Engineering

AIR QUALITY MONITORING SYSTEM BASED ON LARGE-SCALE WSN: A STEP TOWARDS A SMART CITY

Alexandru LAVRIC[1]
Valentin POPA[2]

ABSTRACT:
THIS PAPER PRESENTS THE DEVELOPMENT, IMPLEMENTATION AND TESTING OF AN AIR QUALITY MONITORING SYSTEM. THE SYSTEM IS BASED ON THE ARCHITECTURE OF A METROPOLITAN WSN SENSOR NETWORK OF THE LARGE SCALE TYPE, SPREAD ON A WIDE GEOGRAPHICAL AREA AND THUS COMPLYING WITH THE SMART CITY CONCEPT. THUS, THE LOCAL AUTHORITIES CAN MAKE DECISIONS CONCERNING THE REDUCTION OF THE POLLUTION LEVEL IN TERMS OF THE QUANTITY OF PM10 PARTICLES IN THE AIR. THE ARCHITECTURE IS OF THE CLIENT SERVER TYPE, USING THE JENNET COMMUNICATION PROTOCOL AND THE SYSTEM CAN INTEGRATE A LARGE NUMBER OF NODES. THE OBTAINED RESULTS SHOW THAT THE SYSTEM HAS A HIGH EFFICIENCY LEVEL AND CAN BE INTEGRATED IN THE SMART CITY CONCEPT.

KEY WORDS: AIR QUALITY MONITORING, LARGE-SCALE, PM10, SMART CITY, WSN.

INTRODUCTION

The reduction of air pollution is a very topical issue and is the focus of numerous research centres. More than half of the world's population now lives in urban areas[3] and, thus, technologies that can contribute to economic development must advance at a rapid pace. According to Schaffers H.[3], the Smart City concept entails the use of technologies for the citizens' well-being and for economic development. Additionally[4], analyses this concept in terms of the economic need for local authorities to take part in this process, through the efficient management of the natural resources, through investments in human and social capital and, last but not least, through the development of the transport and telecommunications infrastructure.

One of the objectives of the Smart City concept is to increase the quality of life, all the while protecting the environment. Fig. 1 presents the architecture of the ecosystems within a Smart City.

---

[1] PhD, Computers, Electronics and Automation Department, Stefan cel Mare University of Suceava, Romania, lavric@eed.usv.ro.

[2] PhD, Prof. Computers, Electronics and Automation Department, Stefan cel Mare University of Suceava, Romania.

[3] Schaffers H., Komninos N., Pallot M., Trousse B., Nilsson M., Oliveira A., *Smart cities and the future internet: Towards cooperation frameworks for open innovation*, Springer Berlin Heidelberg, (2011), 431-446.

[4] Vilajosana I., Llosa J., Martinz B., Domingo-Prieto M., Angles A., Vilajosana X., *Communications Magazine*, IEEE, 51(6), (2013).

Thus, we are here referring to the monitoring and control of the systems: water and sewage, transport and environment, smart metering and street lighting, water and environment protection and, last but not least, waste management.

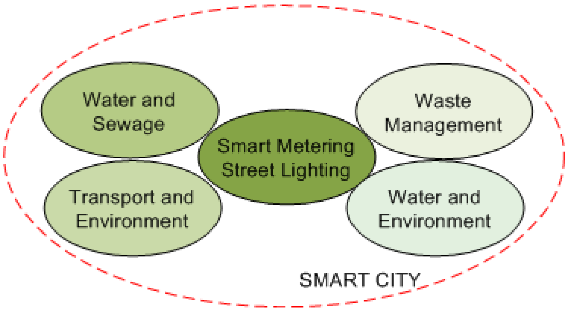


Fig. 1. Smart City concept.

There are a series of papers in the professional literature, that approach the issue of air quality monitoring [5,6,7,8,9], but none of these research papers allow for the integration of a very large number of monitoring points and, at the same time, entail very low implementation costs. Many of these papers discuss or present results obtained by using professional measurement equipment[10]. The main contribution of this paper is the implementation of a low cost air quality monitoring system that allows the integration of a large number of monitoring points.

