Research on the Energy Characteristics of Routing in Wireless Sensor Networks

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Abstract. Sensory devices in agriculture are essential for building a smart farm. With the help of them, continuous monitoring of the entire production is carried out, indicators of temperature, humidity, etc. are monitored.Sensor devices in the aggregate are a sensor network. The most common cause of failure of the touch device is the depletion of battery power. Power consumption is a random variable that is influenced by many factors such as: the distance between the touch device and the base station, the number of repeaters, routing protocol, etc. In this regard, it becomes urgent to study the physical characteristics of sensor devices in order to reduce energy consumption, thereby increasing the period of operation. The paper considers the physical characteristics of sensor devices on the sensor field. The aim of the work is to study the physical characteristics of sensor devices in agricultural applications based on wireless communication technology, depending on network parameters and technical characteristics of sensor devices. The classification of protocols and routing algorithms are analyzed in the paper. An experimental study are conducted. In the course of the study, a theorem is obtained and proved, which allows one to determine the route of message transmission from the source node to the base station at which the minimum power is expended, and a numerical calculation is carried out confirming the provisions of the theorem.

Keywords: wireless sensor network · digital agriculture · energy consumption · Internet of things · smart things · radio signal strength · routing protocol .

1 Introduction

The digital transformation of many areas of human activity cannot ignore agriculture. Along with the digitalization of financial [1], educational [2] and other activities, production activity is also being digitized. As the data [3] show, this brings a significant effect in both agriculture and animal husbandry. The introduction of IoT has reduced water costs by more than 20% thanks to irrigation systems, from 5 to 15%, the cost of seeds was reduced due to precision farming, as a result, productivity increased by more than 10%.

Implementation of Digital Farm technologies allows reducing enterprise costs by about 15% due to efficient feed use and reducing the production cycle, labor costs are reduced due to reduced staff, in addition, the cost of veterinary services is reduced due to the timely detection of diseases, in general, the average cost savings in livestock production is 15-20%.

Among the information systems that allow to achieve such results, belongs to the Internet of things, combining technology for identifying objects, wireless communication networks, autonomous power supply, sensors, etc.

The properties of the Internet of things are largely determined by the properties of wireless networks using end-to-end wireless access technologies [4] for the organization of information interaction of sensor devices distributed in the space of agricultural land. Sensor devices are used, for example, to control the level of moisture and mineralization of the soil, light level and wind strength, temperature monitoring, monitoring animal movement, monitoring animal health, etc.

Work on the creation of such devices is carried out at Knyagininsky University [5]. An example is an unmanned aerial vehicle and a system for monitoring the technological process of cultivating crops in the territory of the Nizhny Novgorod region (see Fig. 1). Scheduled aerial photography is carried out using a drone with a camera, which records in the visible and thermal ranges and allows reliable and timely monitoring of cultivated land and pastures. UAVs are capable of collecting landing information sufficient for accurate application of pesticides in specific locations and herbicides where chemicals are needed. This allows you to save on the use of chemistry, as well as save the environment. At the moment, seven ultralight aircraft with a payload capacity of up to 800 grams of payload have been manufactured, more than 320 hours of flight on a flight simulator and 570 hours of flight on real UAVs, built three-dimensional models of geo-surfaces with the determination of elevations and rendering of the relief.

Another example is the cattle monitoring device, which is being developed at Knyagininsky University. The device will consist of a collar on which there will be several sensors that monitor the condition of the animal, determining the amount of food consumed, the degree of mobility, and this will also allow you to find out the amount of milk yield from cattle. This device is designed to determine the activity of cattle, this allows you to timely prevent the development of diseases, and also identify livestock in a state of hunting, for more productive farming, and reducing costs and resources for continuous spot monitoring of livestock.

