Spatial-energy Model of a Wireless Sensor Network

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Abstract

In agricultural production, wireless technologies are becoming widespread. Over the years, more and more wireless sensor network technologies have developed. A wireless sensor network consists of sensor nodes that can self-organize and transmit information to a base station without direct human intervention. One of the main conditions for the successful functioning of a wireless sensor network is the charging of an autonomous power source. Device power consumption is influenced by many characteristics of wireless sensor networks. Many researchers, when calculating the characteristics of wireless sensor networks affecting energy consumption, assume that sensor devices are located on a plane. This assumption makes sense if the sensor network occupies relatively small areas and does not have a terrain relief. But if these conditions are not met, then it is necessary to take into account the terrain and the fact that the devices can be located at different heights. In this regard, the problem of calculating the spatial and energy characteristics is becoming urgent, allowing to reduce the power consumption of the device, as a result of which the period of operation of the wireless sensor network will increase, and the costs of autonomous power supplies will decrease. In the work, the calculations are based on the assumption that the Earth has the shape of a sphere. The aim of the work is to build a spatial-energy model of a wireless sensor net-work, which allows, taking into account the data on the location of devices, to reduce the power consumption of the network as a whole. The paper analyzes the existing routing protocols. An experimental study was carried out, during which a spatial-energy model of a wireless sensor network was obtained. A numerical calculation is carried out and graphs of the dependence of power consumption on the characteristics of a wireless sensor network are constructed.

Keywords

wireless sensor network, power consumption, sensor device, spatial characteristics, routing protocol, routing algorithm

1. Introduction

The development of modern wireless technologies has led to the emergence of wireless sensor networks. “A wireless sensor network (WSN) is a set of smart things (sensor devices) connected to each other and to a cloud that provide measurement of physical parameters of the environment” [1].

Wireless sensor networks are being actively implemented in agriculture. The period that agriculture is now going through is called “Industry 4.0”, at the World Government Summit, this revolution is called “Agriculture 4.0” [2]. This revolution allows agricultural enterprises to

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significantly increase yields and reduce production costs. Most agricultural applications based on WSN technology monitor the status of indicators affecting agricultural production. The nodes of the wireless sensor network are autonomous, they function due to an autonomous energy source (battery) [3, 4]. The energy reserve in the battery is not unlimited, and over time it depletes. Due to the failure of the sensor device, the functioning of the sensor network is compromised. In this regard, the problem of increasing the life cycle of a wireless sensor network by reducing the power consumption of sensor devices becomes urgent.

Kireev A. and Svetlov A. in their work [5] note that despite the fact that the field of wireless sensor networks is successfully developing, the main limiting factor is the limited energy resources for network nodes, since this factor determines the commercial suitability of the network as a whole. Hasnullin V. and Glushak E. believe that the bulk of the energy of the wireless sensor network is spent on receiving and transmitting data [6]. V. Galkin carries out energy consumption analysis of wireless sensor networks in article [7]. Various approaches to reducing pow-er consumption are discussed in [8], the authors believe that to improve the energy efficiency of the network, it is necessary to put as many nodes as possible into sleep mode.

To a large extent, the power consumption of a wireless sensor network depends on the routing protocol [9]. Due to the routing protocols, the nodes in the network self-organize, and in accordance with the algorithm in the protocol used, the nodes choose the most optimal route for transmitting the message. Let's consider the main protocols of wireless sensor networks. AODV (Ad hoc On Demand Distance Vector) is a single-route protocol used in mesh networks such as ZigBee. The algorithm of this protocol is as follows: if the source node needs to send a message, it sends a broadcast request to find a route to the destination node. This request is transmitted to all neighboring nodes of the source, and they transmit this message to their neighbors, this happens until the re-quest reaches the destination node. All this time, while the request was being transmitted, each node made a corresponding entry in its routing table, which indicated the "logical distance" from the sender of the request to its recipient, with each step of transmitting the request, the "logical distance" increased. The destination node sends a response to the device from which the packet came with the minimum "logical distance", the message is sent to neighboring nodes with the minimum distance, so the message returning along the optimal path forms a table of the forward route of packet transmission from the source node to the destination node [10].

