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Using Wireless Sensor Networks in Special Applications for Mining with Accident Potential Location

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Abstract: ***In this paper, the properties and perspective of wireless sensor networks (WSN) used in special applications is approached. For a better understanding of such a problem the first part of the paper treats a short evolution and developing of WSN as ubiquitous computing together with his important properties and performances. In the next part of the paper the special applications are defined, for potentially aggressive environments to ensure the health and safety of the staff. Three conditions can be considered: (1) If there is an unfriendly environment that facilitates the risk of accidents, (2) If there are aggressive equipment in that location that can compete to cause accidents, (3) If there are work security breaches for staff that can cause accidents. These conditions define the Triangle of accidents. If any of the first two conditions may occur defines an Potentially Accident Location is defined.The presence of all three conditions defines an Accident Risk Location. Work is only allowed in secure locations by intervening on all three factors as follows: Ensuring a nonhazardous working environment, using safe equipment and removing security breaches. This is the duty of employers and managers of those activities. Properties of WSN can help the monitoring of environments with Accident potential, using a combined solution consisting of WSN and SCADA systems when exists in such locations. In the last part of the paper an example of using WSN in underground mining extracting coal was develop. This example is validated by modeling and simulation using CupCarbon software environment with good results.***

Keywords: WSN properties, special applications, triangle of accidents, secure, accident potentially, accident risk, WSN and SCADA strategy, mining applications, CupCarbon validation

1. Wireless Sensors, Evolution and Perspective

1.1 Wireless sensors as ubiquitous computing

The transmission of information by wire or cable, through radio waves, has a certain history. Techniques and technologies are developed in step with the scientific researches in the field of electronics, the qualitative leap being made with the achievements in microelectronics.

Long-standing monitoring and control systems have been known, some of which are being used successfully today. For example, SCADA (Supervisory control and data acquisition) is a standard used in Electric Power plants or other technical installations distributed on extensive surfaces such as City Water Supply, Hydro Power Plant, [9]. In explosive atmospheric mines, a SCADA system for controlling and monitoring underground atmospheric parameters called Tele-metrics Central has been used for decades, [13]. Note that SCADA has the ability to transmit information both by cable and radio over long distances. All these systems have a common feature: Data control and processing is centralized, requiring very expensive and energy-intensive hardware and software resources. Wi-Fi wireless technology for the Internet, Bluetooth for data transfer between nearby equipment, GSM mobile communications have become increasingly affordable as the installation and cost increase the use of wireless networks to the detriment of wired networks.

Thus, the idea of the structure of a system of unlimited capacity that is functional under any circumstances and the data to be instantly accessed anywhere and anytime is possible. A big step in this direction is the wireless sensor network integrated into the environment it occupies.

Wireless Networks Sensors or WSN are part of the "Ubiquitous computing" category and were introduced by Mark Weiser under the Ubicomp acronym in 1991. Defined in 2009 as the ubiquitous computationally integrated environments that become almost physically invisible with the goal of helping people not to obstruct their tasks.

An Ubicomp technology computing system consists of a number of physically-specialized computing devices that work together, perceive and control certain parameters of their physical environment through wireless transmissions, [3].

Wireless sensor networks are a new class of distributed systems integrated into the physical space it occupies. Unlike networks with multiple microcomputers, the sensor networks are integrated into the environment (omnipresent), inform, communicate with each other, reconfigure and act on the real world in which they are found. It is considered that this position is a "bridge to the physical world" opening up a multitude of applications both related to the environment and to what is in that environment, [5].

1.2 Structure and architecture of WSN, examples

A wireless sensor network, WSN (Wireless Sensor Network), consists of a relatively large number of intelligent sensors, called nodes, integrated into an environment with wireless communication capabilities, which through collaborative actions form a unitary network with the purpose of inform and act on the environment it occupies, [6].

