WIRELESS RADIATION MONITORING SYSTEM

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KEYWORDS
Simulation, radiation monitoring, routing protocols, wireless communication.

ABSTRACT

A wireless sensors network to monitor the radiation level of radioactive contaminated risk areas is proposed in this paper. An experimental, low power, low cost wireless device, designed to collect and transmit radiation measurements data from radioactive waste dumps to servers was realized and tested. It becomes active and transmits information only when a given level of radiation is exceeded, offering the advantage of a reduced power consumption.
The data transmission was simulated in a mesh network. For the performance analysis was used the discrete event network simulator Qualnet 5.01 version, AODV and OLSR routing protocols being considered for the comparison purpose.

INTRODUCTION

The radioactive pollution records a progressive increase on more and more extended worldwide areas. In the situation in which to old, natural factors (radioactivity in minerals, cosmic radioactivity etc.) determining this phenomenon, new ones are added, the cumulative effect of successive irradiances becomes significant and will manifest itself (occur) during long time periods. A large quantity of radioactive tailings and wastes has been formed as a result of producing and reprocessing of uranium ores in the whole world.
The threat of radioactivity increases considerably in the vicinity of radioactive waste, due to uranium mining related activities, even after mining activities ceased. The means by which humans can be exposed to radiation include atmospheric, terrestrial and aquatic pathways. The atmospheric pathways are responsible of the inhalation of radon and its progeny as well as airborne radioactive particles (Viena 2002).
During the last years, the specific problems related to *activities* involved in *uranium mining* and processing, including perils and long term grave effects on environment, human health state and on evolution and equilibrium of ecosystems, were permanently notified and highlighted (Furuta, et al. 2002, Sainzand, C. et al. 2009).
Measurements accomplished in these zones indicate an increased level of soil and water radioactivity, often exhibiting a pronounced dependency on meteorological and seasonal influences.
Currently, the radiation management plans, worldwide imposed for uranium explorers, focus on the minimization of the human radioactive exposure. In this context, radioactive sites monitoring is the first step for the minimization of the possible radioactive contamination (Australian Government 2005, Australian Government. 2011). This process have to be continuous in time and starts from the opening of mining facilities (Vienna International Atomic Energy Agency. 2002), the measuring of workers exposure to radiation being critical during the uranium exploitation. Also, after the mining activities stop, the monitoring process can help to minimize or prevent the associated environmental and health risks for the nearby communities.
The greening work of uranium waste dumps leads to a significant exposure of workers. Consequently, it is important to control this radioactivity in different, interest sites, in order to monitor and warn against exceeding. Releases can be caused by the mass movement of the waste or the cover, geotechnical instability, erosion, human intrusion in relation to the waste. In different sites of the waste dump, radiation level may vary within wide ranges, depending on the wind speed and direction, temperature, humidity or other factors (Viena 2002). The determination of exposure pathways plays a decisive role for correct assessment of contamination of large areas, to obtain a complete image of the related radioactive pollution.
In the majority of cases, the existing data are not yet sufficient to derive relevant conclusions regarding the longtime variability of radiation and their environmental impact, especially because it is strongly influenced by local, particular conditions. Taking into account the above considerations, the design and implementation of reliable and cost effective monitoring systems, capable to offer consistent data regarding the evolution of radiation exposure levels on considerable periods of time, remains an important objective.
It must be mentioned that the development of wireless communication technologies opened a new perspective in this field, promising results being published in many research papers (Vijayashree and Rajalakshmi 2016.).
A solution based on wireless sensors networks to detect the radiation was proposed by Libelium, being awarded in the Data Acquisition category for its Radiation Sensor board. The authors connect to the Waspmote wireless sensor networking platform a Geiger Muller

Proceedings 31st European Conference on Modelling and Simulation ©ECMS Zita Zoltay Paprika, Péter Horák, Kata Váradi, Péter Tamás Zwierczyk, Ágnes Vidovics-Dancs, János Péter Rádics (Editors)
ISBN: 978-0-9932440-4-9/ ISBN: 978-0-9932440-5-6 (CD)

detector to create an emergency radiation sensor network for measuring the beta and gamma radiation. These information and GPS (Global Positioning System) position are sent to a control center via ZigBee and GPRS (General Packet Radio Service) (Gascon and Yaza 2011).