The main disadvantage of this protocol is that it requires a significant amount of memory in each device to store route tables, and it also generates a lot of traffic.

LEACH (Low-Energy Adaptive Clustering Hierarchy) is a self-organizing adaptive clustering protocol that randomly distributes the energy load on the net-work between sensor devices. Each node with a certain probability makes the decision to create a cluster. The probability is calculated based on the required number of clusters, the number of nodes in the network, the node's energy reserve, and the number of stages that have passed since the node was designated as the master. To create a cluster, the head node broadcasts a request to join neighbors. If a node receives requests from several head nodes, it will select the closest one and inform it about joining. At the end of the clustering procedure, in order to avoid collisions when sharing a common transmission medium, a schedule for the activity of cluster nodes is formed. Nodes within the cluster transmit data at regular intervals. When the head node receives all messages within its cluster, it sends messages to the base station. To rationally distribute energy consumption within the cluster, the head node is re-elected after a certain period of time, each of the nodes within the cluster can become the head. The disadvantage of the protocol is the in applicability of the protocol to networks for large regions, and due to the fact that the dynamic clustering protocol introduces additional costs [11].

LEACH-C consumes less energy when transmitting data compared to LEACH protocol. Unlike the previous protocol, this protocol also has a centralized approach. Before selecting the head node in the cluster, all sensor devices send in-formation to the base station about the amount of remaining energy and about the coordinates of the location. The base station then calculates the average remaining energy of the sensor nodes and sends this information to all nodes within the cluster. Further, as in the LEACH protocol, the head node is randomly selected, but the candidates to become the head node are only sensor devices with more than aver-age energy remaining.

LEACH-F is similar to LEACH-C, but clustering is performed once during the node data collection phase. At the beginning of each next stage, only the head nodes of the cluster are changed. This reduces the duration and power consumption of the cluster formation phase.

The PEGASIS (Power-Efficient Gathering in Sensor Information System) protocol is designed for the same networks as LEACH, but, unlike it, unites network nodes not into clusters, but in chains. In addition, the head node is not selected randomly, but based on the remaining energy of the sensor device. The chain starts from the farthest node. Each next node in the chain becomes the node closest to the previous one, unless it is contained in the chain. To communicate with the coordinator, one of the chain nodes is selected in some way. The data for transmission is collected sequentially, starting at the end nodes of the chain. Each subsequent node aggregates the received and own data, reducing the amount of metadata. The dis-advantages are the increased power consumption due to the aggregation of data and their transmission, in addition, there is a large time delay when the message is transmitted from the base station to the most remote nodes [12].

Using routing protocols, you can minimize power consumption in a wireless sensor network by identifying the optimal path for transmitting a data packet for nodes.

2. Materials and methods

The paper [13] proposes an approach that allows one to determine the route of message transmission from the source node to the base station at which the minimum power is spent, based on the cosine theorem. This approach assumes that the sensor devices are on a plane, and does not take into account the location of the node in space. It should be taken into account that one device may be on the surface of the earth, and the other is higher, for example, on a post or tree. Since the Earth's surface is closest in shape to a sphere, we will take this figure as a basis (see Fig. 1).

To know the distance between the sensor nodes, you need to know the coordinates of the nodes. The base station makes a request for the location of the sensor device, which in turn, having received the request, communicates with the satellite, receives its coordinates and sends them to the base station. Coordinates come in degrees, for calculations it is necessary to convert

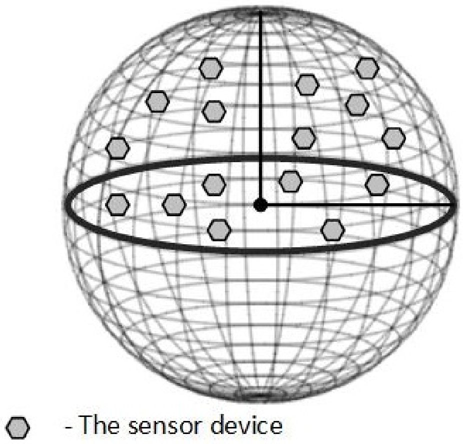

Figure 1: Sensory field in volumetric form.

them to radians

$$\lambda = \frac{\lambda^\circ \cdot \pi}{180}, \varphi = \frac{\varphi^\circ \cdot \pi}{180} \tag{1}$$

where λ is longitude in radians, φ is latitude in radians.

