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A METHOD FOR THE SELF-ORGANIZATION OF A SENSOR NETWORK IN BELT CONVEYOR EXPLOITATION

Keywords

Monitoring, rollers, sensor network, self-organization, Internet of Things.

Abstract

Systems for monitoring, control, and automation, which are capable for learning and adaptation, are increasingly used in the industry. The Internet of Things (IoT) technology and Machine-to-Machine (M2M) direct communication technology have a stronger and stronger impact on the structure and functionality of machine control systems, shaping the Industry 4.0 idea. Control systems that are in accordance with IoT use the communication channels, which are often highly complicated and which combine all subassemblies, modules, actuators, and sensors. The range of using the intelligent systems in the Polish mining industry also increases. The problem of the self-organization of communication routes (routing) in the complex sensor grid monitoring the operation of belt conveyor's rollers is presented. The sensors creating the grid are independent, and they are equipped with an electronic measuring system and a Measuring and Transmitting Unit (MTU). Swarm Algorithm (SA), based on a swarm behaviour, was suggested for

the creation and optimization of transmission routes in the suggested communication structure.

Introduction

The mining industry is one of the important sectors of the Polish economy, where there are strong challenges and demands regarding the automation of machines and technological processes as well as requirements for improving health protection and safety. That is why the use of artificial intelligence in control systems becomes more and more popular. Regarding the mining industry, artificial intelligence can be used, among others, in the monitoring and diagnostics of components and subassemblies wear [3, 9, 12–13, 25] as well as in the control of machines and mechanization systems [11, 24]. Implementations enabling the intelligent adaptation of machines to changeable operational conditions are known. Future mining of the seams with high methane content, threatened by impacts as well as high temperatures, forces the designers to develop autonomous systems to withdraw personnel from dangerous zones and to reduce the role of human beings mainly to supervision activities.

Operational problems described above have an impact on control systems and the safety of mine transportation, including belt conveyors used in run-of-mine transportation lines. Research projects aiming at increasing the reliability of those machines and at permanent monitoring of the parameters of conveyors' belts and drives are known [8, 14, 15]. Work on the development of technical solutions that enable reliable supervision of the rollers is also being carried out [21–23]. Information on the rollers' rotational speed, vibrations, and temperature of bearings as well as monitoring in a real time are of key importance for work safety in underground workings, especially in regards to fire hazards. Now, systems of acoustic or infrared diagnostics deliver information, which is not enough, and additional employees are required to take measurements periodically.

Solving the problem of powering the measuring system, which can be installed inside the roller equipped with an autonomous monitoring system, is the first stage of the development of such rollers. Solutions based on micro generators converting the rotational movement of the roller into electricity (Energy Harvesting) or on a battery-powered system are available on the market. The measuring system for the determination of rotational speed, bearing temperatures, and vibrations generated in the audible and ultrasonic bands is the next stage of the work. After the acquisition of data, a wireless communication system between the rollers (Ad Hoc communication) and transferring data to the central computer is the last stage of the measuring cycle. Bearing in mind the number of rollers installed in conveyors of the main transportation system, the measuring grid has a complex structure of mesh topology. In such grids, we more frequently find the implementation of routing protocols based of artificial intelligence technology and methods. Effective routing is especially important in the case of grids of mesh topology with implemented Ad Hoc mechanism. Ad Hoc networks are often multi-hop structures, where very low throughputs can be found between nodes and communication can be realized only in one direction. The grids of the complex structures have many problems that must be solved. Most important of them are as follows [1, 2, 4, 5, 7, 10, 16–20]:

- Mobility,
- The number of data packages hops,
- Self-organization,
- Saving of energy,
- Scalability, and
- Safety.