Another application for radiation detection is proposed in (Kyker et al. 2004). It is based on ad-hoc wireless sensor networks, the authors aiming to realize a system which provide flexibility and adaptability for a variety of applications.

The power consumption, reduced size and convenient cost were other aspects taken into account during the designing process. For this reason, many current implementations of radioactive radiation detection are performed using the ZigBee technology (Adamu and Muazu).

Even though many of the mentioned references contribute to the performance enhancement of radioactivity monitoring networks, they do not take into account specific particularities for data collection in the proximity of uranium waste dumps. In this type of areas and in many cases there are no clear boundaries inside the contaminated surfaces (e.g. areas hosting tailing deposits, chaotically covered with vegetation, that overlap with areas where local population performs daily tasks), and the radioactive radiation reaches values that depend on varying natural and external factors.

The current research present a system capable to transmit reliable information from such areas types. A mesh network composed of fixed sensors nodes and also mobile ones (including communication devices carried by local workers during some daily activities) was considered to measure radiation levels. Furthermore, for testing and validation purposes, specific radiation measurement devices were designed and built.

The proposed radioactive radiation monitoring system was simulated, the protocols OLSRv2 and AODV being used for routing purposes (Uludag et al. 2012).

WIRELESS MONITORING SYSTEM ARCHTECTURE

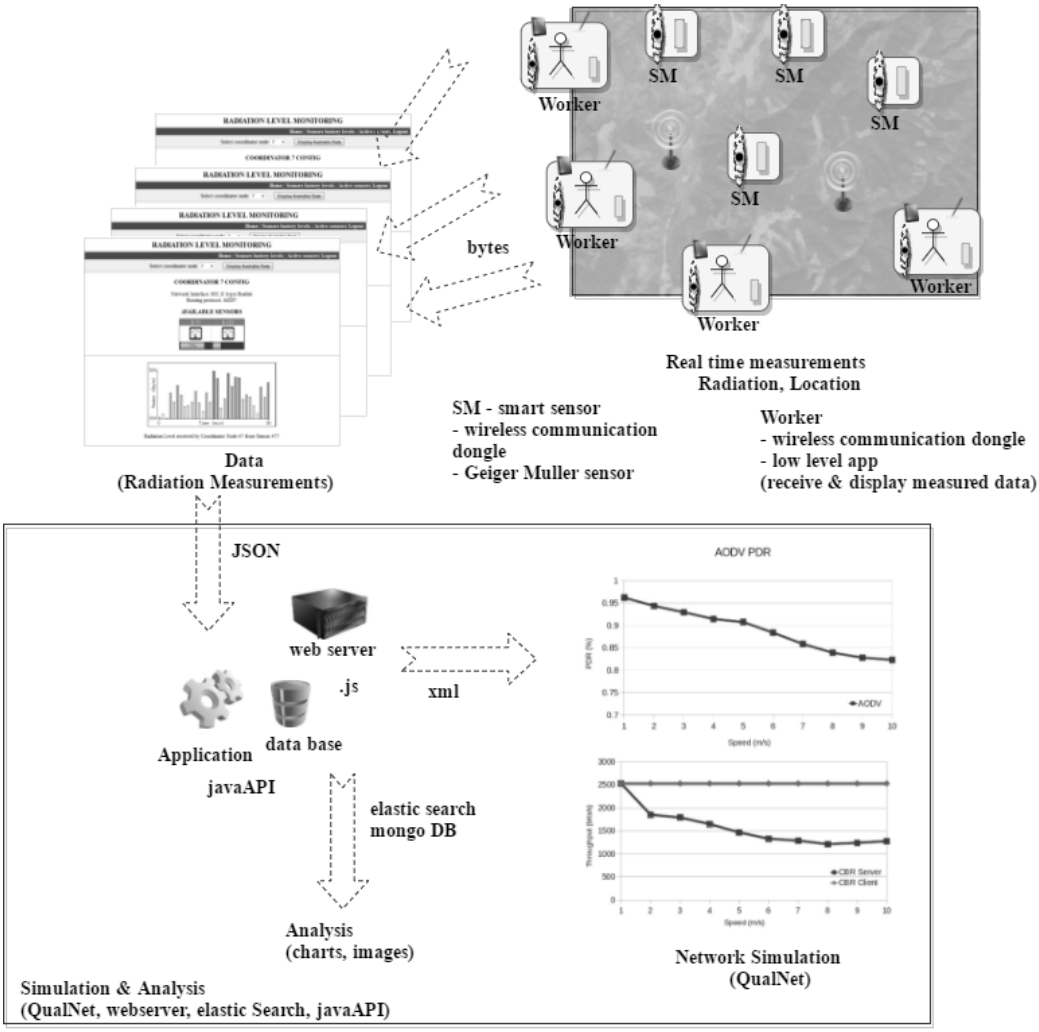

Figure 1. The architecture of the wireless monitoring system

The wireless monitoring system is composed of two parts: the real time measurements part and the simulation and analysis module.
The real time measurements are accomplished by several smart sensors (mobile and fixed, enabled with wireless communication and Geiger Muller detector) and Workers (mobile). All the measured values are sent to simulation and analysis module.
The measured data are stored and can be visualized on a web page. Java and .js api were created to data manipulation (filtering, storing in a data base, retrieving from the data base, chart creations, and analysis). For analysis purposes and realistic evaluation of the communication behavior the QualNet simulator was used as network simulator.