The distance between two points on the sphere, taking into account their longitude and latitude, can be determined using the haversine formula [14]

$$hav\frac{d}{r} = hav(\varphi_2 - \varphi_1) + cos\varphi_1 \cdot cos\varphi_2 \cdot hav(\lambda_2 - \lambda_1) \tag{2}$$

where d is the distance between two points along the great circle of the sphere; r is the radius of the sphere.

A graphical representation of the distance between two points along the great circle of the sphere and the radius of the sphere is shown in figure 2. The term haversine appeared in 1835 in D. Inmans work Navigation and Marine Astronomy: For Use by British Mariners [15]. This term was used in navigation to simplify the determination of the distance between two points on the surface of the Earth.

The central angle between two points is equal to the ratio of the distance be-tween two points along the great circle of the sphere to the radius of the sphere

$$\theta = \frac{d}{r} \tag{3}$$

The Haversine function of the central angle is as follows:

$$hav(\theta) = sin^2(\frac{\theta}{2}) = \frac{1 - cos(\theta)}{2} \tag{4}$$

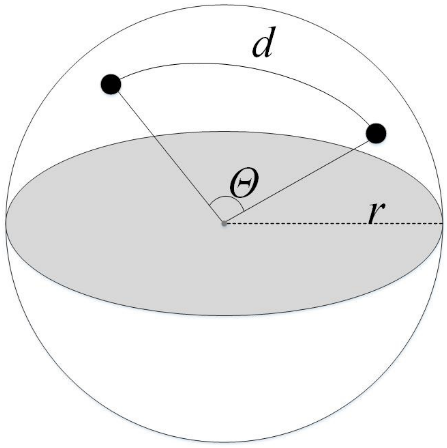

Figure 2: A graphical representation of an arc *d* and a radius *r*.

To find the distance d, you need to use the arhaversine (reverse haversine) or the arcsine function

$$d = r \cdot archav(h) = 2r \cdot arcsin(\sqrt{h}) =$$

$$2r \cdot arcsin(\sqrt{hav(\varphi_2 - \varphi_1) + cos\varphi_1 \cdot cos\varphi_2 \cdot hav(\lambda_2 - \lambda_1)}) = \tag{5}$$

$$2r \cdot arcsin(\sqrt{sin^2(\frac{\varphi_2 - \varphi_1}{2}) + cos\varphi_1 \cdot cos\varphi_2 \cdot sin^2(\frac{\lambda_2 - \lambda_1}{2})})$$

Since the Earth's surface has irregularities, it cannot be imagined as an ideal sphere, because of this its radius varies, so you can use the reference value of the radius set by the World Geodetic System (WGS) [16], which is approximately equal to 6371 km. In open space at large distances, the Friis formula [17] is used to find the power of the radio signal. Let us find the power of the radio signal at the transmitting antenna by substituting the distance into the Friis formula [17]

$$P_{per} = \frac{16P_{pr}\,\pi^2 d^2}{C_{pr}\,C_{per}\,\gamma^2} \tag{6}$$

where γ – wavelength [m] of the transmitted radio signal, C_{per} – coefficient gain of the transmitting antenna, C_{pr} – coefficient gain of the receiving antenna, P_{per} – is the power of the radio signal at the transmitting antenna [W] (excluding losses), P_{pr} – is the power of the radio signal at the received antenna [W] (excluding losses), d – is the distance between the antennas of the WSN objects in meters. The required signal power at the transmitting antenna (P_{per}), assuming that the power of the radio signal at the receiving antenna (P_{pr}) is constant, is a random variable depending on the distance between the interacting objects.