SYSTEM OVERVIEW

The system is based on a WSN wireless network of the large scale type, spread on the geographical area of a town and used for transferring information. Thus, we can identify two types of communication: local communication, on short distances, from one monitoring module to another, and long distance communication, such as the one between the control centre that processes the information, and the WSN network. The local communication is enabled by using a JenNet type of protocol, based on the IEEE 802.15.4 standard and providing the possibility to integrate a very large number of nodes, without any additional license costs. Long distance communication is enabled by using a TCP/IP connection. Fig. 2 presents the general structure of the system.

[5]Davila S., Beslic I., Pecar-Ilic J., Sega K., *Automated web-based system for air quality monitoring. MIPRO*, Proceedings of the 34th International Convention (2011), 816-819.
[6] T. Q. Ngoc, J. Lee, K. J. Gil, K. Jeong, S. B. Lim, *An ESB Based Micro-scale Urban Air Quality Monitoring System*, 2010 IEEE Fifth Int. Conf. Networking, Archit. Storage, (2010) 288–293.
[7] T. Lin, H. Lu, J. Liu, *Application of a Reliable MAC Protocol for the Urban Air Quality Monitoring System Based on the Wireless Sensor Network*, Southeastcon, (2012) 1-6.
[8] J.-A. Jiang, *Developed urban air quality monitoring system based on wireless sensor networks*, Fifth Int. Conf. Sens. Technol, (2011) 549–554.
[9] S. Mansour, N. Nasser, L. Karim, A. Ali, *Wireless Sensor Network-based Air Quality Monitoring System*, Computing, Networking and Communications (ICNC), (2014) 545–550.
[10] I. Ionel, G. Apostol, F. Popescu, C. Talianu, M. Apascaritei, *Air quality monitoring in an international Romanian airport*, Journal of Environmental Protection and Ecology, 3, (2010) 815–821.

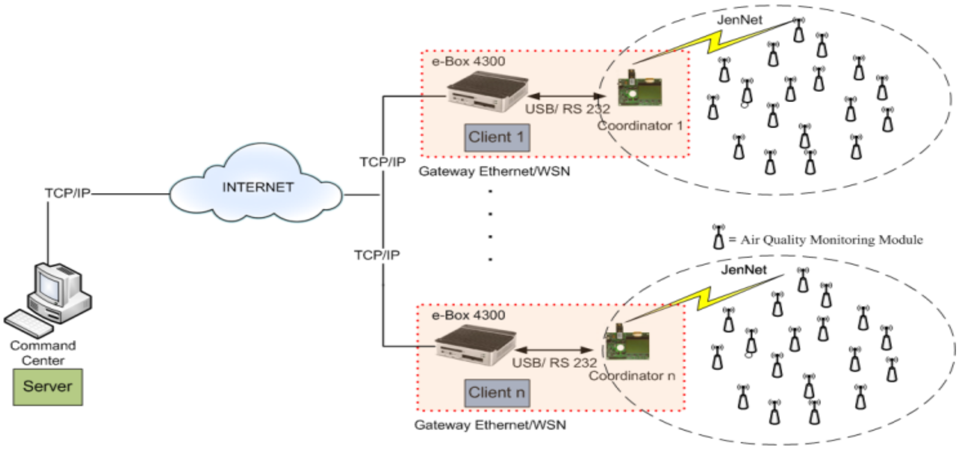


Fig. 2. Air Quality Monitoring system.

In a previous paper[11] the authors developed an automatic channel selection algorithm (ACS) that can be implemented in a large-scale, WSN network in order to avoid the interference caused by other wireless communications operating in the same frequency band. This ACS algorithm is used in the air quality monitoring WSN network.

The monitoring system consists of: the control centre, the monitoring modules and the gateway modules. The monitoring nodes incorporate sensors that measure the level of PM10 (Particulate Matter) particles in the air. The control centre collects and processes the received information

The Gateway module enables the transfer of information within the WSN network, compliant with the IEEE 802.15.4 standard, and the TCP/IP network. The module consists of the WSN network coordinator, connected through a UART (Universal Asynchronous Receiver/Transmitter) communication interface to the e-Box 4300 module. The WSN nodes are of the NXP JN5148 type[12].

Thus, when the values are measured, the information is sent through the JenNet wireless network to the coordinating node which further sends it to the e-Box 4300 module from where it is subsequently dispersed through the TCP/IP network to the control centre.