THE WIRELESS RADIOACTIVITY MONITORING DEVICE

The hardware architecture of the wireless radioactivity monitoring device, Figure 2, consist of: a Wi-Fi module, a CBM 20 Geiger Muller (GM) tube, a DC-DC conversion circuit which produces high voltage (HV) from a +3.0V battery and a reverse power supply protection. The device used for sending data based on Wi-Fi is the RN-131C, produced by Roving Networks.
The RN-131 module is a Wi-Fi hybrid reduced dimension circuit which can be used in mobile applications for analog and digital signal measurements.
The Wi-Fi module can scan the network for discovering the Access Points (APs), being able to associate, authenticate and connect over a Wi-Fi network to a database server using the UDP or TCP/IP protocols. The GM tube is connected to the Wi-Fi module, with a digital line and a pulse detector. Every time the tube detects a radioactive particle, the implemented system outputs a beep with an auto-oscillating buzzer, activates a blue LED and the Wi-Fi module counts the pulses and increments the value (pulses number). After a previously programmed period of time for measurements, the Wi-Fi module sends the data and passes to a sleep mode in order to extend the life time of the battery.

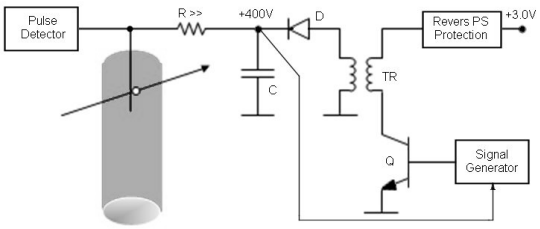

Figure 2. Hardware architecture of the radioactivity monitoring device

The Geiger-Muller tube is built differently depending on the applications in which it is used. For example, if the GM tube is used for monitoring alpha radiation, it will have a thin window at one end. Using this window, the radiations may enter the tube. The high energy electrons are generated by the photo-emission within the tube walls and can be counted. The implemented system presented in this paper is used for monitoring gamma radiation and the radioactive level in different materials. The main advantage of this system is the long lifetime which may reach up two years, due to the fact that it runs on batteries (CR123A lithium type with 3V, 1.5Ah) and that it uses Wi-Fi connectivity. The system may also warn the user by starting an alarm and sending a message when the radiation amplitude passes over a threshold limit.