1. Routing protocols in Ad Hoc networks

A routing protocol ensures the passage of data packages from the source node to the target node. Bearing in mind the mentioned limitations of an Ad Hoc network, the realization of this task is not easy. Many different routing protocols, which can be implemented in Ad Hoc mobile networks, are available. The existing solutions can be classified as the following [1, 2, 4, 5, 7, 10, 16–19]:

- Proactive protocols: In each node, the newest possible information is kept on routes to other nodes. The routes are stored in routing tables, which are updated regularly.
- Reactive protocols are also known as routing protocols on demand. This is the class of protocols in which the route is determined at the moment when the source node requires the information package to be sent to the specified target.
- Hybrid protocols combine the properties of proactive and reactive protocols. In the majority of protocols from this group, the network is divided into smaller parts and nodes keep the tables of routes for these separated areas.

2. Concept of self-organizing structure of sensor network

The author’s concept of self-organizing communication structure, named SSKIR [21–23], is based on one of artificial intelligence technologies, “swarm intelligence,” which is a direct implementation of phenomena and behaviour in nature among organisms living in large groups. Their behaviour, to some extent, can be transferred to the operation of routing protocols. The system structures developed by humans (irrespectively to real implementation), using the swarm algorithm, have high possibilities for adaptation and high operational reliability. In 1987, during the SIGGRAPH conference, the programmer Craig Reynolds, in the paper entitled *“Flocks, Herds, and Schools: A Distributed Behavioral Model,”* suggested three basic rules of self-organization based on observed groups of animals, as follows [6]:

- Collision avoidance is control eliminating a local concentration of individuals. Collision avoidance eliminates accumulation of hardware and decision structures.
- Flock centring are actions towards the average behaviour of local groups of individuals.
- Velocity matching are actions towards the average objective of local groups of individuals. Velocity matching enables the individual to adapt its actions to other individuals from its local group.

Based on the above rules, the creation of a communication system made of a sensor network in which routing is based on a swarm algorithm was suggested [21–23]. Each data frame transferred by the Measure Transmission Unit (MTU) is marked by a quality coefficient W_P specifying the transmission priority referring to the effectiveness of data transmission to the main transceiver stations. This coefficient can take a value that conforms to one of connections or path metrics [2, 5]; therefore, transmission speed and number of hops of transmitted frames containing the following measuring data is based on data propagation times:

- Expected Transmission Count (ETX) is a metric that is widely used in mesh networks. ETX is the metric specifying the number of expected transmissions, which is indispensable when sending data to the next node without errors. The number varies from 1 to infinity. An ETX metric equal to 1 indicates a perfect data transmission path, and an ETX approaching infinity represents the connection that is not functioning.
- Expected Transmission Time (ETT) is an extension of ETX metrics, since it takes into consideration the difference in the speed of data transmission. The ETT of connection l is defined as an expected duration of the successful transmission of a data package in connection 1. The importance of *p* path is defined as a sum of the ETT of all possible connections along the given path. The relationship between ETT and ETX can be expressed as follows:

$$ETT_l = ETX_l \frac{s}{b_1} \tag{1}$$

where

– b_l is a speed of transmission of information in connection l,
– s is a size of transmitted package.

- Hop count is the most often used routing metric in the existing routing protocols, such as DSR (Dynamic Source Routing), AODV (Ad Hoc On-

Demand Distance Vector), or DSDV (Destination-Sequenced Distance Vector). Hop count is the routing measure used to measure a distance between transmitting and receiving stations counting the hops. The next hop can be a receiving station or device intermediating in the exchange of information. The protocol using the Hop count metric determines the route with the lowest number of hops between transmitting and receiving stations.

- Weighted Cumulative ETT (WCETT) is a metric that includes both the quality of a connection (losses, throughput) and the number of hops. Thus, we can reach a compromise between delay and throughput

$$WCETT(p) = 1 - \beta \cdot \sum_{l \in p} ETT_l + \beta \cdot \max_{1 \le j \le k} X_j \tag{2}$$

where

- β is a set parameter from the range $0 \le \beta \le 1$. Higher values of β give priority to paths using many channels and its lower values give priority to shorter paths,
- $\max\limits_{1 \le j \le k} X_j$ counts the maximal time of appearance of the same channel in a given path.