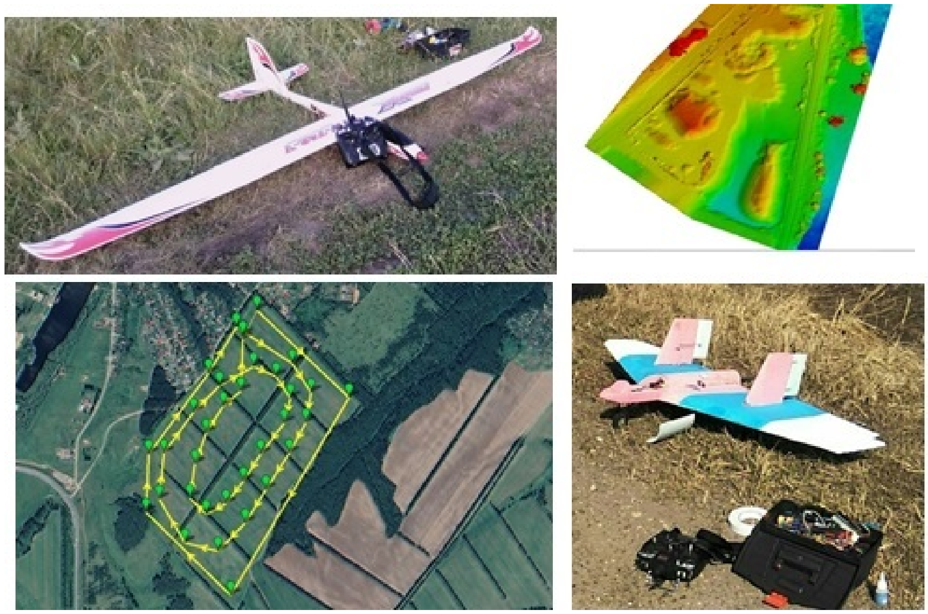

Fig. 1. Unmanned aerial vehicle and a system for monitoring the technological process of cultivation of crops in the territory of the Nizhny Novgorod region.

In addition, a data visualization system has been developed using augmented reality for devices of the Internet of things in digital agriculture. A smart collection point is a collection of devices, sensors, sensor actuators for collecting and transmitting data. The server, in this case, is a service providing a platform for processing streaming data coming from a smart collection point and proxying system client requests for some permanent network address. The client for displaying information is any device running Android OS version 4.4 or higher. An application based on Unity and the Vuforia framework is used to interact with the server. The application requests streaming data from the server, and also interacts with a physical label using augmented reality technologies, projects data from sensors. Application testing was carried out on augmented reality glasses EPSON MoveRio BT-300.

The effect of using sensor devices to monitor the state of agricultural land arises when they are massively introduced and used to collect the data they generate using wireless sensor networks [6]. At the same time, there are problems with the power supply of devices that in the vast majority of applications cannot be provided with centralized power and receive energy for the implementation of their functions from an autonomous battery. The lifespan of a device is mainly determined by the capacity of the battery and its energy consumption [7].

As studies [8, 9] show, the main consumer of battery energy is a radio transmitter, which consumes a million times more energy to process one bit than sensors or microcontrollers of a sensor device. In [10], it was shown that the main parameter by which it is possible to control the energy consumption of the radio transmitter is the distance between the antennas of the interacting sensor devices. The required signal power at the transmitting antenna is directly proportional to the square of this distance, therefore, in a number of cases, the use of sensor devices that are located "on the path" of signal transmission as repeaters reduces the overall power consumption of the "source- repeater" pair.

The distance which in the process of functioning of wireless touch devices will have to overcome the signal emitted by the transmitting antenna, depends on the routing protocols. In this case, routing is understood as the process of determining the transmission path of a data packet from one node to another in communication networks. To find the best way to transmit a data packet, a data routing algorithm is used, which in the general case consists of 3 stages: 1. the allocation of the headers of the packet destination addresses; 2. search in the routing table of the line corresponding to this address; 3. update the packet header, and transfer it to the switching unit [11].

In [12, 13], a classification of routing algorithms is given, for clarity, this classification must be constructed as follows (see Fig. 2). Using routing algorithms,

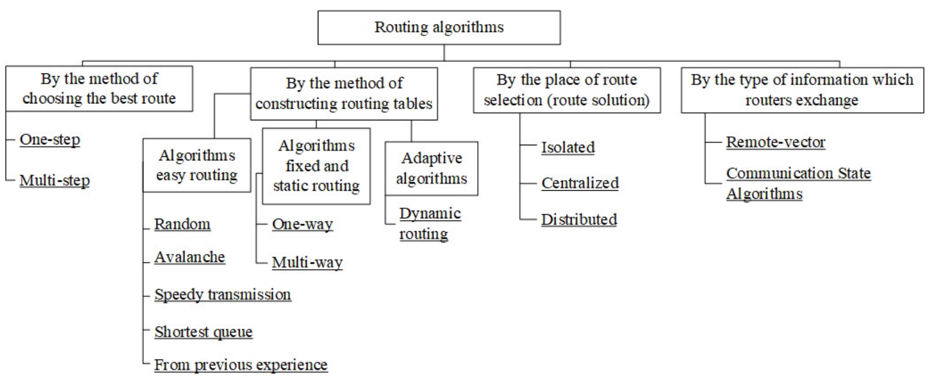

Fig. 2. Classification of routing algorithms.

routing protocols are implemented. The classification of routing protocols is given in [14, 15] based on the research data, the following classification is given (Fig. 3). Topological protocols have information about all routes, and use data on existing connections between nodes, while geographic ones use satellite data on the geographical location of nodes, using this data, connectivity between nodes is predicted.