SYSTEM DEVELOPMENT

The air quality monitoring system integrates an optic sensor of the Sharp GP2Y1010AU0F type[13], that measures the air PM10 particles. The sensor output voltage is directly proportionate to the level of particles in the air.

Ample research has been conducted in the past two decades in order to identify the negative effects of the particulate matter suspended in the atmosphere on the human body. The research shows that the long term effects of having been exposed to PM 10 (Particle Pollution – particles smaller than 10 μm) and PM 2.5 (particles smaller than 2.5 μm) can seriously affect health[14].

---

[11] Lavric, A., Popa V., Sfichi, S., *Adaptive Channel Selection Algorithm for a Large Scale Street Lighting Control ZigBee Network*, Elektronika ir Elektrotechnika. 19(9), (2013) 105-109.
[12] On-line: Datasheet JN5148, http://www.nxp.com/documents/data_sheet/JN5148.pdf. (14.01.2015).
[13] On-line: Datasheet Sharp GP2Y1010AU0F, http://sharp-world.com/products/device/lineup/data/pdf/datasheet/gp2y1010au_appl_e.pdf. (20.12.2014).
[14] M. Budde, M. Busse, M. Beigl, *Investigating the Use of Commodity Dust Sensors for the Embedded Measurement of Particulate Matter*, Networked Sensing Systems (INSS), (2012) 1-4.

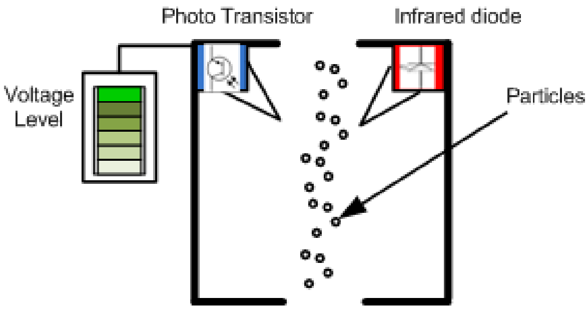
Suspended particles are a complex mixture of microscopic solid and liquid particles that remain suspended for a long time. They have negative effects on the vegetation and can be inhaled by people, leading to serious respiratory conditions. Road transport causes particle pollution, resulting from car tires when braking and from the incomplete burning of the fuel. Almost 70 % of the pollution recorded in Bucharest is caused by road traffic and, therefore, the most exposed areas of the city are those where the average road traffic is very high. The most polluted area of the country has been identified as the Titan neighbourhood in Bucharest, where the monitoring station has recorded PM10 values ranging between 75 and 95 $\mu g/m^3$, above the maximum approved level of 50 μ/m^3. According to the national monitoring network, the daily maximum level of PM10 particles people can be exposed to without endangering[15] their health amounts to 50 $\mu g/m^3$.

The size of the particles is directly related to the probability of causing effects. One particular problem is the case of the particles with an aerodynamic diameter smaller than 10 micrometers that enter through the nose and the throat and go directly into the lung lobes, causing inflammation and intoxication[16]. The most affected are especially people who suffer from cardiovascular and respiratory conditions, children, the aged and those suffering from asthma. Particle pollution aggravates the asthma symptoms, i.e. coughing, chest pains and difficulty breathing. The long term exposure to a low concentration of particulate matter can cause cancer and premature death[16].

An optical sensor for monitoring air particles, of the GP2Y1010AU0F type is integrated in the air quality monitoring system, as can be seen in Fig. 3.

The sensor is installed in the WSN modules. An infrared diode (IRED) and a phototransistor detect the light reflected by the particles in the air. The optical detection process is highly efficient in detecting very fine particles[17]. The sensor has a very low power consumption (maximum 20 mA) and can be powered with a DC voltage of maximum 7 V. The sensor output has an analogical voltage that is directly proportionate to the measured particle density, with a sensitivity of 0.5 V per 0,1 mg/m^3.

a) Sharp sensor



b) Internal structure

Fig. 3. The Sharp sensor.

[15] On-line: *Reteaua Nationala de Monitorizare a Calitatii Aerului*. http://www.calitateaer.ro/parametri.php. (15.01.2015.).

