Zhilbert TAFA*

AIR POLLUTION MONITORING AND MANAGEMENT USING WIRELESS TECHNOLOGIES

Abstract: Air pollution (AP) is one of the main causes of lung cancer and stroke. It has also been correlated with cardiac, ophthalmologic, psychiatric, and many other diseases. In order to minimize the negative health impacts, AP should be properly monitored and managed. Conventional systems are expensive and sparsely deployed, hence cannot provide the required spatiotemporal resolution. This paper reviews the emerging (wireless) technologies for real-time AP monitoring. The implementation of machine learning (ML) in AP monitoring and management is also considered.

1. INTRODUCTION

The development of human societies and the accompanying growth in the consumption of natural resources, especially over the past couple of centuries, has given rise to a multitude of human-induced environmental problems [1]. Air pollution is becoming one of the greatest threats to the human health. Traditionally, it has been monitored by using sparsely deployed expensive instruments. However, the AP has a much higher spatiotemporal resolution. Precisely, due to the metrological (temperature, humidity, wind, etc.) and terrain conditions, the pollutant concentration may quickly vary over a small portion of an area and may not be necessarily accumulated in the close vicinity to the AP source. Some experimental justifications can be found [2] and [3]. Consequently, data acquired from just one station or a few devices may be insufficient to describe the pollution distribution over a given region. The development of high-sensitivity multi-parameter, densely

* Zhilbert Tafa, Indiana University, Bloomington, USA and UBT College, Priština, Kosovo

deployed, and inexpensive real-time monitoring systems appear to be of crucial importance to the appropriate pollution prevention and/or management.

The advances in wireless communications and low-cost embedded systems have opened opportunities of ubiquitous computing [4]. Small smart sensors can sense, locally process, and transfer environmental data, virtually from anywhere. Being densely deployed, network can provide a more precise AP distribution over a given region. Such a georeferenced and time-stamped data can further be processed with ML techniques for AP source localization and AP distribution prediction.

In order to eliminate, decrease, or prevent the AP; the monitoring and management information systems work in the inverse feedback manner. They provide real-time sensing and data transmission, remote data visualization and analytics, AP forecast, early warning, etc. Main aspects of such a system may be summarized in: (a) data acquisition, (b) data dissemination, (c) energy management, (d) data utilization.

This article presents a short review on data acquisition and dissemination for AP monitoring. After the introduction, the target parameters and the overall architecture of an AP monitoring system are presented. The modules of a sensor node are described along with the main issues related to the design and implementation. The available wireless technologies and possible topologies are presented in the similar manner. Energy-related issues, as being an important aspect of the Wireless Sensor Networks (WSNs), are also shortly presented. In order to exemplify the aforementioned concepts, two prototype systems developed in the laboratory are presented as well. Some notes on using ML for different tasks in AP monitoring and management are given before the conclusion. Finally, last section concludes the article.

2. WSNS FOR AIR QUALITY MONITORING

Air quality analysis involves the examination of the biological, physical, and chemical properties of the air. Although public concern has been mostly focused on urban areas, due to cooking, spraying pesticides etc., indoor areas may be also highly contaminated. Traditional air quality analysis involves periodical sensing and data reporting from the accurate and reliable instruments. These instruments are expensive (of the order of few thousand dollars) and of large physical dimensions (Fig. 1). As such, only one or a few of them are typically used to cover an urban area (e. g., a city).

WSN nodes can be placed anywhere. They are low-cost (of order of few hundred dollars), power autonomous, and of small physical dimensions. As such, they can provide sensing systems of high sampling and spatial

