Wireless data collection technology in automated process control systems

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Abstract. This paper describes an example of a wireless data transmission network in a control system. The wireless network is proposed to be based on ISA100.11A standard. The object of automation is a training-simulator complex designed for energy resources accounting. Simulator automation complex scheme based on wireless technology is presented in the form of three-level hierarchical structure. The lower level includes field equipment using wireless technologies. The controller level accommodates the control computer complex. The upper level is represented by the computer equipment on the basis of which the workplaces of operators, engineer's and MAC resource manager's stations, as well as PC designed to work with the MAC wireless network control stations are implemented. A reasonable choice of a wireless field instrumentation system based on the ISA100.11a standard has been made in order to create an automation system for the training and engineering complex. The paper also presents the main stages of the calculation of a wireless field network. These stages include calculating the information load of the network using the Nazarov methodology and calculating the energy parameters of the network, taking into account the total losses in radio wave propagation.

1 Introduction

During the operation of process equipment, even a single unplanned downtime due to an abnormal or emergency situation can have a variety of negative consequences. Start-ups and shutdowns require a huge amount of energy, which significantly increases the energy consumption of the plant [1]. The financial cost of repairs and start-ups has an impact on operating costs. In addition, unplanned emissions of pollutants into the environment occur as a result of production activities, which has a negative effect on the environment. The natural desire of plant owners and managers is to reduce unplanned downtime. One of the ways of achieving this goal in recent years has been the introduction of wireless data transmission technology in production facilities to solve the most difficult tasks [2]. The use of wireless technology makes it possible to obtain information that was simply unavailable in the past due to the high cost of measuring equipment or physical limitations. Also, wireless technology makes it possible to add new data acquisition points, use the intelligence of existing field devices, including alarms and limit value alarms during the normal course of the technological process [3].

The use of wireless networks is in some cases a more rational solution than wired networks, as they offer the following advantages:

- installation of wireless devices in places where the functioning of wired devices is impossible or economically impractical;
- possibility of creating an intelligent digital network which, apart from communication functions, ensures monitoring of the status of measuring and executing devices, monitoring of the status of diagnostic systems and changing of adjustment parameters of devices;
- autonomy, which is achieved by ensuring the operation of wireless sensors from the internal battery pack;
- security. A high degree of protection against unauthorized access and information leakage is ensured by controlling the connection point and using reliable data encryption algorithms [4, 5].

Wireless technology in process and production automation enables real-time access to information about the control object. Industrial wireless devices take into account specific industry features that enable their use in the following industries:

1) oil and gas;
2) in transport;
3) energy industry;
4) mining industry, etc.

Wireless technologies provide an opportunity to connect measuring instruments with a wireless network for further transmission of information through a wireless gateway to an automated control system [6].

In the era of ubiquitous implementation of wireless technology, as well as to familiarize students on specialized specialties, it is proposed to consider an example of creating a wireless data transmission network of measurement data in APCS using modern field-level wireless technical means [7, 8].

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To develop wireless networks in automation systems, it is necessary to consider the following list of issues: study of network organization features, analysis of wireless data transmission technology, creation, calculation and design of wireless network structure for an object and proper placement of access points [9].

In this work it is proposed to build a wireless data network based on the ISA100.11a standard, as this standard is the first in the open ISA100 family of standards, which focuses on the needs of the manufacturing industry. This enables the rapid creation, modification, optimization, and scaling of wireless networks [10].

ISA100.11a was developed by the International Society for Automation and is based on open standards such as IPv6 and UDP. The structure of an ISA-100.11a based network is shown in figure 1.

The network consists of: nodes with switching function (routers), nodes without packet switching function (I/O nodes), handheld device, core routers, system manager, security manager, and gateway.

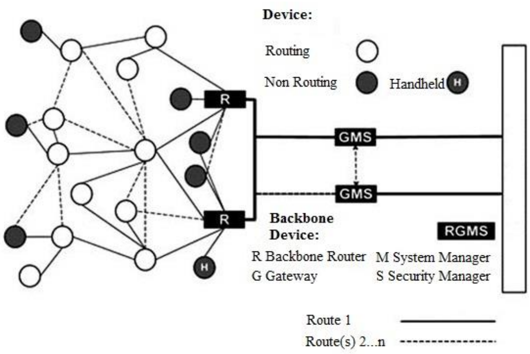

Fig. 1. ISA-100.11a network structure

With this structure, data is transferred from sensors to destination in multiple stages, with routers being responsible for correct data forwarding, using different information delivery paths for increased reliability.

ISA100.11a has the capability of using trunk routing and the ability to use individual field devices in switching mode. The use of trunk routing can significantly improve the response times of standalone field devices and reduce the load on their power cells. The time slots in ISA100.11a are variable.