[16] M. I. Khadem, G. Stamatescu, *Wireless Measurement Node for Dust Sensor Integration*, SENSORCOMM 2012, no. c, (2012) 159–164.

[17] Alexandru Lavric, Valentin Popa, Codrin Males, Ilie Finis, *A Performance Study of ZigBee Wireless Sensors Network Topologies for Street Lighting Control Systems*, International Workshop on Mobile Ad-Hoc Wireless Networks iWMANET, France, (2012) 130-133.

The diode must be powered through a PWM signal that has a frequency of 100 Hz, a period of 10 ms, and the length of a pulse is of 0.32 ms, as can be seen in Fig. 4 that presents the sensor's supply circuit.

An optical sensor for monitoring air particles, of the GP2Y1010AU0F type is integrated in the air quality monitoring system. The sensor output has a voltage that is directly proportionate to the density of the particles that are present in the air.

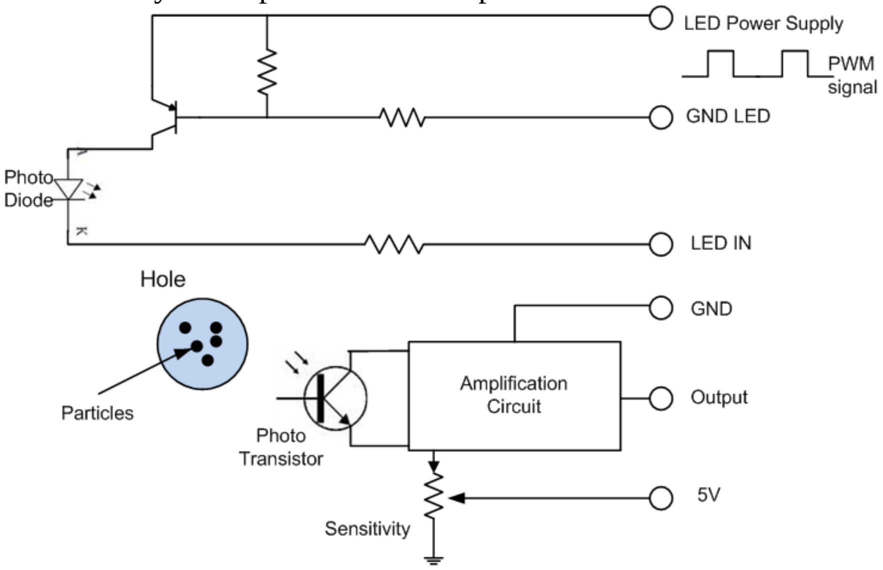


Fig. 4. Sharp sensor supply circuit.

Fig. 5 presents the assembly made for integrating the sensor within the system. The careful monitoring of the air quality is conducted by integrating the sensor within the system. Thus, note the JN 5148 module that has the Sharp sensor connected at the ADC converter input. The network topology used in the WSN network is of the tree type, as it ensures a high efficiency level and provides the possibility of integrating a very large number of nodes[17]. The main advantage of this system is the very low implementation cost, since the system does not require additional data transfer subscriptions, as the data transfer is conducted through TCP/IP.

Fig. 5. Air Quality Monitoring System.

Fig. 6 presents the logical operations conducted by the WSN module. It reads the values from the Sharp sensor output and sends it to the coordinating WSN node.

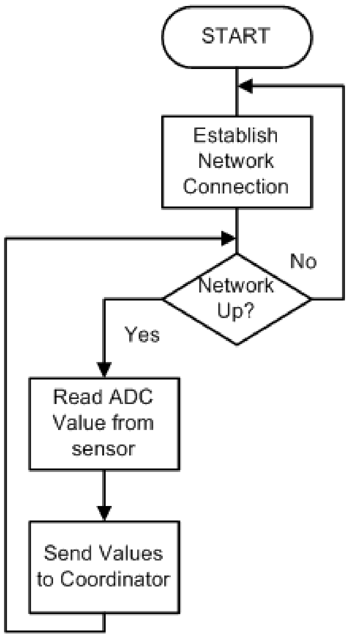


Fig. 6. WSN logical diagram.

