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COMPLEXATION OF TELECOMMUNICATIONS AND ELECTRICAL SYSTEMS IN MINES AND UNDERGROUND FACILITIES

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The possible options for the integration of telecommunications and electrical systems of mining enterprises are considered. Based on an analysis of the current state and prospects for the development of telecommunications systems, various technical solutions are proposed for sharing the power supply networks available in mines and underground structures in order to solve the problems of telecommunication, automate process control and ensure the safety of operations. The analysis of the possibilities of applying the PLC technology in underground structures and mines for solving specific telecommunication problems has been carried out, and examples of their possible technical and hardware implementation are given.

Key words: complexation; power supply network; telecommunications; energy interchange; energy compatibility

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Introduction. Mining and coal mining industries of our country have traditionally been considered as a the foundation of its economy. Tendencies of modernization of technological processes and increase of the level of production management efficiency are especially noticeable here. In order to ensure and develop competitiveness, advanced Russian mining enterprises are increasingly investing in finding and developing new fields, equipping enterprises with a modern fleet of transport equipment for open and underground mining, developing power supply systems, and improving various auxiliary equipment [1].

Along with this, the level of accidents and injuries is growing at an alarming rate in the mining industry, and the miner's profession is one of the few modern professions with extremely high levels of risk [5]. The creation of extreme emergencies in the mining enterprise leads, as a rule, to loss of personnel management and leads not only to significant material losses, but also to human losses. These circumstances predetermine the specific requirements for telecommunication networks and equipment of such enterprises. One of the most important areas of modernizing the technological equipment of mining enterprises is to ensure occupational safety, which can be achieved by replacing obsolete and outdated mine ventilation equipment, drainage systems, technical diagnostics, as well as installing a system of non-contact environmental monitoring sensors in mines and the construction of modern alert systems and communications.

In recent years, the situation with telecommunications in Russian mines has begun to gradually improve, and more and more mining companies are beginning to introduce modern telecommunications solutions and technologies. The opportunities provided by telecommunication systems to quickly obtain up-to-date information on the progress of work significantly reduce the likelihood of various production errors and violations of their production technology, and also make it possible to optimize the coordination of rescue operations. According to some estimates, after the introduction of modern telecommunications systems, production time can be reduced to 30-50 % [2]. New telecommunications systems are designed to not only optimize the production process, but also significantly improve occupational safety. As noted by the leadership of the Ministry of Energy of Russia, almost all major accidents with casualties in coal mines in recent years have been caused by explosions of methane-air mixture with the direct participation of coal dust. In this regard, regardless of the technologies used, telecommunications facilities in mines

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and at facilities of other industries where there is a risk of fire or explosion must meet certain specific requirements. In particular, telecommunications equipment used in explosive atmospheres must be certified for compliance with Russian explosion protection standards [1]. Separate requirements are imposed on communications in coal mines. In particular, they should be equipped with a backup alternate link with the rescue service.

At present, the most famous companies in the Russian market among manufacturers and suppliers of various types of security systems that provide communications, warning and locating personnel in mining, are: Information Mining Technologies LLC (Russia), Mine Radio Systems Inc. (Canada), Davis Derby Ltd (United Kingdom), Information Industry LLC (Russia), Radius National Exhibition Center (Russia), Granch NPF (Russia) and some others [1].

For all the listed security systems, the most important parameters of operation are the data transfer rate and the associated data update rate, the reliability of the system as a whole, and the reliability of its components. As a rule, all manufacturers of security systems use wired and wireless communication channels, providing informational and functional balance (Fig.1).

Most manufacturing companies use high-performance wired systems built on copper cable or optical fiber for their main wired highways. For example, MRS (Flexcom), DavisDerby (MineWatch, WiPan), Ingor-Tech (MIKON) systems use only optical and copper communication lines with 100BASE-FX, TX performance, which corresponds to a speed of 100 Mbps, to build the basic