The network based on ISA100.11a standard can serve a variety of devices that transmit data periodically and require time synchronization. And also, those that are most of the time are inactive, i.e., the transfer message packets, occurs only if the data changes or when the events that do not require time synchronization happen [11-15].

2 Materials and methods

The object of automation is a training-simulator complex, designed for accounting different kinds of energy resources [16].

The complex consists of three laboratory units:

- laboratory bench, simulating operation of heat energy metering unit;

- a laboratory bench, simulating operation of a liquid energy carrier (petroleum product) metering unit;

- a laboratory bench simulating the operation of a commercial metering installation for gaseous energy carriers.

Figure 2 shows the three-level hierarchical structure of the complex of technical means of automation of the training and training complex based on wireless equipment.

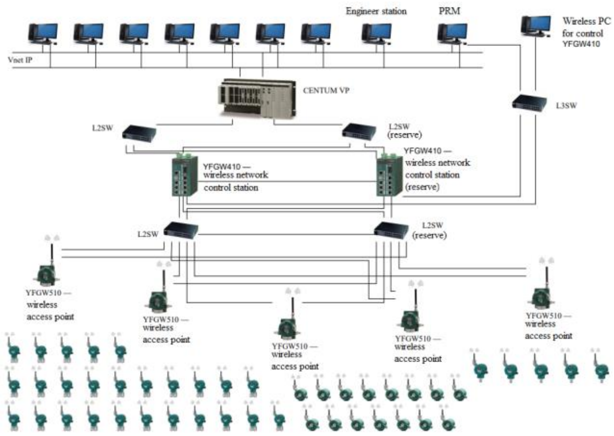

Fig. 2. The structure diagram of the complex of technical resources of automation of the training complex based on wireless equipment

The lower level comprises field equipment using wireless technologies.

The higher level contains the control computer complex based on the CENTUM VP controller.

The upper level is represented by the computer equipment on which the operator workstations, the M&E engineer and resource manager stations, and the PC designed to work with the wireless M&E control stations are implemented [17].

Communication between the field equipment and the controller is performed using the unified open industrial communication protocol ISA 100.11a. Communication between the controller and the computer equipment is based on specialized industrial computer networks that provide a complete cycle of data exchange between the devices [18].

3 Results

To implement the automation system of the training complex on the basis of ISA100.11a, it is proposed to replace existing equipment with equipment using wireless technology.

To measure the temperature of media, platinum temperature converters and thermocouples complete with YTA510 wireless transmitters which convert signals from primary measuring transducers into a unified open industrial communication protocol ISA 100.11a. YTA510 transmitters have two inputs: one for differential temperature measurement and one for average temperature measurement. They also offer a redundancy feature that allows automatic switching to a back-up probe, thus increasing reliability in the use of these transmitters in potentially hazardous environments [19].

It is proposed to measure pressure in measuring lines using the EJX510B wireless absolute and gauge pressure transmitter. It is capable of measuring pressure of liquids, vapours and gases. The DPharp technology implemented in this type of sensors enables simultaneous measurement of differential and static pressure, which eliminates the need for additional pressure sensors [20].

Differential pressure measurement on filters, flow, level and density measurements will be carried out with the EJX110B wireless pressure and differential pressure transducer [21].

In order to create a distributed wireless network of ISA100 standard with topology control capability, it is proposed to use wireless instrumentation access point YFGW510 [22]. The availability of various communication interfaces allows the KIP wireless access point to connect through various types of interfaces, while the built-in Duocast function provides reliable redundancy at each level of the wireless network.

The YFGW410 MRC Wireless Management Station acts as a router (gateway). Together with wireless access point YFGW510 it ensures secure operation of the network as well as performs firmware and software updates of wireless sensors [23].

In addition to equipment selection, it is also necessary to calculate the information load of the network and calculate the energy parameters of the network [24].

Calculation of information load is made by using Nazarov's method. The expected load taking into account the number of subscribers and the number of applications is defined as:

$$B_{ip}^{K} = N_{ai}^{K} \cdot T_{c}^{K} \cdot \gamma_{i}^{K} \cdot B_{max}^{K}, \quad (1)$$

where N_{ai}^{K} – the number of K-service subscribers at the site i; γ_{i}^{K} – the number of requests received from a K-service subscriber per unit of time, equal to

$$\gamma_{i}^{K} = \frac{l}{t} \quad (2)$$

$$\gamma_{i}^{K} = \frac{\gamma_{N}^{K}}{3600}, \frac{1}{s} \quad (3)$$

where γ_{N}^{K} – number of calls to the Kth service in the highest load hour; T_{c}^{K} – the average duration of a subscriber's session per time unit; B_{max}^{K} – maximum speed of the K-service.

In this case, subscribers refer to the number of wireless sensors in use, of which there are 46.