A node has in its structure 4 basic components: environmental sensors, data and program memory microcontroller, wireless communication interface, power supply, Fig.1. The important features of a node are: reduced size, long-term weather resistance, low power consumption, possibly including a power management software, distributed software for real-time applications, low cost.

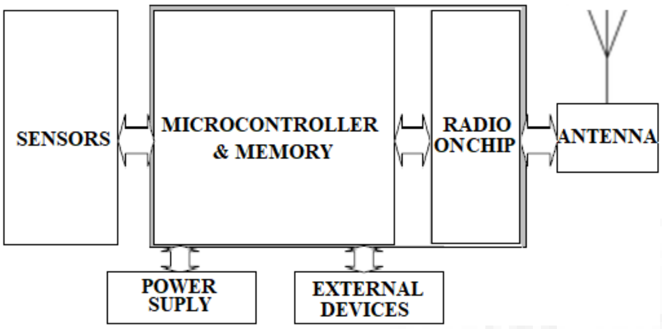


Figure 1: Structure of a WSN node

A first example was the MICA Mote system developed at Berkeley University, the size of a matchbox with Atmega processor, transmission distance of 40 m, light sensors, temperature, seismic, accelerator, acoustic and magnetic sensors with 2 AA batteries sufficient for months. Uses the TOS operating system, [18].

In 2001, the Smart Dust concept was launched, consisting of millions of millimeter-sized sensors that launch in the environment to monitor various phenomena. Each microdeposit has all four elements of a node structure, they can float in the air, they can plug in the plastering of the buildings, they are configured and maintain themselves.

It has become a standard, the ZIGBEE family of XBEE variants, designed to equip sensor networks for monitoring and control of building environments and beyond, [12]. In addition, ARDUINO technology offers affordable price and configuration modules for application testing with sensor networks. The architecture of the sensor networks, is the way the nodes interconnect with each other and the functions they have, is made through three categories of nodes: final nodes such as those containing sensors and connecting to the environment, routing nodes or routers having the role of receiving and unmodified retransmission of information and reception nodes receiving environmental information. In Fig.2 is the internal structure of a node, views of several products on the market, and the architecture of a ZIGBEE node sensor network where F are the final nodes, R are routers, and C is the coordinating node of reception, [5].

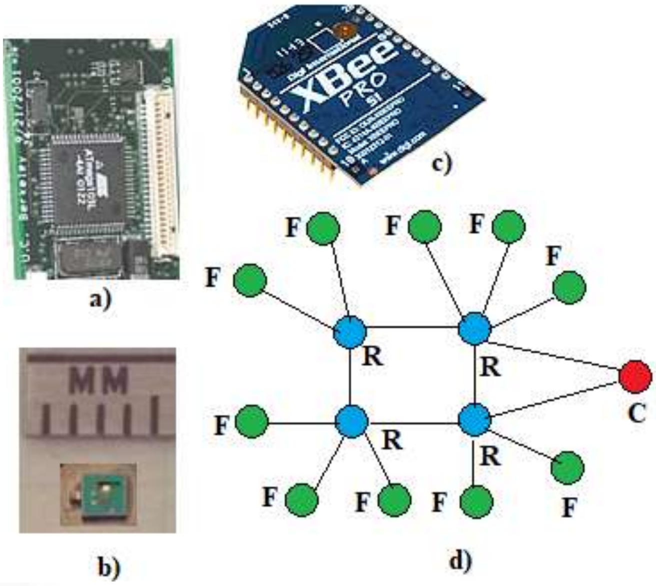


Figure 2: Examples of WSN structure: Small a), Smart-dust b), XBEE c) ZIGBEE architecture d)

The WSN architecture with respect to the relation between nodes is exemplified in Fig.3 in the case of connections with ZIGBEE equipment.