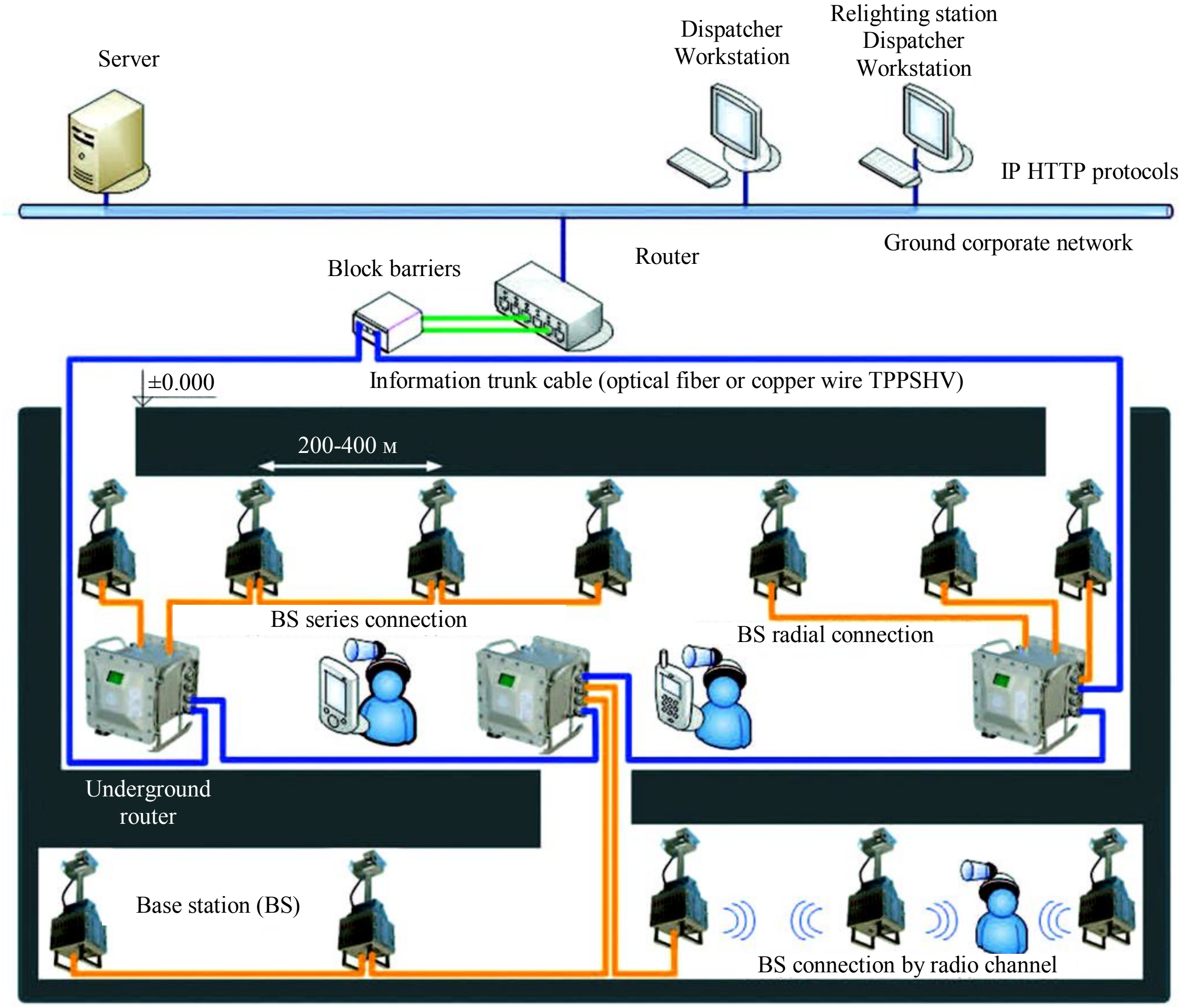

Fig.1. SBGPS Underground Infrastructure [1]

data transmission infrastructure /with. In the systems of NPF Granch (SBGPS) [6] and Cisco (ConnectedMining), in order to ensure high performance of data transmission lines, they also use only copper and optical cables that provide throughput in the range of 100-600 Mbps.

The main differences between these systems are related to the number of network nodes and the power supply methods chosen. It is known, for example, that copper «twisted pair» (Ethernet 100BASE-TX) has a significant limitation on the length of the wire connecting the nodes. Therefore, every 100 m of the network you need to install the next node, or provide a signal amplifier, which also requires wired power. Equipment manufacturers are trying to overcome this limitation in various ways. So, for example, DSL-modems are used in the equipment of the Ingortech company, and Granch NPF engaged special SBNI-modems of its own design. These developments provide an increase in the length of wired sections up to 400-450 m without a significant reduction in the performance of the main line. For sections of optical networks of the Ethernet 100BASE-FX standard (100 Mbit/s) and Ethernet 1000BASE-FX (1 Gbit/s), there are practically no limitations on typical «mine» topologies. The only limitation in building the main wiring of the system is the wired power line of the communication nodes, since in an explosive environment there is a restriction on the electrical power transmitted as well as the capacity of batteries for autonomous power sources.