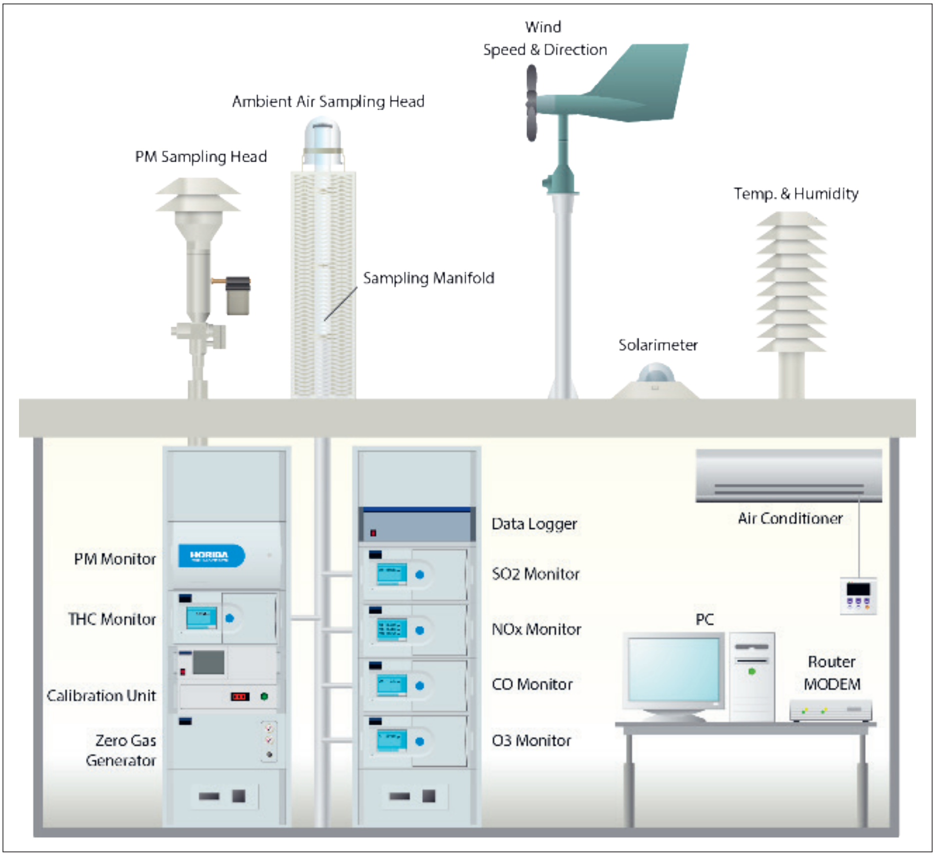


Figure 1: A conventional AP monitoring station [5]. The stations are expensive and of relatively large physical dimensions (typically occupy an area of few m^2).

resolution. Equipped with wireless transceivers, they can report readings in real time. However, the implementation of the WSNs has limitations, such as energy issues, wireless link instability, the environmental and electromechanical influences, etc.

2.1 Air Quality Indicators

Different countries and organizations have set different standards for AP evaluation. Most of the outdoor systems are focused on measuring: carbon monoxide (CO), nitrogen dioxide (NO_2), ground level ozone (O_3), ammonium (NH_4), particulate matter (PM), sulfur dioxide (SO_2), lead (Pb), temperature, and humidity. Indoors, carbon dioxide (CO_2), Particulate Matter (PM), Volatile Organic Compound (VOC), temperature, and humidity, are mostly measured. In order to provide a single understandable information, so-called Air Quality Index (AQI) is extracted from the measured parameters. AQI is usually measured as worst index of separately calculated indices for each pollutant. US EPA categorizes QA in six categories, in scale from 0 to 500. In EU countries, Air Quality Framework Directive specifies AQI in range of 0–100. Some countries (e. g., Canada and UK) use 10-point scale to quantify the overall AQI etc.

2.2 The Elements of a WSN-based Systems for AP Monitoring and Management

The emerging systems for AP monitoring and management rely on WSN infrastructure. A WSN is a data acquisition and dissemination platform that enables data reporting from smart sensors to a web server and/or to data center. The information system should provide the means of data visualization in real time. Also, it should contain modules for data analytics, prediction and early warning. The workflow scheme of such a system is depicted in Fig. 2.

In order to minimize the negative influence of the AP to human health, after identifying the pollution sources, or possible future pollution hotspots, the authorities can act towards the elimination or minimization of the contaminant's concentrations or AP sources.