- MIC is metric that improves the operation of WCETT by solving its isotonicity and inability of detecting the collisions. MIC metrics of p path can be defined as follows:

$$MIC(p) = \frac{1}{N \cdot \min(ETT)} \sum_{linkij \in p} IRU_{ij} \sum_{nodei \in p} CSC_i \tag{3}$$

where

- N is a number of all nodes in the network,
- *min(ETT)* is the lowest ETT in the network and it can be determined on the basis of the lowest speed of data transmission in radio charts.

Additionally, the following principles resulting from swarm phenomena are assigned to each data package so that the system can react to changes in a node structure (failures, nodes displacement):

I. The package matches its speed to the packages moving in paths of higher W_P coefficient.
II. The package uses the path parallel to the optimal route (of highest known W_P value), if its W_P decreases.
III. The package uses the optimal path (of higher known W_P value), if the W_P coefficient of the current route decreases.

IV. The package avoids transmission through the nodes that are marked as damaged.
V. The package can leave the present path, if the main transceiver station is found.

Local data, which is indispensable for the realization of tasks resulting from the above principles, are calculated and stored in nodes. There is no need to create a master routing table. The use of these rules causes that the group of MTUs creating the transmission connection automatically develops the structure of reliable transmission routes while neglecting the damaged units.

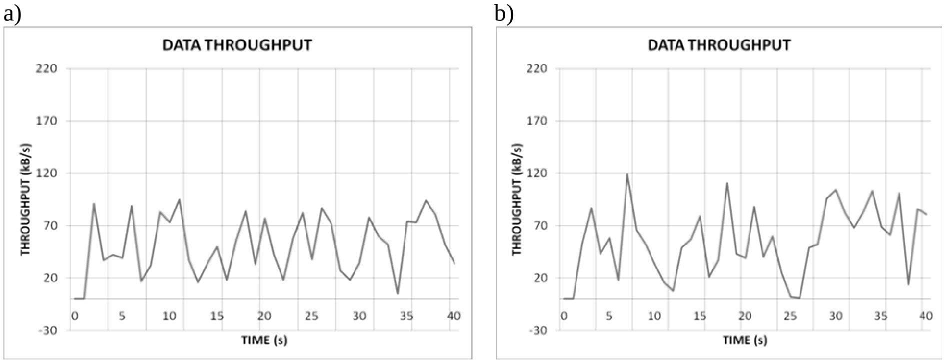
3. Results of simulation tests

A stationary MESH network, operating in a Wi-Fi technology, in which there is an Ad Hoc connection between two nodes, where node A sends information to node B, was simulated. Analysis of the efficiency of data transmission in the network of mesh topology was made based on generated diagrams in relation to node B receiving data, including the bit rate of incoming packages and the total incoming volume.

The analysis was made based on the results from the network simulated in NCTUnc software, including the following assumptions:

- Routing protocols in comparative analysis:
  - AODV – Ad Hoc On-Demand Distance Vector,
  - SSKIR – method based on a swarm algorithm;
- The size of the network of mesh structure:
  - Small network – 5x50 nodes,
  - Large network – 5x400 nodes.

The distance between nodes is 2 meters (the reach of each node covers only neighbouring nodes). Sample network's throughputs obtained during simulation are given in Fig. 1. In the developed SSKIR protocol, significant increases in transmission throughput and transmission stability were found.