If for communication over wired lines, different companies use similar technologies, in the wireless communication segment, everything is different. The overall performance of a wireless node in a telecommunications system depends on the communication protocol used and on the specific technical implementation (power, antennas, orientation stability in development) and the topology of the wireless network (location of communication nodes, number of nodes in the subnet). The scope of standards for modern wireless transmission of information is shown in Fig.2. In Fig.2, for comparison, gray indicates the scope of standards for wired network segments.

Based on the principles of digital signal processing in telecommunication systems, an increase in the speed of data transmission is usually associated with an increase in the frequency at which the

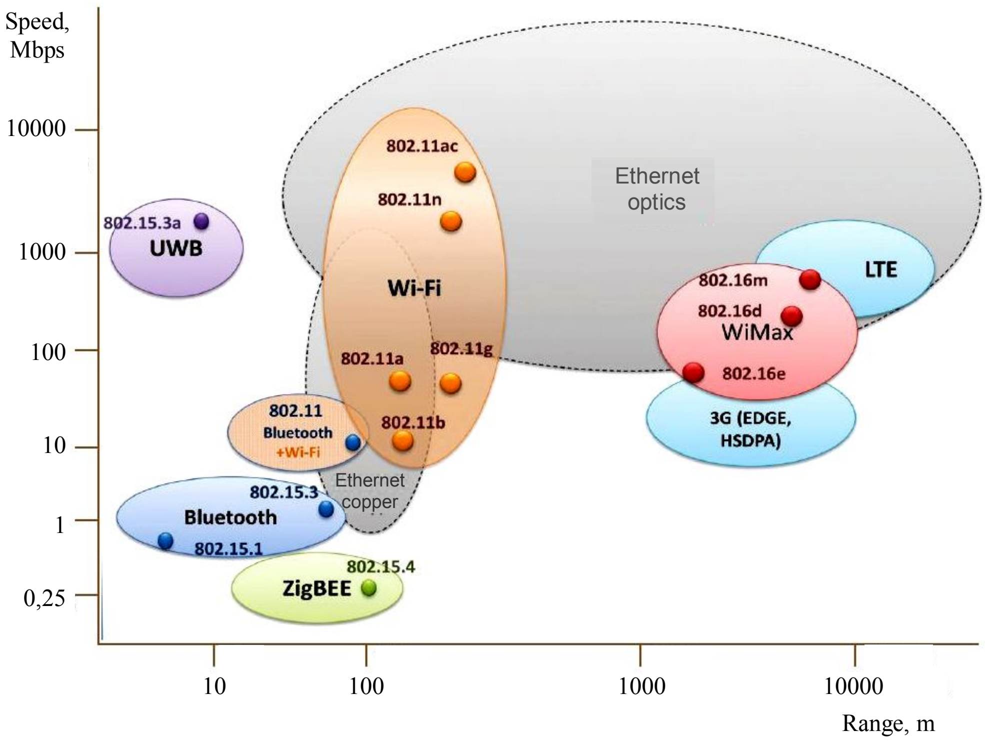

Fig.2. Coverage area of various standards of modern telecommunications systems [1]

system operates. To efficiently transfer data from any point on the network, it is necessary that all involved segments of this network have close performance [4]. These considerations are based on the development of modern wireless technologies [3]. Standard solutions in this area are usually implemented on the basis of wired highways, complementing them with equipment configurations using wireless WiPAN communication nodes, networks based on ZigBEE technology (IEEE 802.15.4, 250 Kbps).

