. The routing is based on the shortest path principle taking into account the load of the nodes.

Conclusions. Using the proposed integration method of nodes operation mode

the significant reduced energy consumption can be achieved due to a sleep mode. This method allows you to reduce node density on some area, improve the coverage correspondingly without increasing energy consumption, and improve the scalability of the system.
Keywords: energy efficiency, wireless asynchronous networks, scaling, Internet of Things, routing.