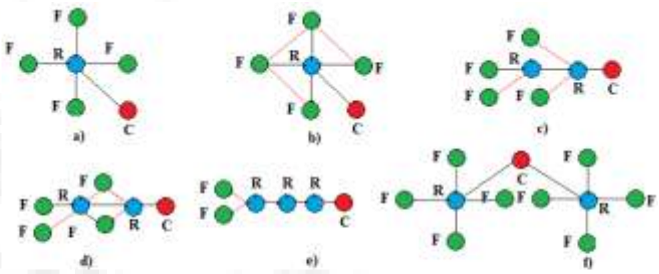


Figure 3: WSN architectures: star a), mesh b), tree c), ad-hoc d), multi-hop e) cluster f)

Thus, according to Fig.3, the final nodes F can be connected in the star on a router R, which transmits to the coordinating node C. A multiple connection between each end node and the router forms the mesh architecture and if a common axis of routers connects the final nodes, it forms the tree architecture. The combined architecture between the above is called the most-used ad-hoc that self-configures, and if a number of routers are connected in series, a multi-hop architecture is obtained. A combination of several star connections on a common tree is cluster architecture.

The operating systems and programming languages used by WSN represent an extensive category of information products called Middleware and provide an infrastructure for interoperable applications, and those that work with environmental sensors are called MAC. Among these are: SensorWare, DSWare, TOS, etc. In general, the programming languages used by WSN are restrictions of the classical languages: C, C ++, BASIC, JAVA, etc.

The development of wireless technologies to meet the needs of efficient and quality data communication has imposed the IEEE 802.x series of standards. Along with these, there have been standardized various software environments dedicated to wireless networks or even embedded systems such as

Zigbee with IEE 802.15, [2]. There are also modeling-simulation platforms like CupCarbon. A comparison of the "field / transmission rate" communication is given in Fig.4.

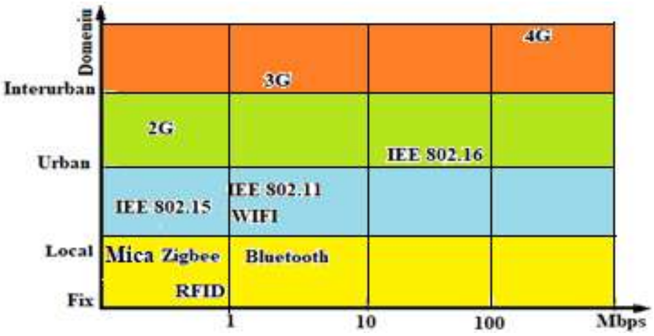


Figure 4: Comparison between various WSN communication systems

2. WSN properties and performance for use in special applications

2.1 Properties and performance

Unlike other technologies, WSNs have some common basic properties that are primarily due to being integrated into the real world. Here are some of the most important properties of WSN, [8].

- **WSN forms a control loop with the real world**

Sensor networks detect the natural parameters of the real world and this information is transmitted and processed as a control information that actuates actuators on the real world. A control loop is formed with the real world. This loop is different from a classical control loop that closes through the virtual world, Fig.5.

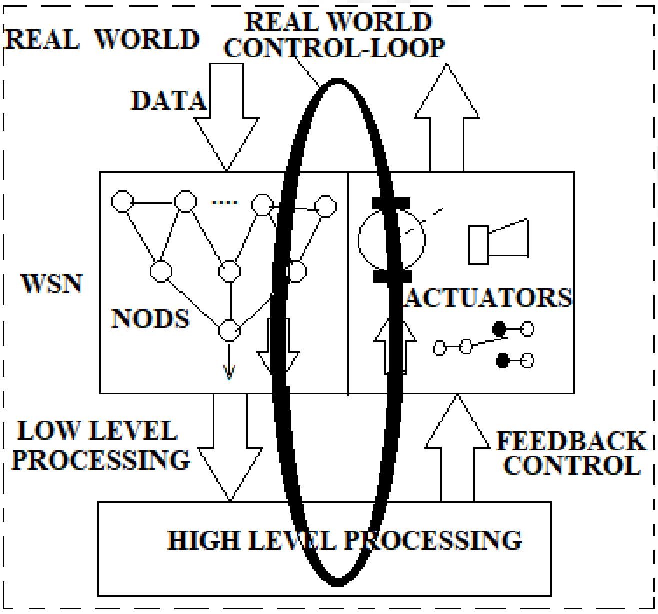


Figure 5: Real world control loop

- **Individual WSN sensors are called nodes. WSNs are a lot of nodes that work together as a whole.**