For example, Mine Radio Systems' Flexcom system offers a «ring» mag for data transmission based on fiber-optic technology with coverage expansion using a wireless technology-based segment (IEEE 802.15.4, 250 Kbps). Developers of domestic systems are working in this direction. Thus, the well-known manufacturer of Russian automated process control systems, the company Ingortekh, also uses radio routers based on NanoLOC technology (IEEE 802.15.4, 1 Mbps) in its wireless segment [10]. A similar technical solution is used in the positioning and voice communication system Real-Trac «Mine» of the company «RTL-service» [11], but with the UWB technology. From our point of view, the wireless network segment is most efficiently implemented in Cisco devices (ConnectedMining) and Granch NPF (SBGPS). In these systems, the performance of the wireless segment corresponds to Wi-Fi technology (IEEE 802.11 b/g/n, 50-200 Mbps), which is comparable in speed to wired networks. In this case, the power of communication nodes radiated into space is within 20 dBm [9]. Transmission of signals into space is carried out using directional antennas.

When analyzing and researching the specific features of building wireless networks under the ground, it is necessary to consider not only quantitative, but also qualitative characteristics of the proposed solutions. For example, the «hidden node problem» was already mentioned: the influence of neighboring communication nodes on the overall performance of the entire network segment, typical of a series (chain) of wireless repeaters. According to some estimates, the network performance in this case can decrease by 8-10 times. For the same reason, solutions that use a large number of wireless nodes in one segment [11] are forced to limit the maximum segment length to 10-15 nodes.

The following conclusions can be drawn:

– mining enterprises should first of all be guided by the possibility of a phased development of telecommunications based on a single communication infrastructure;

– as a result of the analysis of options for implementing technical requirements for telecommunication systems based on solutions from various manufacturers, a significant number of flaws were discovered and problems were identified in ensuring their compliance with current regulatory documentation;

– to meet all the requirements for modern telecommunications systems, we can recommend the Cisco Connected Mining system or the SBGPS Granch system (a fairly effective combination of wired and wireless segmentation, providing wide functionality, high potential for increasing the load, sufficient survivability and resistance to accidents, the presence of scanning aero gas control, ensuring continuity of positioning in normal and emergency mode);

– further development of telecommunications systems in mines and underground structures requires the introduction of redundant alternative systems, especially for emergency services.

Methodology and technology. One of the possible directions for further improvement of telecommunication systems in mines and underground structures may be their complexation with power supply systems. The transmission of any information and the implementation of power supply via common wired channels is effectively carried out in various technological applications. There are situations when the implementation of laying new cables is either very undesirable or not possible. In such cases, it is almost always possible to limit oneself to the existing electrical infrastructure – to use

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the existing wire network of the power supply system to organize a sufficiently high-speed and stable information transmission channel that is branched throughout the structure.

Telecommunication technology PLC (Power line communication), based on the use of industrial power supply networks to ensure information exchange through the joint transmission of data by modulating the standard industrial alternating current, is quite simple in technical implementation, as well as high-speed installation of devices based on it. One of the first data transmission devices in power supply networks appeared in the 1940s, they were mainly used to solve signaling problems in power systems and on railways due to very low throughput [8]. In the last decade of the twentieth century, a number of different telecommunications companies implemented the first fairly serious projects in this area, but during their operation, major problems were discovered, the main one of which was low noise immunity. Operating at short distances from PLC-modems, various impulse devices, powerful power supplies and chargers, industrial electrical appliances, as well as electric motors and equipment with high power consumption caused impulse noise in unshielded high-frequency radiations of electrical wires, which, as a rule, caused sufficiently a marked decrease in the reliability and reliability of information transfer. The heterogeneity of electrical wiring lines, poor quality of wire materials and high wear of electrical networks, cable joints made of electrically non-uniform materials (for example, copper and aluminum), the presence of twists, etc. also did not contribute to the sustainable functioning of such systems, and especially their capacity. Thus, the total reduction in data rates could reach 20-60 %. In some cases, in buildings and places of operation of PLC-devices, deterioration in the operation of radio receivers at a distance of 3-5 m from the location of the PLC-modem, especially noticeable on medium and short waves, was recorded. This phenomenon appeared, as the electric network wires began to be radiating antennas, which significantly violated the electromagnetic environment [13].