Hardware implementation of the monitoring device

The design experiments were conducted using the LabVIEW™ graphical programming language. The background radiation (Figure 3) was measured, using the implemented system.

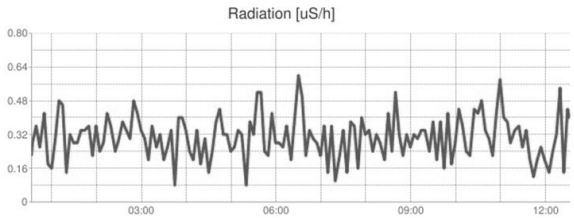

Figure 3. The background radiation

Based on the measuread values, it was observed that a permanent background gamma radiation between 0.1 and 0.5 µS/h exists in the city environment. Equation 1 is used for converting from counts per minute (CPM) to microSievert per hour (µSv/h). It is directly determined by the GM tube characteristics:

$$\mu Sv / h = CPM * 0.0057. \quad (1)$$

The electronic scheme of the DC-DC convertor to higher voltage is presented in Figure 4a. The oscillator frequency, between 1 and 3 kHz, depends on the output voltage level, which has a direct influence in reducing or increasing the power consumption. An important advantage of the implemented scheme is the current consumption, lower than 1 mA. A voltage multiplier was implemented (Figure 4b), because the power consumed by the conversion circuit is lower than the one that would be consumed in the case in which a mono alternation rectifier was used. The voltage is regulated using a feedback network implemented with the Zener diodes D11 and D12 and the resistors R21, R22, R26 and R27. The presence of particles is signaled acoustically and optically. For further data processing, the signal waveform may be acquired using the analog-to-digital converter included in the RN-131 module (with 14-bit resolution and 33 kSps rate; the input range is - 0.2 ... +0.6V). The electronic scheme implemented for connecting the RN-

131C Wi-Fi module with the particle detector is presented in Figure 5.

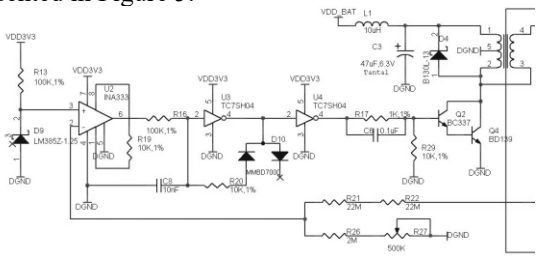

Figure 4a. DC-DC converter oscillator

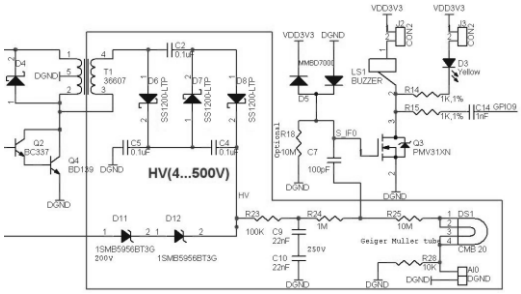

Figure 4b. DC-DC converter-voltage rectifier

The environmental temperature may also be measured using a 10 KΩs board thermistor (RT1). A green LED is turned on when the communication is performed and a red LED is used for implementing the alarms. The reverse power supply scheme is presented in Figure 6. The first version of the developed radiation detector employing the RN-131C Wi-Fi module and the CBM 20 Geiger Muller tube as a radiation detector is shown in Figure 7. The pulse shape in the Geiger Muller tube circuit is presented in Figure 8. The sample was obtained by using a Tektronix TDS1012B oscilloscope having the input probe attenuation set to 10x; the impedance is of 10 MΩs and the capacitance is of 16 pF. The comparison with a commercial system was performed for testing the proposed solution. The test system includes: a DT116 Geiger Muller detector from Fourier Systems and an USB-6009 data acquisition system from National Instruments Corp. A data logger was implemented using the Lab-VIEW^{TM} 2010 environment. The user interface is presented in Figures 9 and 10.