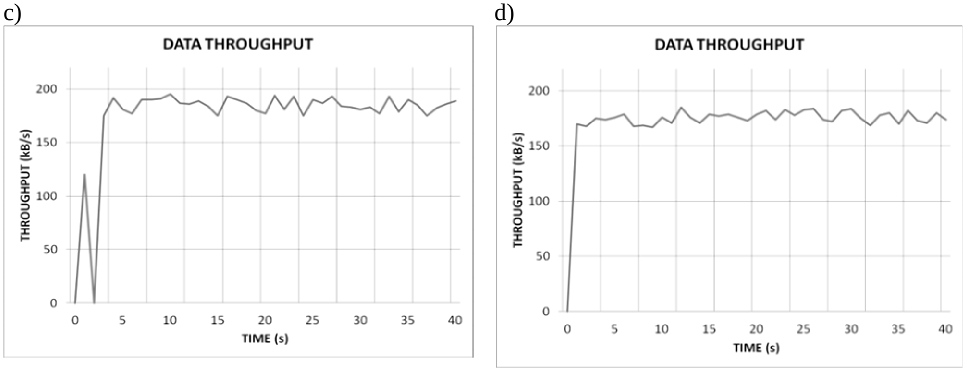


Fig. 1. Data throughput for mesh network: a) consisting of 250 nodes with AODV protocol, b) consisting of 2000 nodes with AODV protocol, c) consisting of 250 nodes with SSKIR protocol, d) consisting of 2000 nodes with SSKIR protocol

Summary

The method of the self-organization of the communication system based on a swarm algorithm enables implementing a state-of-the-art and effective routing technology in the networks of mesh topology, including those used in underground mines, especially in diagnostic systems, monitoring and in the protection of machines, and subassemblies of the networks equipped with MTU nodes can be treated as the components of a measuring swarm. This is especially important in work safety in underground mines due to the reliability of mesh networks.

Analysis of simulations shows that the number of intermediate nodes in communication between transmitting and receiving nodes has a significant impact on the data transmission rate. A reduced number of nodes increases the rate of data transmission. Changing the structure of the network does not significantly affect the data transmission rate. However, short breaks in transmission can occur due to the loss of a connection with an existing node and reconnection with another node. The analysis proves that reactive protocols, including SSKIR, are a better solution for networks of a high number of nodes. In such a case, there is no need to keep a central routing table, which significantly relieves the machine design. These protocols are scalable to large networks, because there is no need to store a high volume of information. Nevertheless, the route is not available until the process of finding the path is completed, which causes delays in the network. The quality of transmission is set during routing and should be continually monitored through the intermediate nodes.

The author’s concept of the system is presented with the coefficients for quality assessment and principles for the functioning of the suggested self-

-organizing system. Additionally, the test results showing the increase of data transmission efficiency in the network, in which the described algorithm was used, in relation to the available most popular solutions, are presented. The obtained results indicate high potential for the development of the suggested solution.

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Metoda samoorganizacji sieci sensorycznej w eksploatacji przenośnika taśmowego

Słowa kluczowe

Monitoring, krążniki, sieć sensoryczna, samoorganizacja, Internet rzeczy.

Streszczenie

Systemy monitoringu, sterowania i automatyzacji, zdolne do adaptacji i uczenia się, są co raz szerzej stosowane w praktyce przemysłowej. Techniki Internetu Rzeczy (IoT – *Internet of Things*) oraz komunikacji bezpośredniej Maszyna do Maszyny (M2M – *Machine to Machine*) coraz mocniej wpływają na strukturę i funkcjonalność systemów sterowania stosowanych w maszynach, kształtując przy tym ideę Przemysłu 4.0 (*Industry* 4.0). Systemy sterowania zgodne z IoT wykorzystują sieci komunikacyjne, często o dużym stopniu komplikacji, łącząc poszczególne podzespoły, moduły, elementy wykonawcze i sensory.Wzrasta również obszar zastosowań systemów inteligentnych w polskim górnictwie węgla kamiennego. W artykule przedstawiono zagadnienie samoorganizacji ścieżek komunikacyjnych (trasowanie, routing) w złożonej sieci sensorycznej monitorującej działanie krążników przenośnika taśmowego. Poszczególne sensory, tworzące sieć, są niezależne i wyposażone w elektroniczny układ pomiarowy oraz transmisyjny MTU (*Measuring and Transmitting Unit*). W celu utworzenia i optymalizacji ścieżek transmisyjnych, w proponowanej strukturze komunikacyjnej, zaproponowano algorytm klasy SA (*Swarm Algorithm*) bazujący na zachowaniu roju.