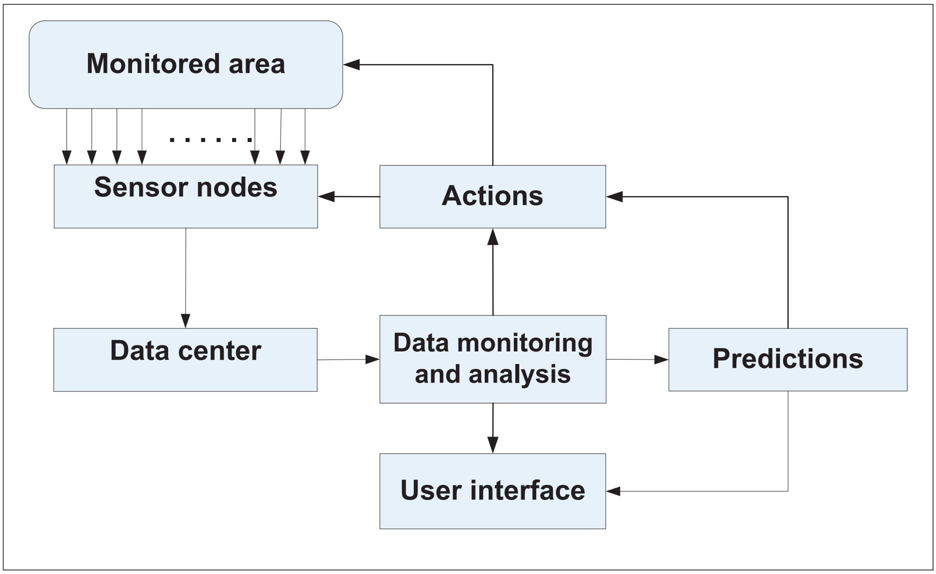


Figure 2: An AP monitoring system contains data acquisition module, data dissemination infrastructure, data center for data visualization and utilization, user interface, and (sometimes) actuators for AP and node's management.

2.3 Data Acquisition Architecture and Issues

Main components of a sensor node are: (a) sensors, (b) signal conditioning module, (c) computing module, (d) communication module, (e) energy management module. The core elements are depicted in Fig. 3.

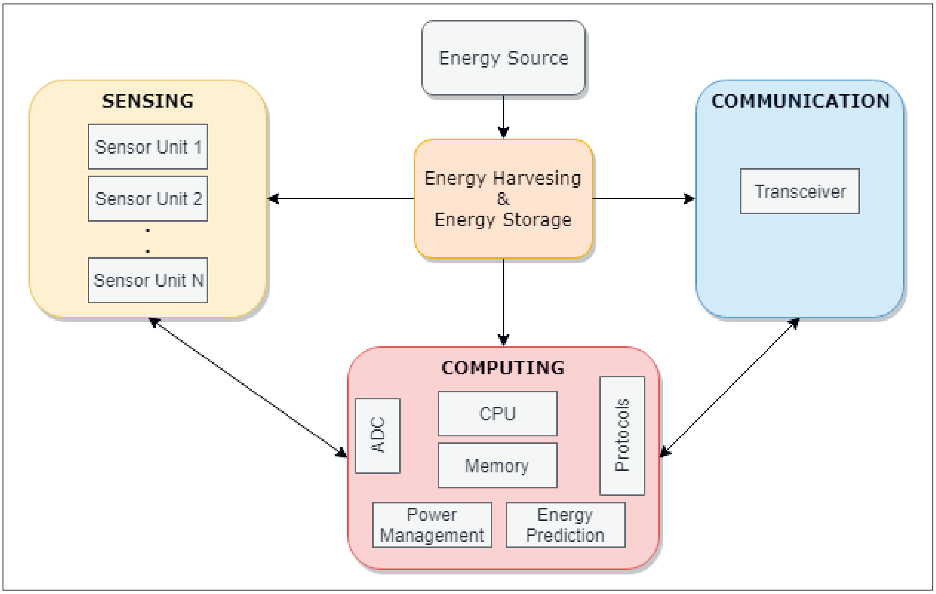


Figure 3: Signals are conditioned, sampled and digitized. Then, they are forwarded to the communication module for wireless transmission. Energy management module is focused on the energy optimization.

The existing AP low-cost monitoring nodes are either based on off-the-shelf components or are delivered as fully integrated plug-and-play solutions. The last ones are easier to integrate and have robust electro-mechanical design, but lack in flexibility (Fig. 4).

Continuous AP reporting based on low-cost sensors has several constrains. Most of them are related to sensors' performances. Precisely, sensors come with somewhat unknown and unpredictable settings. Prior to their integration into AP measurement system, they need to be evaluated in terms of accuracy, selectivity, sensitivity, and precision. The evaluation should be followed with the calibration process. Because of the aging effects, they should also be periodically rechecked on the aforementioned metrics and recalibrated.

The sensor performances vary from sensors to sensors. Also, some of them might show good performances regarding specific parameters, but they

Figure 4: Libelium Air Quality station [6] — an example of integrated low-cost sensor for AP monitoring. This module also enables for the online calibration by using artificial intelligence.

may be not as accurate to measure other parameters. For instance, for NO_2, data acquired from Alphasense [7] show high R^2 correlation with data obtained from standard instruments. On the other hand, the correlation is not satisfying regarding the O_3 parameter.

Low-cost sensors for AP monitoring are highly sensitive to the operating conditions and impose aging drift in time. Their readings are influenced by wind, temperature, humidity, etc. They are also influenced by external or internal noise, such as mobility and low sensitivity, respectively.

The electromechanical gas sensors consume a considerable amount of energy. As compared to the humidity or temperature sensors, they are much greater energy consumer. This questions the nodes' autonomy in some applications. The energy-saving schemes often include lowering the duty-cycle. However, turning off the gas sensor for a longer time is not suitable, because they need some time to heat-up before they become operable again.