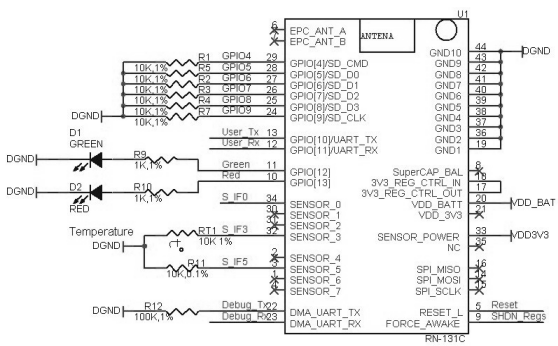

Figure 5. Wi-Fi module-connection scheme

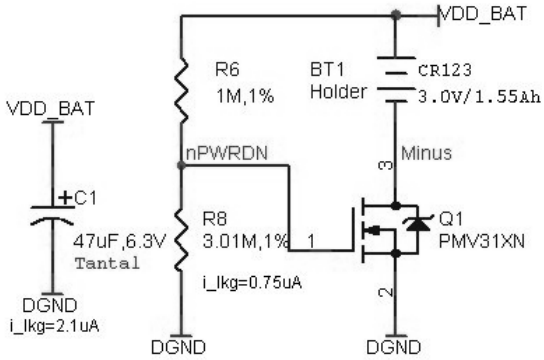

Figure 6. Reverse power supply protection

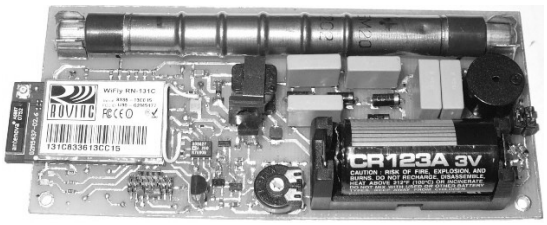

Figure 7. Radiation detector-first version

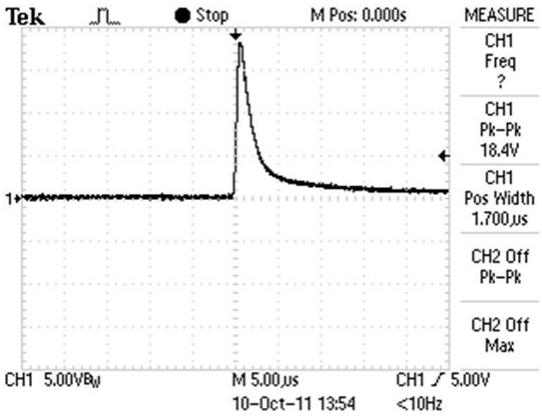

Figure 8. Geiger Muller pulse shape

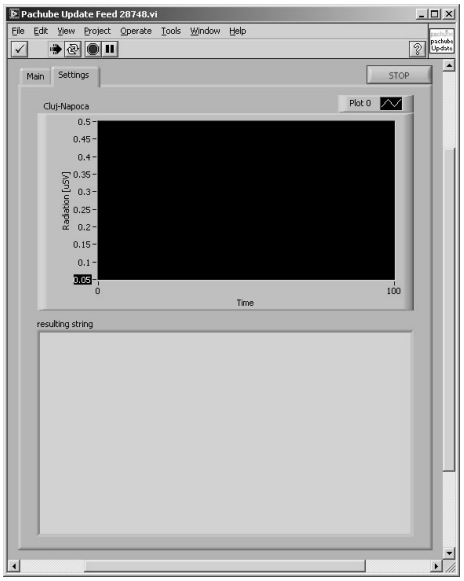

Figure 9. User interface

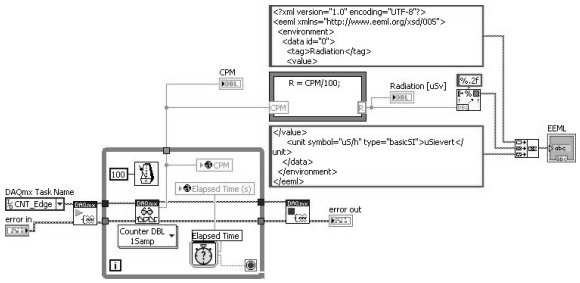

Figure 10. User interface-block diagram

PERFORMANCE ANALYSIS

Network scenario

For wireless communication network simulation we used OLSRv2 (Optimized Link State Routing) and AODV (Ad-hoc On Demand Distance Vector Routing) as routing protocols. OLSRv2 is a proactive routing protocol based on the link state algorithm. It makes use of periodic message exchange to obtain network topology information at each node. The protocol uses multipoint relays to eficiently ood its control messages. OLSRv2 provides optimal routes in terms of number of hops, available immediately when needed and it is suitable for large and dense mobile networks.
AODV is a routing protocol suitable for dynamic self-starting networks, providing loop free routes. It computes the routes on-demand and does not require periodic control messages, improving the overall bandwidth usage eficiency. The protocol scales to a large number of network nodes.
As a discrete event network simulator Qualnet 5.01 version was utilized. The detailed parameters for the network configuration are listed in Table 1.

Table 1 Parameters for the network configuration

Parameter	Values
Simulator	Qualnet 5.01
Routing Protocol	AODV and OLSRv2
Simulation area	1500 m x 1500 m