The technology of transmission of information through the power supply networks was widely used commercially only at the beginning of our century, and its industrial introduction and rapid wide distribution were based on the appearance of the necessary element base, especially high-performance specialized microcontrollers and high-speed DSP processors (digital signal processors), which allowed for the implementation of special methods of digital signal modulation and modern highly reliable encryption algorithms. This circumstance allowed to achieve not only a high level of reliability of reliability in data transmission, but also to ensure their effective protection from unauthorized access. Equally important was the widespread introduction and dissemination of standardization in various areas of this technology. The most authoritative communities and organizations currently regulating PLC device requirements are IEEE, ETSI, CENELEC, OPERA, UPA and HomePlug Powerline Alliance. The latter organization is an international alliance, which brings together about 75 fairly well-known companies in the telecommunications market (Siemens, Motorola, Samsung and Philips) [8]. This alliance, organized in 2001, aims to organize and conduct research and practical tests to ensure the compatibility of devices from various manufacturers that use this technology, as well as to support and promote a single standard called HomePlug.

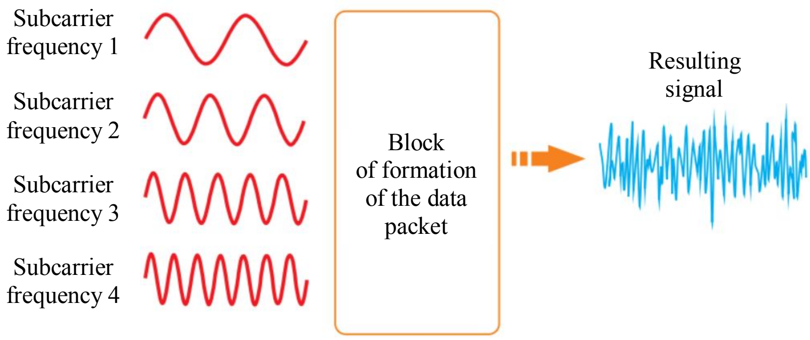

Fig.3. Frequency separation of the original signal [3]

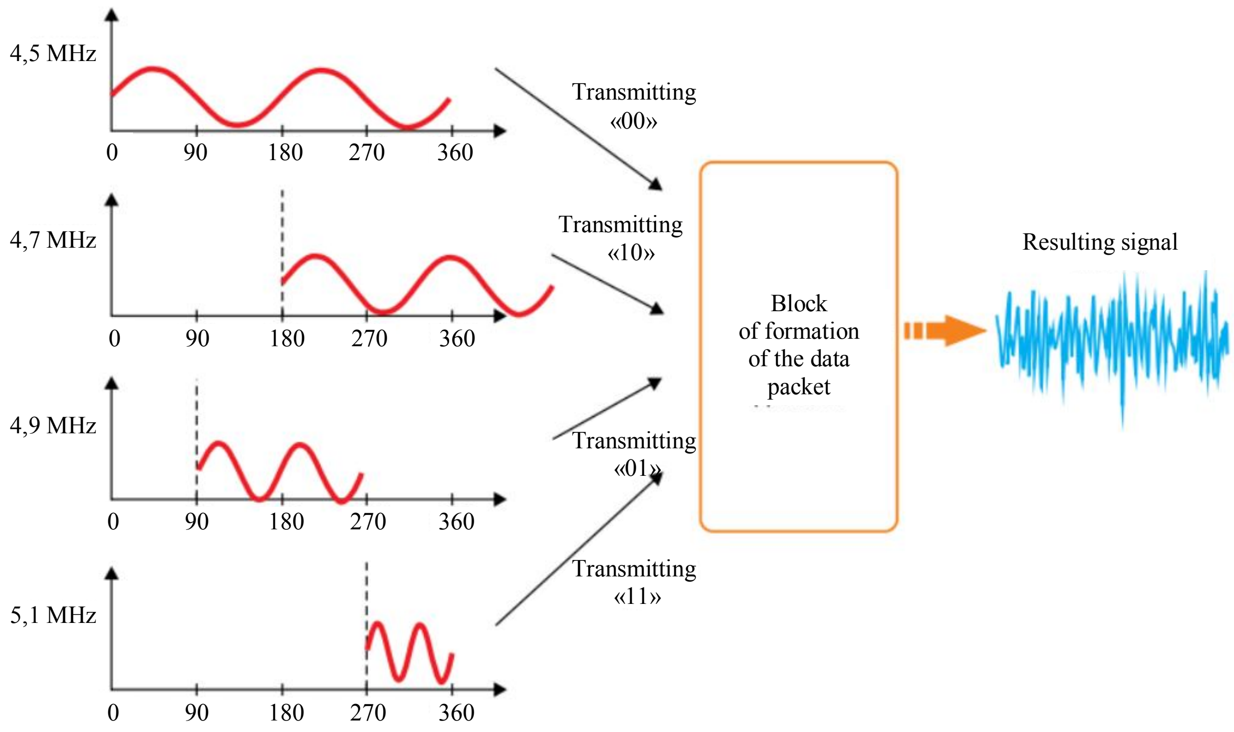

Fig.4. DQPSK signal modulation [3]

The basis of telecommunication and electrical systems complexation technology is the use of frequency separation of an information signal, as a result of which a high-speed data stream splits into several relatively low-speed streams, each of them is transmitted on its separate subcarrier frequency with a further connection to the resulting signal (Fig.3) [3].