Consider the case where all sensors are polled at the same time, i.e. $\gamma_{N}^{K} = 46$, that said $T_{c}^{K} = 5s$. The ISA100.11a data rate will then be

$$B_{max}^{K} = 256\,kbit/s. \quad (4)$$

The total expected load on the wireless control station is calculated using the formula:

$$B_{\sum p} = \sum_{K=1}^{K} B_{np}^{K}. \quad (5)$$

Next, the minimum throughput for a single service on the application layer must be calculated. The number of applications will be determined by the formula:

$$\gamma^{1} = \frac{\gamma_{N}^{1}}{3600} = \frac{46}{3600} = 0.0128 \quad (6)$$

Thus, the load at the application level will be

$$B_{p}^{1} = 46 \cdot 5 \cdot 0.0128 \cdot 256 = 753.664\,kbit/s. \quad (7)$$

In doing so, this load at the transport level will increase by an amount of $K_{TCP} = 1.0156$.

As a result, the expected load at the transport level will be

$$B_{\sum TCP} = K_{TCP} \cdot B_{\sum np} = 1.0156 \cdot 753.664 = \\ = 765.42\,kbit/s \quad (8)$$

The wireless network to be projected should be connected over a 100BaseTX interface or higher. The network level load will be calculated

$$B_{\sum cem} = K_{IP} \cdot B_{\sum TCP} = 1.0156 \cdot 765.42 = \\ = 777.362\,kbit/s \quad . \quad (9)$$

When calculating the energy parameters of the network, the total propagation loss, which includes losses in free space, in partitions and walls inside the building as well as losses due to interference and fading of the signal, must be taken into account, i.e.:

$$L_0 = L_1 + L_2 + L_3, \quad (10)$$

where L_0 - total radio propagation losses; L_1 - free space losses; L_2 – losses in partitions and walls inside the building; L_3 - losses due to interference and signal fading.

Free space losses are determined by

$$FSL = 33 + 20(lgF + lgD), \quad (11)$$

where *FSL (Free Space Loss)* – free space loss, dB; F - central frequency of the channel on which the communication system operates, MHz; D - distance between two points, km.

The total system gain is equal to

$$Y_{dB} = P_t + G_t + G_\tau + P_{min} + L_t + L_\tau + L_P, \quad (12)$$

where P_t is transmitter power, dB mW; G_t is transmit antenna gain, dB; G_τ is receive antenna gain, dB; P_{min} is receiver sensitivity at a given speed, dB mW; L_t is signal loss in the cable and connectors of the transmit path, dB; L_τ is signal loss in the cable and connectors of the receive path, dB; L_P is attenuation of electromagnetic wave in objects (loss). Due to the fact that the equipment is located within one room, losses in objects can be neglected.

In order to account for some of the disturbing factors affecting the communication ranges, a concept such as radio energy reserve is introduced into the calculation and accordingly free space losses can be defined as follows:

$$FSL = Y_{dB} - SOM, \quad (13)$$

where *SOM* (*System Operating Margin*) is the margin in radio power (dB).

Normally the *SOM* is taken to be 10 dB, as it is believed that a 10-decibel margin of gain is sufficient for engineering calculation.

The result is a formula for the communication range::

$$D = 10^{\left(\frac{FSL}{20} - \frac{33}{20} - lgF\right)} \quad (14)$$

To determine the signal loss in the free space and calculate its range, it is necessary to analyze the technical specifications of the equipment used:

- the output power of the YFGW510 access point and the YFGW710 gateway is 11.6 dBm;

- the gain of the two internal antennas is 2 dB.

Wireless sensor specifications EJX110B, EJX510B and YTA510:

- output power is 11.6 dB;

- dipole antenna gain is 2 dB;

- Sensitivity for ISA100.11a standard is - 90 dBm or less.

Taking into account the characteristics considered, the free space loss is:

$$FSL = 11.6 + 2 + 2 - (-90) - 1 - 1 - 0 - 10 = 93.6 dB \quad (15)$$

when range is:

$$D = 10^{\left(\frac{93.6}{20} - \frac{33}{20} - lg2425\right)} = 0.442 km = 442 m. \quad (16)$$

4 Conclusion

The wireless network project was implemented on ISA100.11a standard using 5 YFGW510 access points for redundancy and scalability.

The network will be computer controlled using a wireless field control station connected via a Layer 3 switch using a CAT-5e cable fitted with an RJ-45 connector. The control station will be connected to the controller and to the access points via Layer 2 switches using a CAT-5e cable fitted with an RJ-45 connector.

The information load on the projected data transmission network will be 777.362 kbit/sec, the total system gain will be 103.6 dB and the range will be 442 meters.

This project will allow students of specialized professions to consolidate in practice the theoretical knowledge gained about the features of creating and configuring wireless networks based on the ISA100.11a standard.

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