Proactive, also called table protocols, send messages about changing the network topology, based on this information, the node builds a route to other network nodes and stores it in the routing table, these protocols guarantee a minimum packet delay time, but network overload often occurs due to sending messages. Reactive protocols work at the request of the network, the node that

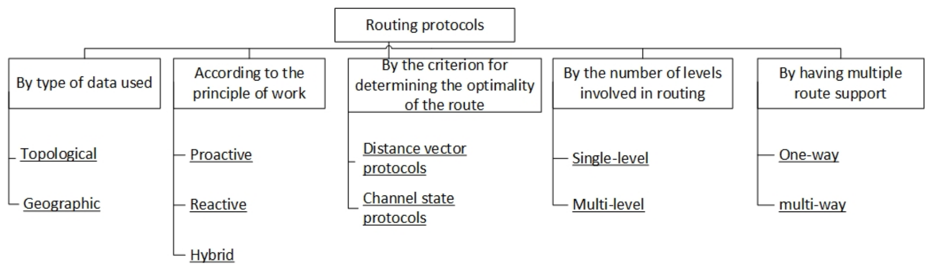

Fig. 3. Routing Protocols Classification.

is about to start transmitting the packet sends information about the start of transmission throughout the network, the node that receives the packet sends confirmation to the sender, along the established route, which is saved in the routing table, in case of repeated transmission , if gaps appear on the line, the process of searching for a new route starts. Hybrid ones are a mixture of proactive and reactive protocols, the network is divided into several subnets with proactive protocols, and the interaction between subnets is implemented using reactive protocols, this reduces the network load and the size of routing tables.

Distance vector protocols always choose the route with the smallest number of repeaters, unlike channel state protocols, which, in addition to repeaters, take into account other criteria, such as delayed packet delivery, bandwidth, etc.

Single-level routing protocols work only at one network level of the, and multi-level interact with several levels, while receiving additional information about the routes.

One-way protocols choose among all routes one that is most optimal for packet transmission and save it to the routing table, multi-way protocols enter several optimal routes into the table, and if a gap appears, an additional route is read instead.

There are several criteria for choosing the optimal route, for example, the minimum number of repeaters. The relief method allows you to find the shortest path by the criterion of minimizing repeaters [16]. The idea of reducing the number of repeaters is associated with the desire to reduce the time of message delivery, but in many agricultural applications this is not the main characteristic of the network functioning process. Delay can be measured in minutes and hours, and not fractions of a second as in other subject areas.

In agriculture, one of the main criteria for the functioning of a wireless sensor network is energy consumption [17]. When transmitting a message, the sensor device consumes a certain amount of energy, in order to increase the life cycle of the network, it is necessary to minimize the energy consumption of the sensor devices, this can be done by choosing the right routing algorithm.

2 Materials and methods

All studied protocols have a common idea - the choice of the most optimal route inside the wireless sensor network, to increase the reliability and performance of the network. We propose the development of this general idea.

The source sensor device according to a given routing algorithm solves the problem of selecting the route for transmitting a message to the base station. Inside this sensor device is a program that receives data from a satellite and, based on these data, determines the coordinates of other points and accordingly decides how best to transmit the message.

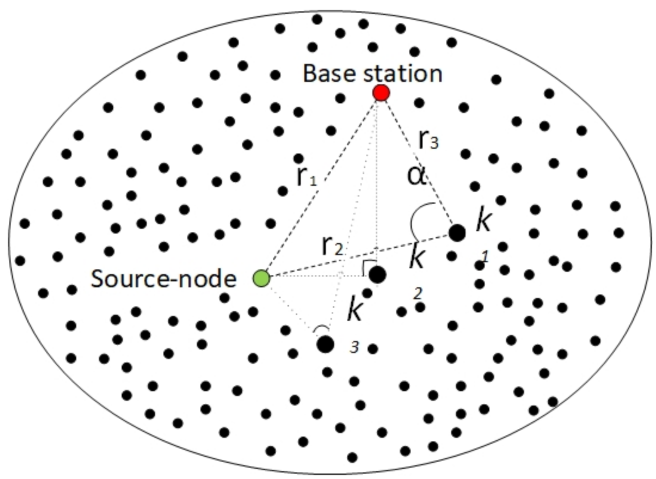

Fig. 4. The process of transmitting a message from a source-node to a base station.