Number of nodes	41
Nodes placement	Random
Mobility	RWP, max speed 0-10 m/s
Simulation Time	100 seconds
Average Packet size	32 bytes
Transmission Interval	0.1 s
MAC Protocol	IEEE 802.11
Physical Layer Model	PHY 802.11b
Pathloss Model	Two Ray Ground
Shadowing Model	Constant
Shadowing Mean	4.0 dB
Transmission Range	270 m
Data Rate	11 Mbps

For the considered simulation we designed a network composed of 41 randomly placed nodes, in a 1500 square meters topology. The proposed topology was choosen as a good trade of between a quite dense network and computation complexity. Because the nodes speed needs to be close to urban mobility, we chosed the range of the speed from 1 m/s to 10 m/s. The data packet length is 32 bytes and contains the radiation level and the remaining battery capacity of the sensor. To be able to evaluate the worst case scenario for radiation level transmission in the network, we considered 6 CBR sources that operate in the same time interval and send data packets at a transmission interval of 100 ms.

Simulation results

Figure 11 shows the PDR (Packet Delivery Ratio) in this scenario. In Figure 12 is representing the dependency between the speed changing and PDR. AODV provides the best performances in terms of packet delivery, with more than 95% PDR for slow speeds and a minimum of 82% PDR at 10 m/s, Figure 13. In comparison, OLSR provides poor performances even at slow speeds (79% PDR at 1 m/s), Figure 14. Taking into account these results, we can state that AODV protocol is more suitable than OLSR for the proposed simulation scenario.
The web server corresponding image of the measured values sent by sensors is presented in Figure 15.