Fig. 7 presents the logical operations executed by the coordinating node. It monitors the radio activity and resends the information received from the WSN network to the e-Box 4300 module, and the information will be further sent through the TCP/IP network to the control centre where it is saved in a data base.

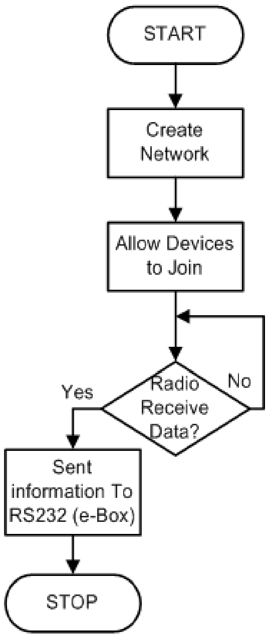
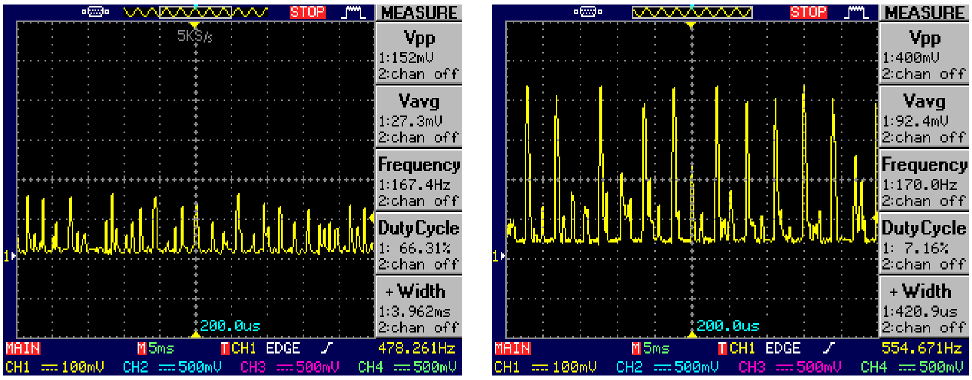


Fig. 7. Coordinator logical diagram.

TEST RESULTS

This section presents the experimental results acquired after installing the proposed system in the field. Fig. 8 presents the signal sent from the sensor output. It is applied to the

ADC converter input. As can be seen, if the level of the particle density in the air increases, the voltage will directly increase at the sensor output.



a) Good Air Quality b) Poor Air Quality

Fig. 8. Sharp sensor output signal.

Fig. 9 presents the variation of the values recorded by the ADC converter from two different locations where they have been installed. The acquired results show that the air quality in the second location is much worse and, implicitly, the number of PM10 particles is much higher, as compared to the results recorded in the first location. We should mention that with the second location, the monitoring module had been installed in the vicinity of a heavy traffic road in Suceava city, Romania.

The values collected from the sensor are sent through the TCP/IP network to the control centre where they are saved in a database.

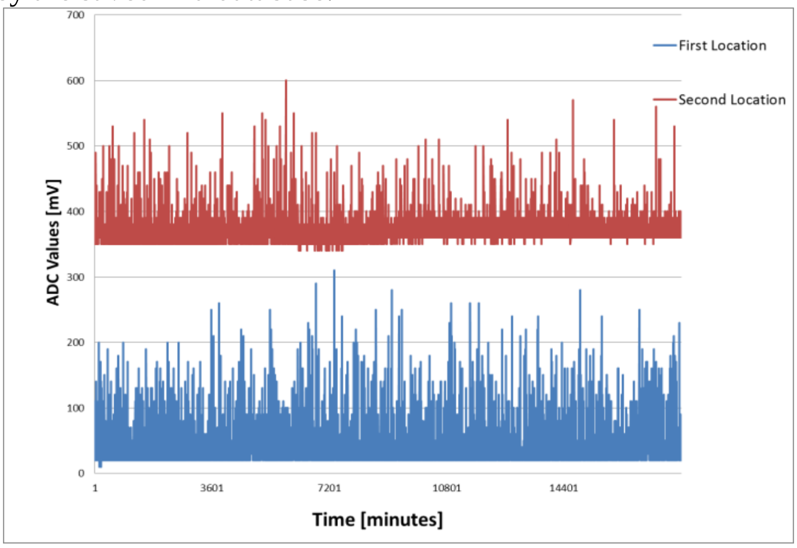


Fig. 9. Values recorded by the JN 5148 ADC.