Nodes have a simple structure, proprietary software, low cost, cooperate with each other, developing new properties, being well superior to a set of individual sensors. They transmit high-level processed information to users.

- **WSN nodes process environmental data and integrate the human experience with the real world.**

WSN differs significantly from any other computerized network because the network nodes perform a primary processing of information taking into account the human knowledge and experience of the environment in which the network is located and delivers to users the resulting conclusions.

- **Nodes work on the principle of energy conservation.**

Processing of primary information in nodes, internode cooperation, delivering the user only information synthesis, distance management and transmission bandwidth management, using an energy management software module, ensures the conservation of the energy of each node and the entire network.

- **WSN is adaptive to the real, self-configurable and can run without maintenance**

Network nodes in very large numbers cannot be maintained or replaced if for some reason it goes out of function, so the architecture needs to adapt to the real-world changes to configure itself to take over the tasks of the missing nodes.

- **WSNs are automatically located in space and synchronized in real time.**

Wireless sensor networks are located where possible via GPS and inside or underground by other means. WSN also works synchronously with the real-time clock. These facilities allow reconfiguration of networks, collaborative and quality processing.

- **WSNs are tiered architecture platforms as a local / global level compromise.**

At the local level, WSN requirements should refer to nodes as: cost-effective, flexible, portable, easy to integrate into the real world, simple algorithms for processing, storage and communication, and energy efficiency.

Figure 6: Tiered architecture platforms

Globally, integrated WSNs need to best meet application requirements: many nodes, high data storage capacity, high processing speed, broadband communications. The current achievements are Platforms whose "tired architecture" is oriented either to the local level, such as the MICA MOTO product with TinyOS software, or to the LINUX-based client-to-server level, as is the case with ZIGBEE. There are platforms with intermediate design level using micro-servers like ARDUINO, Fig. 6.

2.2 Special applications of WSN

WSN applications are multiple such as: agricultural, mining, chemical, oil, military, industrial, urban agglomerations, individual houses, water, seismic, atmospheric, education, etc. They can be monitored and remotely controlled in real time.

But the sensor networks have gained a lot of use in the technical field as well. Their applications are expanding more and more due to the possibilities offered by them in terms of capturing, processing and transmitting information, as well as reducing the cost and continuous hardware / software improvements.

Hazards refer to work Lately, more and more applications have appeared in potentially aggressive environments on the health and safety of staff. Such situations will be called Special Applications, [7].

In some activities, staff needs to work in an unfriendly or even aggressive environment where the environment in which they operate can affect the health and safety of the workforce. These are risks such as: explosions, physical injuries, health and illness, accidents, etc. These situations exist in some sectors: chemistry, mining, military, marine, oil and gas, construction etc. For example, in underground coal mining, a mixture of air (oxygen) and methane produces an atmosphere that can explode in the present af a flame or spark. Other in unfriendly environments: Narrow workplaces, proximity to moving machines, drops or breaks of materials or rocks, work at heights and free space unprotected by weather, such as construction, military activities in theaters of operations and so on. Some equipment or installations may be aggressive: Moving machines, electrical equipment, weapons, explosives, dangerous processes, etc., if the staff comes in contact with them. Work safety breaches such as inconsistencies in working regulations, norms, the presence of human errors in driving cars, installations, handling explosive materials or weapons in theaters of military operations.