When using traditional modulation with frequency division (FDM – *Frequency Division Multiplexing*) the available signal spectrum is consumed quite inefficiently. This is due to the presence of guard intervals inserted between different signal subcarriers necessary to counteract the mutual influence of signals. Therefore, orthogonal frequency-division multiplexing (OFDM – *Orthogonal Frequency Division Multiplexing*) has found wide application in PLC devices, in which the centers of all subcarrier frequencies are located so that the peak value of each next signal coincides with the zero value of the previous, available signal spectrum in this case will be spent more rationally.

Before starting the connection procedure into one common signal, all subcarrier frequencies included in it are subjected to a phase modulation process, each subcarrier modulated by its own bit sequence. After the end of this operation, they arrive at the signal conditioning unit, where they are combined into a common information packet, which is called an OFDM symbol. Figure 4 depicts an example of «relative quadrature phase shift keying» (DQPSK – *Differential Quadrature Phase Shift Keying*) for the selected four frequency subcarriers in the 4500-5100 kHz range.

In solving practical problems of PLC implementation, signal transmission is carried out, as a rule, with the use of 1536 subcarriers with further selection of a certain number of the best of them in the range from 4 to 64 MHz and depending on the state of the transmission line, also available interference level. The application of this method provides for the PLC-technology sufficient adaptability when used in various operating conditions. For example, a working PLC device may interfere with radio reception at certain frequencies. Another example is the case when a device or application already uses part of the operating range. Technological elimination of unwanted interference can be achieved by applying special settings, which are called Signal Mode and Power Mask on devices

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where appropriate capabilities can be provided. Signal Mode is a software method of allocating a certain operating frequency range, and Power Mask is a software procedure for limiting the band of frequencies used. Due to these methods, PLC-devices can operate stably together with radio communication systems in one common space and not make noise on the radio frequency band.

When transmitting information signals via the industrial power grid, very high levels of attenuation of the transmitted signal at some frequencies can also occur, which can lead to complete (partial) loss and distortion of the transmitted data. To ensure the adaptation of the signal information to the physical transmission medium, it is possible to apply the method of dynamic, inter-period signal switching, which allows detection and correction of errors, as well as the elimination of signal conflicts. The essence of this method is to organize continuous monitoring of signal transmission channels in order to identify the part of the spectrum where a certain threshold attenuation level is exceeded. When such a situation is detected, the use of the «problem» range is suspended for a certain period of time until an acceptable attenuation value is reached, and information data is transmitted at other frequencies during this period. The application of the proposed method will significantly improve the efficiency, reliability and noise immunity of the transmitted information.

Another significant difficulty that arises when transmitting information over industrial power supply networks is the presence of impulse noise, which can be generated by various network (charger) devices, lighting systems (especially halogen lamps), connecting and disconnecting from the network type of electrical devices. The seriousness of this situation is that the modem cannot always have time to adapt to the dynamic environmental conditions, since the duration of these processes may lie in the interval of several microseconds, and as a result, some of the bits contained in the information signal may be lost [3].

According to the results of the research, the use of the method of two-stage or cascade noise-resistant transcoding of bitstreams before their modulation and transmission over the data channel is proposed as the most effective way to combat impulse noise. Its essence is to add redundant («protective») bits to the source information flow of a predetermined algorithm, which will be used during subsequent decoding at the receiver to detect and correct the detected errors. For example, cascading a block Reed-Solo-mon code and a simple convolutional code decoded according to the Viterbi algorithm, allows correcting not only single errors, but also error packets, which significantly increases the integrity of the transmitted data [3]. It should also be noted that the use of robust coding will increase the security and integrity of the transmitted data from the point of view of ensuring their protection against possible unauthorized access.