Fig. 10 presents the variation of the PM10 particle concentration in the environment in two locations. Since the values recorded by the sensor can vary sporadically, the WSN module makes an arithmetic mean of the last 50 measurements and subsequently sends the resulting value to the coordinating node.

The acquired results show that the concentration of air particles is much higher in the second location (as the graph is centered on a much higher value). The maximum recorded value amounts to 0.12 mg/m^3 for the second location. The value is far above the maximum value allowed, which is of 0.05 mg/m^3. Thus, the system is able to monitor the air quality, so that the local authorities can make decisions towards reducing the pollution levels.

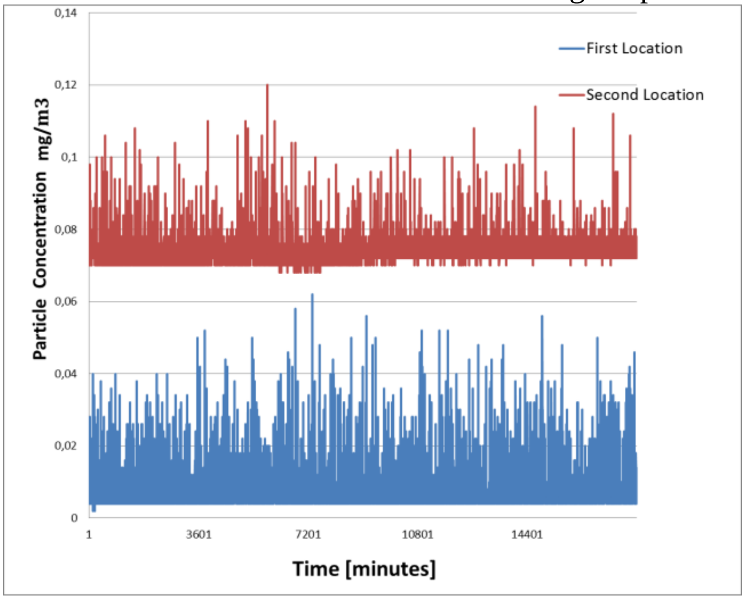


Fig. 10 Concentration of particles in the air.

Fig. 11 shows the intuitive graphic interface of the air quality monitoring system. The interface is fitted with a map that displays the values recorded from the sensors installed in various locations in the city.

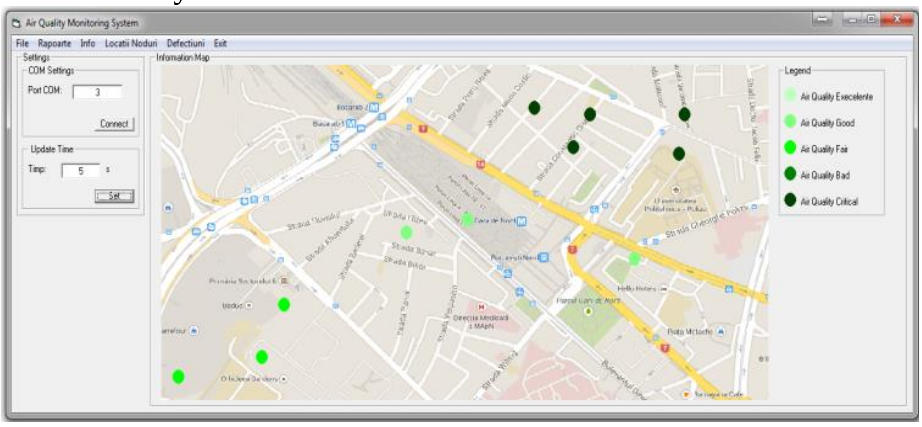


Fig. 11. User Interface.

An Apache 2.44 web server functions at the control centre. The server runs a HTML page that allows the access of authorised personnel to the air quality monitoring system. Thus, the data collection can be conducted from any location with Internet access and from any type of terminal. If certain maintenance work is being conducted, the user can make various configuration operations in the field by means of a smart phone. Additionally, the server hosts a portal through which the population can check the PM10 particle concentration in the air and the information is updated every two minutes.