Of course, not all activities in these sectors are dangerous, many of them are protected by security rules and by appropriate equipment or installations. However, there are many situations where the risk of accidents is present or even imminent.

Analysis of a location to determine the risk of accidents should evaluate the following three conditions:

- If there is an unfriendly environment that facilitates the risk of accidents;
- If there are aggressive equipment that can compete for the cause of accidents;
- If there are work security breaches for staff that can cause accidents.

All three of the above conditions define the Accidents triangle, Fig. 7.

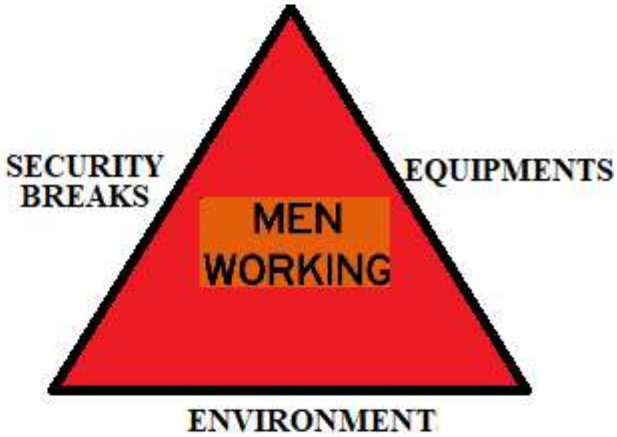


Figure 7: Accidents triangle

If any of the first two conditions may occur accidentally, we have the location with potential for accidents. The presence of all three conditions defines an Accident Risk.

In general, a Safe Location can become a Location with potential for accidents in the presence of an unfriendly environment (mine with methane gas, military operations) and / or aggressive artifacts (electrical equipment, explosive materials). A location with potential for accidents turns into an accident-risk location in the presence of security breaches (sources of ignition, misuse of explosives). Any activity should take place in Safe Locations: A non-hazardous working environment, the use of Safe Artefacts, the removal of security breaches. This is the duty of employers and all managers.

For example, in underground coal mines that have methane emissions, although the work environment is a potentially fatal location, it is considered as a safe location by limiting methane content in the work environment and using anti-explosive equipment. To maintain a safe work environment, a SCADA underground methane monitoring and control system is used, along with methane disposal through a workplace air system. There are strict regulations on working with machines and installations so that there is no security flaw as far as possible. A location is safe from accidents, if the environment is safe and the artifacts introduced in it are non-aggressive. Making a Safe Location is largely a strategy for developing the technology process. If a security breach appears in a safe location, the risk of accident must be null. If under certain circumstances the location became unsafe then the security breach would cause accidents or even catastrophes. Unfortunately from time to time such unfortunate events occurred even if the locations seemed secure, controlled and monitored.

This paper addresses a software solution that combines the Individual Sensor Scanning System (SCADA) with Wireless Sensor Networks (WSN) to bring about improvements in avoiding the risk of accidents. These are special applications aimed at providing safer workplaces.

3. Modelling simulation and WSN implementation of monitoring extracting coal

3.1 The extraction process of coal

Mining is the most used long-term activity used for the exploitation of coal and other mineral resources and which provides jobs for a large number of people. Unfortunately, the specificity of the work is very dangerous due to the fact that there are many accidents, with serious consequences on human life and causing great economic damage, [15]. Depending on the geological-mining conditions, extraction of the coal from the slag is made by two methods of exploitation: Slicing (1) with combine (2), mechanized complex (5) and conveyor (3), Fig. 8.a or Drilling-Perforation, Conveyor and Individual Support Operation, Fig. 8.b.

a) b)

Figure 8: Methods of exploiting coal with combine (a) or drilling-perforation b)

In the first case, the exploitation method has the advantage of good productivity with a reduced physical effort but a high electricity consumption. In the latter case, the method has the advantage of high productivity, low power consumption, but with a high physical effort and accident risk. It should be noted that in both methods, coal is exploited for empty spaces called exploited spaces (5) where gases such as methane and carbon oxides accumulate.