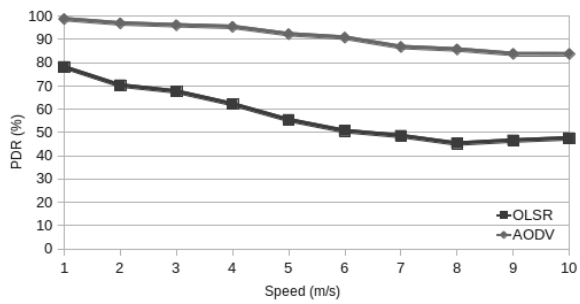

Figure 11. Packet Delivery Ratio

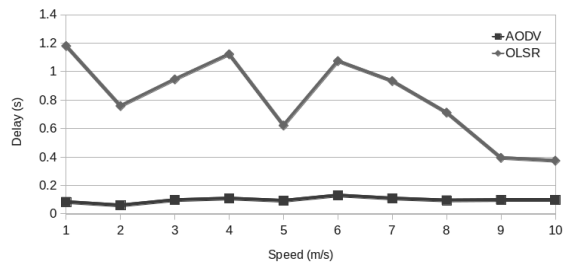

Figure 12. Average delay

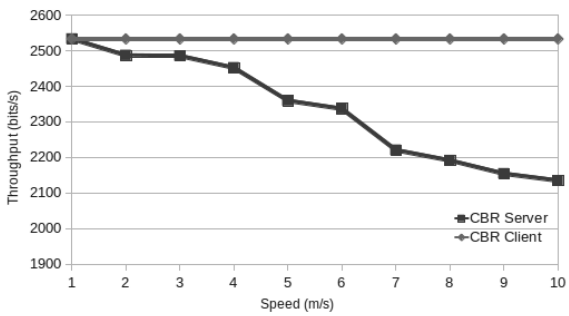

Figure 13.AODV Throughnput

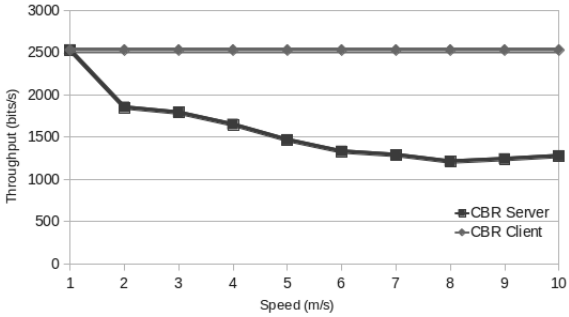

Figure 14. OLSR Throughnput

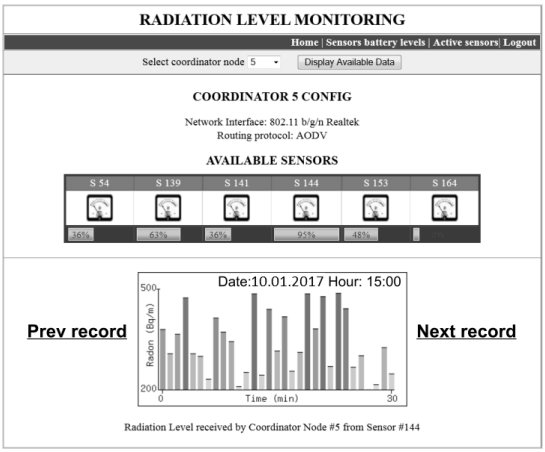

Figure 15. Radiation level monitoring system

As an illustration of the final utility of this proposed system, a virtual map of radioactive contamination, generated by simulation, in the vicinity of a real radioactive waste dump is presented in Figure 16a – Figure 16d. Climatic and meteorological information was considered to determine possible spread of radioactive particles in the proximity of the site.