The wavelength is related to the frequency of the signal flow $\gamma = \frac{v}{f}$, where v – is the speed of light (~ $3 \cdot 10^8$ m/s).

In the work of Astakhova T., Verzun N., Kolbanev M., Polyanskaya N. and Shamina A. [1], intermediate calculations were carried out, during which the formula for the energy spent on

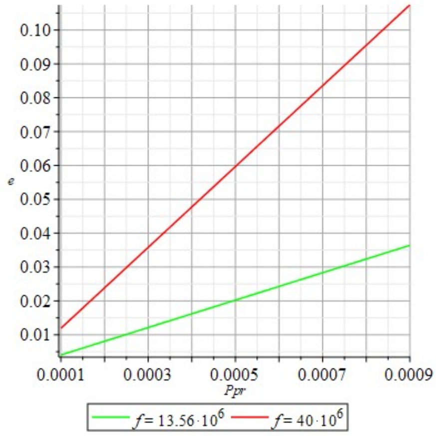

Figure 3: A graph of the dependence of power consumption on the power of the radio signal at different values of the signal flow frequency.

transferring a block of a smart thing was obtained, for our case the formula will look like this

$$e = P_{per} \cdot t = \frac{8P_{pr}\pi^2 d^2 f I b}{C_{pr} C_{per} v^2} \tag{7}$$

where I – the intensity of the transmission blocks, b – the length of the transmitted blocks (bits).

3. The numerical calculation

Substituting the values into the above calculations, we will carry out a numerical calculation, and we will obtain graphs of the dependence of power consumption on the parameters of the wireless sensor network with the following values:
$v = 3 \cdot 10^8$ m/s, $C_{per} = 1$, $C_{pr} = 1$, $P_{pr} = 0,1 \cdot 10^{-3}$ W, $d = 6731 \cdot 10^3$ m, $f = 13,56 \cdot 10^6$ Hz, $b = 64$ bit, $I = 1$ block/s. Longitude and latitude of two points are taken from the calculation of geographical coordinates in the Nizhny Novgorod region: $\lambda_1 = 55,83^\circ, \varphi_1 = 45,05^\circ, \lambda_2 = 55,89^\circ, \varphi_1 = 45,00^\circ$.

In figure 3 shows a graph of the dependence of power consumption on the power of the radio signal at different values of the signal flow frequency.

An increase in the frequency and power of the radio signal, entails an increase in power consumption, it is most beneficial to use lower frequencies, because the antenna aperture is proportional to the square of the wavelength.

The dependence of power consumption on the transmission intensity of the block at different values of the signal flow frequency is shown in Figure 4.

The graph shows that with an increase in the transmission intensity of the block, the power consumption also increases, this also applies to the signal trans-mission frequency.

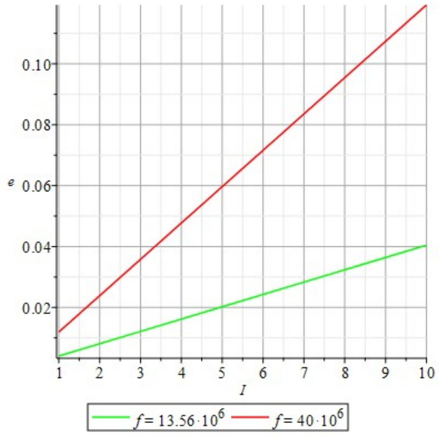

Figure 4: A graph of the dependence of power consumption on the transmission intensity of blocks at different values of the signal flow frequency.

4. Conclusion

In the course of the study, an analysis of existing routing protocols was carried out, it was revealed that the power consumption of a wireless sensor network largely depends on the routing protocol. Due to the optimally built algorithm for transmitting the data packet, energy consumption can be minimized.

An experimental study was carried out, in the course of which a spatial-energy model of a wireless sensor network was obtained, which allows calculating the power consumption of the network taking into account geographical coordinates.

A numerical calculation of energy consumption is carried out taking into account spatial characteristics, and graphs of the dependence of energy consumption on various characteristics of a wireless sensor network are constructed.

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