First, extraction regardless of the method requires from the outset to organize the location as a "safe work environment". In this sense, gas degassing that could create an explosive atmosphere must be controlled and maintained in a perceived percentage as non-hazardous, and equipment, plant and machinery must be explosion-proof. Under these conditions, the abode becomes a safe job even if it is potentially explosive and work can be carried out under normal conditions.

The risk of explosion can occur only in the following coincidence: if there is methane in a hazardous percentage and if there is a source of ignition. Although methane sources in the mine are continuously coming from the mass of coals that are being exploited but also from already exploited spaces, severe methane removal measures are maintained, creating a non-hazardous inferior boundary, [1], [6]. This limit is monitored by continuous scanning using a centralized SCADA system. Investigations of underground mining and geological phenomena have concluded that a real-time systemic monitoring of the mining atmosphere, maintaining machine safety, is a good way to prevent accidents and disasters.

These systems have greatly reduced the explosion hazards but have not completely removed them so they are unfortunately still producing.

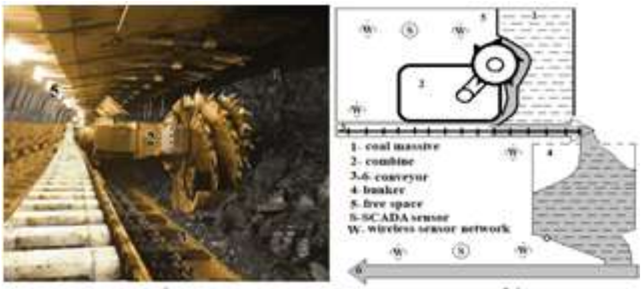
A long time agou in November evening a catastrophic explosion occurred at Livezeni mine in Jiu Valley Romania. A whole production sector has been affected, many miners were killed, others injured or blocked by the surge of rocks. The saviors have worked continually for days and nights to release their comrades but have not found survivors. The explosion resulted in 53 dead 27 wounded and huge economic damages.

Were difficult to determine and explain what hapen because the sector was moniorized by dozens of gas detectors scanned continuously from the surface by SCADA. The atmosphere was potentially explosive, but was safe from the point of view of the risk of accidents. Although it seems totally unlikely that there will be an explosive atmosphere and a spark of initiation at the same time, the catastrophe has occurred and from time to time the exhibits have been in the area as well as in other locations around the world. The probability law of large numbers shows that this is still possible.

The complexity of processes and the density of equipment, the narrow workspace, the natural phenomena that are hard to avoid, the imperfections of some machines, the non-collaborative working of the sensor system of the indvidual sensors, the non-use of the human experience in the field combined with some human errors represent only a short list of possible causes. Protective measures can and still need to be improved and this must be treated with all seriousness, [10], [11].

The solution proposed in this paper is: Combined use of sensor networks with the SCADA scanning system. In addition, some mining companies have announced that they are in the advanced phase of implementing mining sensor networks [17], [14]. In Fig.9 is shown an example of mechanically supported coal extraction (a) and a combined process monitoring scheme (b).

Such an approach limits the risk of global accidents through the SCADA scanning system of S sensors. WSN networks of W sensors, using the principles listed in the preceding paragraph, including: collaborative processing, software integration of human experience in the field, synthetic information, adaptability and self-configuration, limits risks at local level.



a) b)

Figure 9: Combined method of mining atmosphere monitoring scheme for coal extraction

3.2. Modeling and simulation of WSN monitoring for mining explosive potential atmosphere

For modelling and simulation exists many software platforms. One of very suitable is CupCarbone. CupCarbon is a SCI-WSN simulator of the ANR project PERSEPTEUR. Its objective is to design, running, debug and validate algorithms for monitoring, environmental data collection, and to create scenarios with fires, gas and other events used in educational and scien-tific projects, [16].