CONCLUSION

The system is able to monitor the air quality so that local authorities can make decisions toward reducing pollution. The acquired results show that the proposed system is highly efficient and can be integrated in the Smart City concept. The implementation costs of the air quality monitoring system are very low, since the long distance transfer of information is made by means of a TCP/IP connection that does not entail additional costs as compared to using the cellular data network that entails the presence of an additional data subscription. Thus, the system helps protect the environment by monitoring the air quality.

ACKNOWLEDGMENT

This paper has been financially supported within the project entitled „SOCERT. Knowledge society, dynamism through research", contract number POSDRU/159/1.5/S/132406. This project is co-financed by European Social Fund through Sectoral Operational Programme for Human Resources Development 2007-2013. Investing in people!

REFERENCES

1. **Alexandru Lavric; Valentin Popa; Codrin Males; Ilie Finis;** *A Performance Study of ZigBee Wireless Sensors Network Topologies for Street Lighting Control Systems*, International Workshop on Mobile Ad-Hoc Wireless Networks iWMANET. / France, (2012) pp. 130-133.
2. **Davila S.; Beslic I.; Pecar-Ilic J.; Sega K.;** *Automated web-based system for air quality monitoring. MIPRO*, Proceedings of the 34th International Convention (2011), pp. 816-819.

I. Ionel; G. Apostol; F. Popescu; C. Talianu; M. Apascaritei; *Air quality monitoring in an international Romanian airport*, Journal of Environmental Protection and Ecology, no. 3, (2010) pp. 815–821.

3. **J.-A. Jiang,** *Developed urban air quality monitoring system based on wireless sensor networks*, Fifth Int. Conf. Sens. Technol, (2011) pp. 549–554.
4. **Lavric, A.; Popa V.; Sfichi, S.;** *Adaptive Channel Selection Algorithm for a Large Scale Street Lighting Control ZigBee Network*, Elektronika ir Elektrotechnika. 19(9), (2013) pp. 105-109.
5. **M. Budde; M. Busse; M. Beigl;** *Investigating the Use of Commodity Dust Sensors for the Embedded Measurement of Particulate Matter*, Networked Sensing Systems (INSS), (2012) pp. 1-4.
6. **M. I. Khadem; G. Stamatescu;** *Wireless Measurement Node for Dust Sensor Integration*, SENSORCOMM 2012, no. c, (2012) pp. 159–164.
7. **On-line**: Bucureștenii respira praf, http://www.ziare.com/articole/bucuresti+poluare+pulberi+suspensie. (24.12.2014.).
8. On-line: **Datasheet JN5148**, http://www.nxp.com/documents/data_sheet/JN5148.pdf. (14.01.2015).
9. On-line: **Datasheet Sharp GP2Y1010AU0F**, http://sharp-world.com/products/device/lineup/data/pdf/datasheet/gp2y1010au_appl_e.pdf. (20.12.2014).
10. **On-line**: Reteaua Nationala de Monitorizare a Calitatii Aerului. http://www.calitateaer.ro/parametri.php. (15.01.2015.).
11. **S. Mansour; N. Nasser; L. Karim; A. Ali;** *Wireless Sensor Network-based Air Quality Monitoring System*, Computing, Networking and Communications (ICNC), (2014) pp. 545–550.
12. **Schaffers H.; Komninos N.; Pallot M.; Trousse B.; Nilsson M.; Oliveira A.** , *Smart cities and the future internet: Towards cooperation frameworks for open innovation*, Springer Berlin Heidelberg, (2011), pp. 431-446.
13. **T. Lin; H. Lu; J. Liu;** *Application of a Reliable MAC Protocol for the Urban Air Quality Monitoring System Based on the Wireless Sensor Network*, Southeastcon, (2012) pp. 1-6.
14. **T. Q. Ngoc; J. Lee; K. J. Gil; K. Jeong; S. B. Lim;** *An ESB Based Micro-scale Urban Air Quality Monitoring System*. 2010 IEEE Fifth Int. Conf. Networking, Archit. Storage, (2010) pp. 288–293.
15. **Vilajosana I.; Llosa J.; Martinez B.; Domingo-Prieto M.; Angles A.; Vilajosana X.;** Communications Magazine, IEEE, 51(6), (2013).