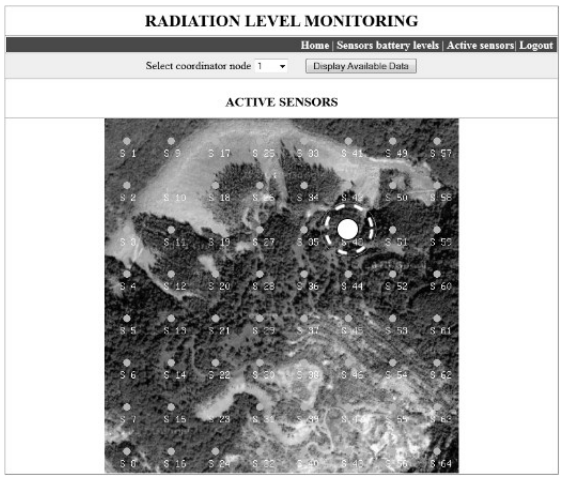

Figure 16a

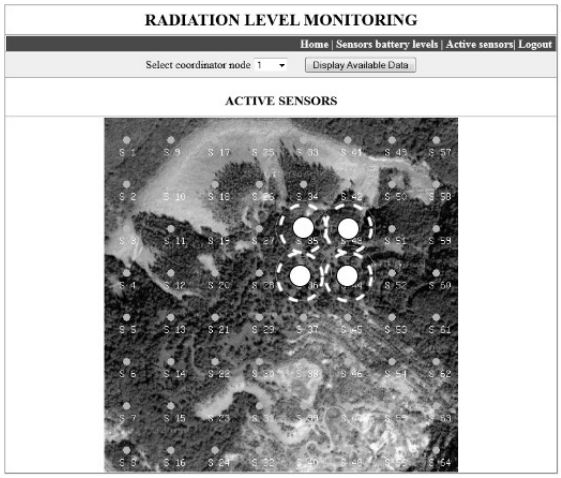

Figure 16b

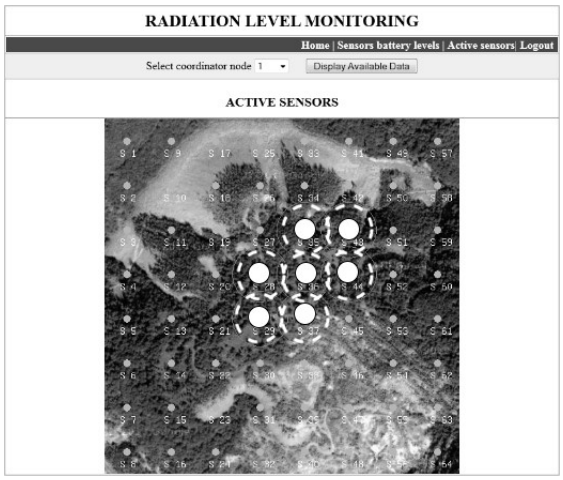

Figure 16c

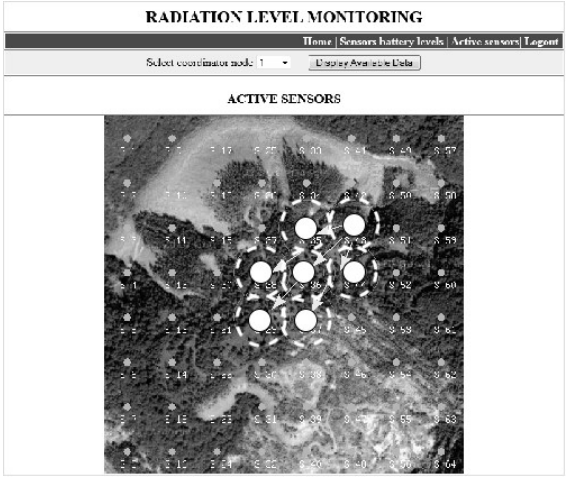

Figure 16d

CONCLUSIONS

The radioactivity monitoring network proposed in this paper can be used not only to transmit data related to the time evolution of the radiation level in potential radioactive contaminated areas, but also to give long-time information about background radiations and the radioactive emissions of different materials and structures. By integrating a very low power wireless device with a Geiger-Muller radiation detector, a portable device which can run on battery power was developed and tested. A mesh network topology was chosen for the considered application, the simulations indicating better results in the case in which the AODV protocol was used for routing purposes. The implemented system can improve the existing solutions presenting mobility and the capacity of storing data locally, for situations in which the wireless connectivity is unavailable for short time intervals.

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