The CupCarbon environment consist of: Graphic user interface (GUI), Design tools, Simulation and Results etc.

On GUI user can design his real world environmental graphic, choose the type of sensors and deploy its on map, is assisted to design the software for sensor nods and test, inserting a scenario of events like a mobile moving on a dedicate way etc.

At the end the model is simulated, it gives the simulation results and can generate the Arduino code for practical testing.

The simulation model for example presented above is designed as following:

- First was designed the Real world of mining location based on the technological model presented in Fig.2.b together with SCADA sensors S.
- Based on human experience the way of methane run from free-space 6, a coal face 3, bunker 4 and conveyor 5. Along this way a mobile run, simulating the methane evolution.
- On this way was deployed the 12 WSN sensors Wi (i=1…12) arranged in an ad-hoc topology. Several of them are routers and the last is receiver connected to the internet hub. The complete model and simulation results are presented in Fig.10.

If the methane is detected the appropriate sensor process the data informs the others WSN sensors and send to the receiver hub the syntheses of situation. So, the managers and process coordinators get the information in real time and can decide based what to do.

Of course, in dangerous situations the SCADA system and the WSN will react by feedback actuators to cut off the electrical energy isolating the hazardous space.

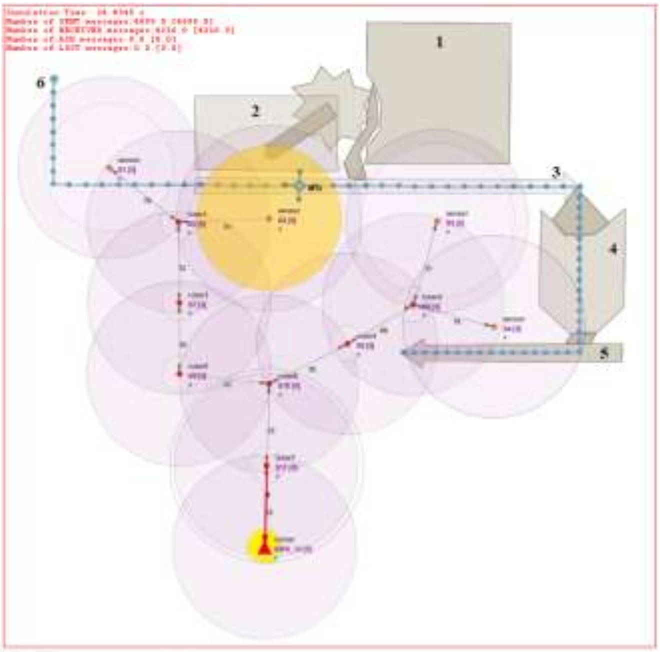


Figure 10: Modelling and simulation of mining atmosphere by combining the WSN-SCADA system

4. Conclusions

Several concepts of human activities are defined in special locations: Safe Zone, Accidental Area, Accident Risk Zone. Such locations can be found in mining, chemistry, military activities, etc.

It defines the concept of "Special Applications of WSN" as the use of these networks in areas with potential for accidents in order to ensure secure workplaces.

The use of Wireless Sensor Networks (WSN), as compared to SCADA Individual Detectors, can be much better integrated into the work environment in order to achieve data collection in areas and pathways that can favor accidents.

WSN Networks performs Integrated Surveillance for Accident Locations and performs real-world data processing using the principles: Collaborative processing, software integration of human experience in the field, synthetic information, adaptability and self-configuration, making a feedback loop to the real world.

Protection measures can be improved by applying the solution "Combined use of sensor networks with SCADA scanning system".

The paper treats as an example the case of mining coal face monitoring where exist SCADA scanning of individual gas detectors combined with a WSN network of 12 sensors that transmit processed information from a supervised location. The modeling and simulation of the application is made using the CupCarbon software platform.

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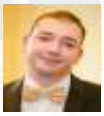

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