Since a sufficiently extensive power supply network acts as a medium of information transfer, then at some point in time several devices connected to the network can begin to transmit information. In this situation, the resolution of intersection and traffic overlap conflicts can be achieved through some kind of regulatory mechanism, which is the Media Access Protocol (CSMA/CA). The resolution of conflicts occurs on the basis of the established system of priorities, which are set when organizing the prioritization of data transfer.

As one of the really working technological examples of the implementation of this technology, PLC products from Semtech can be cited, which is intended for use in various typical power supply lines with low or medium operating voltage [3]. The modem used in this technology, operating with an analog physical line, must have the functional units necessary for processing analog data, digitizing and, of course, for processing digital data. On the transmitting side, the modem must also encode digital data in accordance with a given algorithm, convert it to analog and transmit it to the communication line.

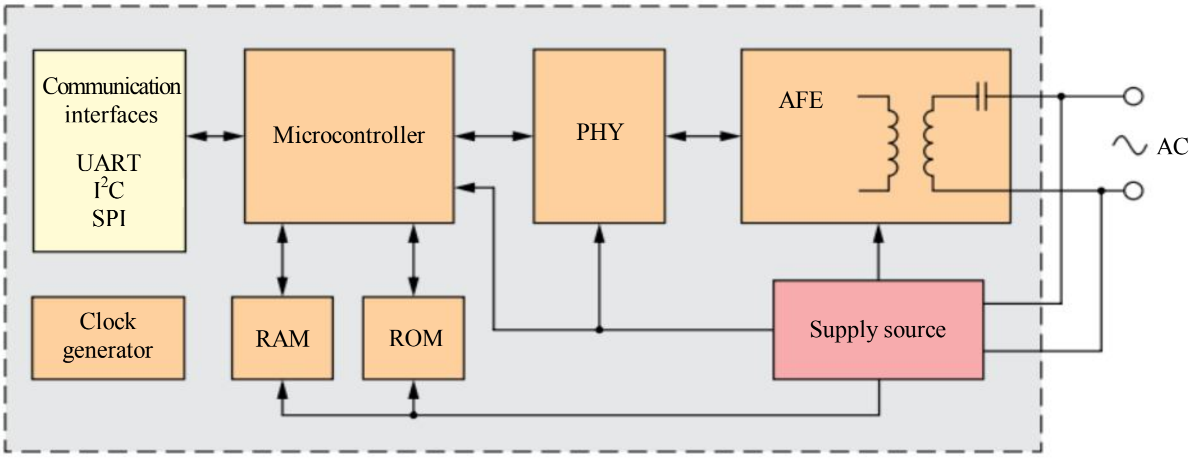

Fig.5. Block diagram of the IS family [3]

All of the above actions are performed by EV8xxx series chips. Narrowband chips are «systems on a chip», which are highly integrated and contain all the necessary structural blocks to implement the physical, MAC, and other protocol layers (WPAN and IEC). The presented devices provide the implementation of several types of modulation (in practice, OFDM is most often used) for the organization of a stable and interference-proof channel. Single-chip integrated circuits that have passed functional compatibility testing in the HomePlug Alliance Netricity are notable for their versatility; both end nodes and network coordinators are designed on their basis. The Netricity specification is designed for network communications over long-distance power lines and is intended for industrial infrastructure, intelligent power distribution networks, and control of production processes. The technology can be used both in dense above-ground and underground power supply networks using frequencies below 500 kHz. It also includes the provision of an IEEE 802.15.4 (MAC) based access layer, which is key to the development of hybrid wired (wireless) networks [3].

A simplified structure with the image of the main functional units is shown in Figure 5, here you can select the following blocks [3]:

• The 32-bit RISC microcontroller provides an in-circuit implementation of the MAC layer, performs data processing, packet generation, data encryption using the AES block encryption algorithm, etc., and also solves application problems.

• The AFE (Analog Front-End) unit represents a set of analog components providing isolation using a transformer with a coupling capacitor, filtering and amplifying the input signal, as well as generating predetermined output signal levels by using the line driver at the OS.

• Peripheral units interface the integrated microprocessor with external chips — EEPROM memory, high-resolution ADC and host controller. For communication, the hardware implementation of the widely used SPI, I2C and UART interfaces is changed.

• The PHY unit provides the interface between the digital part of the chip and the analog line.