Theorem 1. *The transmit power through the relay k 4). is less than the expended transmit power of the message directly from the source-node to the base station, provided that the angle* $\alpha \in (\pi/2; \pi]$*;the transmit power through the repeater is equal to the transmit power of the message directly from the source-node to the base station, provided that the angle* $\alpha = \pi/2$*,otherwise, the least power will be consumed when transmitting directly from the source-node to the base station.*

Proof. We prove the first case from the contrary. Suppose the following inequality holds:

$$P_{per}(r_1) < P_{per}(r_2) + P_{per}(r_3) \tag{1}$$

To calculate the power consumed, we substitute the distance in the Friis formula:

$$\frac{16P_{pr}\pi^2 r_1^2 f^2}{C_{per}C_{pr}v^2} \leq \frac{16P_{pr}\pi^2 r_2^2 f^2}{C_{per}C_{pr}v^2} + \frac{16P_{pr}\pi^2 r_3^2 f^2}{C_{per}C_{pr}v^2} = \\ = \frac{16P_{pr}\pi^2 f^2}{C_{per}C_{pr}v^2}(r_2^2 + r_3^2) \tag{2}$$

Multiply both sides of the inequality by a coefficient $\frac{C_{per}C_{pr}v^2}{16P_{pr}\pi^2 f^2}$, by condition, this coefficient is always positive, therefore, it will not affect the change in inequality.

$$r_1^2 \leq r_2^2 + r_3^2 \tag{3}$$

The resulting inequality contradicts the corollary of the cosine theorem, which means the assumption is not true, which proves this theorem. For the second and third cases, the proof is similar.

3 Numerical calculations

For cases when $\alpha \in (\pi/2; \pi]$ let the distances have the following meanings: $r_1 = 9, r_2 = 6, r_3 = 5$. We will perform the calculations with the following indicators: the power of the radio signal at the received antenna $P_{pr} = 0.1 \cdot 10^{-3}$, coefficient transmit antenna gain $C_{per} = 1$,coefficient receive antenna gain $C_{pr} = 1$,speed of light $v = 3 \cdot 10^8$, signal frequency $f = 13.56 \cdot 10^6$.

We calculate the power spent transmitting a message directly from the source-node to the base station using the Friis formula:

$$P_{per}(r_1) = \frac{16P_{pr}\pi^2 r^2 f^2}{C_{per}C_{pr}v^2} = 0.00261 \tag{4}$$

The next step is to calculate the power spent transmitting the message through the repeater $P_{per}(r_2) = 0.00116$, $P_{per}(r_3) = 0.00080$. The total power consumed during transmission through the repeater is 0.00196.

Thus we obtain that:

$$P_{per}(r_1) > P_{per}(r_2) + P_{per}(r_3) \tag{5}$$

For cases when $\alpha = \pi/2$ let the distances have the following values: $r_1 = 5, r_2 = 4, r_3 = 3$. We perform calculations similar to the previous ones, we obtain $P_{per}(r_1) = 0.000806$, $P_{per}(r_2) = 0.000516$, $P_{per}(r_3) = 0.000290$. Then the total energy expended during transmission through the repeater is 0.000290. Thus we obtain that:

$$P_{per}(r_1) = P_{per}(r_2) + P_{per}(r_3) \tag{6}$$

Therefore, when the angle $\alpha = \pi/2$,the same power is expended both when transmitting a message directly and when transmitting through a repeater.

For the third case, when $\alpha \in (0; \pi/2)$ let the distances have the following values: r1 = 9, r2 = 6, r3 = 7.

We perform calculations similar to the previous ones, we obtain $P_{per}(r_1) = 0.00261$, $P_{per}(r_2) = 0.00116$, $P_{per}(r_3) = 0.00158$. Then the total energy expended during transmission through the repeater is 0.00274. Thus we obtain that:

$$P_{per}(r_1) < P_{per}(r_2) + P_{per}(r_3) \tag{7}$$

Therefore, when transmitting a message through a repeater, the power spent on transmitting a message is greater than when transmitting directly from a source-node to a base station.

4 Conclusion

In the course of this study, classifications of protocols and routing algorithms were analyzed, it was revealed that the wireless sensor network operates under the control of the routing protocol. To reduce power consumption in the network, you must select the most optimal routing algorithm.

A theorem is obtained and proved that allows one to determine the route for transmitting a message from the source-node to the base station at which the minimum power is expended. It was revealed that if the angle formed between the distances of transmission of the message through the relay is greater than 90°, then it is more advantageous to transmit using the relay, and not directly from the source node to the base station.

An experimental study was carried out, during which numerical calculations were carried out, allowing to confirm the provisions of the theorem.

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