• Integrated RAM and flash memory, the size of the built-in program memory varies from 1 to 2 MB, RAM – from 256 kB for the EV8100 to 384 kB for the others, other options are possible.

• Clocking control unit.

• The power subsystem provides all the necessary voltages for individual nodes. As a rule, a power supply is used, which operates on the same AC mains as used for data transmission.

For the practical application of the complexation technology of telecommunication systems and power supply systems in mines and underground structures, five potentially feasible methods can be proposed:

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– inductive branching of signals with separate phase conductors in the distribution cables of the mine;

– branch into the socket or from the socket with low voltage, which may exist in the electrical equipment of the mine;

– a branch of the signals in the grounding of the cable with respect to local grounding;

– wireless branch to or from the cable;

– inductive RF branching on or off the entire high-voltage cable.

Thus, based on the specifics of the functioning of the mining enterprise (mine), the following subsystems can be included in such a combined telecommunications system, focused on monitoring and managing the main technological areas: environmental parameters of the mine; transport chain (conveyors, bunkers, feeders, etc.) from the bottom to the shaft of the mine; the work of fans of local airing; parameters of mining and tunnel complexes; degassing parameters; high-voltage switchgear; installations of main drainage; fan-mi main ventilation; the work of surface objects; technological complex loading of coal.

Another effective use of complexation telecommunications and electrical systems in underground structures can be the use of light control of the underground structure. In the current decade, instead of incandescent bulbs, LEDs will gradually become increasingly used. LEDs have significant advantages over compact fluorescent lamps and incandescent lamps. Such advantages include dimming of the brightness in the whole range of luminescence of the lamps, a much longer service life, the absence of mercury in them and the possibility of adjusting the color temperature. Consider, for example, the lighting system of the mine, which consumes 20-30 % of the funds provided for the power supply of the entire enterprise. In currently used lighting systems, there is no adjustment for the brightness of the lamps, control over color temperature and intelligent switching. To detect the facts of various faults in the lighting requires the use of specialized personnel. Very often, such repair is carried out only after the detection of faults and the receipt of relevant statements.

All of these costs can be avoided if you go to the modern model of using lighting, which will be implemented PLC-technology. Thanks to this connection, it will be possible to organize monitoring and control of each element of lighting. In addition, the periodic adjustment of the brightness of the LEDs helps to increase the service life of the lamp, the lamp with the end of service life can be replaced before they fail, which reduces maintenance costs. Data on lamp life, energy consumption and other service information can be sent to the monitoring center and used later for diagnostics. Installation of LED lamps does not require the laying of additional cables or installation work – the PLC-solution is the most suitable and accessible in such tasks. The control system of high-brightness LED luminaires ensures operation in accordance with an optimized network protocol, allowing you to control individual installations or groups of installations in a power line infrastructure. For example, a PLC system with a Cypress EZ-Color solution can be used for intelligent dimming and gradually turning off high-power LEDs [8].

The same considerations can be applied, for example, to ventilation and drainage systems. In this case, the management of these systems can be organized using the wires of their power supply system, which will greatly simplify and reduce the cost of automation, as well as take into account the impact of the load on the losses in the power supply networks [12].

Conclution

The proposed solutions for the application of integration of telecommunication systems and power supply systems of mining companies will improve the efficiency of solving various technological problems arising from the operation of mines (underground structures), improve production

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safety and reduce the cost of implementing automatic process control systems. Analysis of possible options for the technical implementation of these tasks has shown that this technology may face a number of significant difficulties in implementation. The main ones are related to the fact that electrical wiring of the power supply systems of Russian enterprises is made mainly of aluminum, and not of copper, which is used in most countries of the world. Electric cables made of aluminum have noticeably worse electrical conductivity, which will lead to faster decay of information signals. Another identified problem is that in Russia the main issues of regulatory and legal regulation of the use of such technologies have not yet been resolved. The main factor hindering the rapid development of high-speed PLC systems is the lack of standards for broadband PLC systems, and, as a result, a high risk of incompatibility with other services in the enterprise using the same or close frequency bands. The Saint-Petersburg Mining University is implementing a scientific project to create the theoretical and methodological foundations for integrating telecommunication systems and power supply systems for mining companies, which should result in a scientific and methodological apparatus for building such systems, which is a significant jerk in improving the efficiency of management systems for such enterprises generally.

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