Regardless of the aforementioned limitations, a study performed in [8] shows that, if the reason of using low-cost sensors is not to measure the absolute concentration of AP values, but to indicate the quality of the atmospheric environment through different health impact levels (such as AQI), then low-cost sensor devices may successfully fit this purpose.

The radio-characteristics of a wireless communication module has direct impact to the network coverage and topology, but also directly influence the node's lifetime. For instance, as compared to ZigBee technology, 3G/4G modules can provide much broader coverage, but they consume much more energy.

In contrast to gas sensors and wireless transceivers, modern microcontrollers have very low power consumption. Some of the open-source electronic prototyping platforms integrate high performance low-power microcontrollers (ATmega, PIC, MSP430 etc) to provide design's flexibility and modularity.

Energy management module manages power consumption and power supply of a node. Software-triggered routines enable dynamic duty-cycling as well as dynamic sampling and transmission rate adjustment. Also, when communication is achieved via multi-hop transmissions, energy-aware MAC (Media Access Control) and routing algorithms are often required to minimize power consumption. Finally, energy management modules may encompass some energy-harvesting techniques, such photovoltaic, wind, vibration, etc.

2.4 Wireless Transmission

With power-autonomous nodes, the design of a data dissemination topology and the selection of a most suitable wireless technology is of a crucial importance. Precisely, without considering other (heavy) consumers such as electrochemical gas sensors, a wireless transceiver typically consumes around 70% of the node's energy. The choice of wireless technology and network topology impact the optimal balance between the network coverage, energy efficiency, and network performance. For instance, an „energy-efficient" wireless routing protocol aims to route via the most energy-efficient path (instead via the shortest path). These protocols might impose long end-to-end delays or may fail to find a route [9].

In most of the emerging AP monitoring applications, smart sensors can be power-supplied from the existing power distribution systems, i. e., AP readings can be sent from the positions where some kind of stabile energy source is available. For instance, nodes can be installed on traffic lights, the roof of the buildings, vehicles, etc.

If energy consumption is not a system's limitation, AP systems may use some of the long-range technologies (3G, 4G, GPRS, etc.) to transfer data to the data center. If nodes are energy-constrained, there are two near-optimal sub-scenarios. If a local gateway can be supplied from the power distribution system, then data are locally transferred (to the gateway) via some low-power short-range technology (such as Zigbee, Bluetooth, 6LoWPAN, etc.). The gateway may then use some WAN technology (e. g., 4G, or even cable modem) to transfer data to the data center. If the power distribution system is far from the points of installation, some of the point-to-point Low Power WAN technologies (such as LoRa, NB-IoT, or Sigfox) may be used.

Wireless infrastructure for AP data dissemination can be based on: Static Sensor Networks (SSNs) [10,11], Community Sensor Networks (CSNs) [12,13], Vehicle Sensor Networks (VSNs) [14,15], or combination of the aforementioned [16]. A comprehensive review and comparison of the wireless architectures and topologies for AP monitoring is presented in [17].

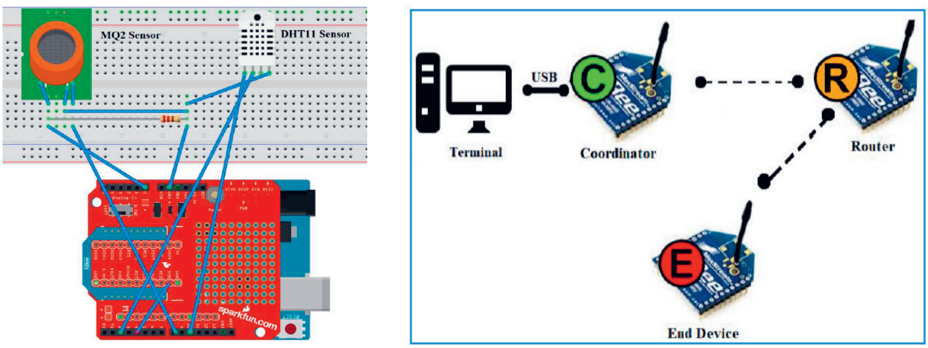
3. EXAMPLES — WSNS FOR AP MONITORING

In the proceeding subsections, two experimental studies on the implementation of WSNs for AP monitoring are shortly presented. The first one was designed for indoor implementation, while the second one has been implemented in an urban area.

3.1 A Multi-Hop Indoor AP Visualization System

According to the Environmental Protection Agency (EPA), indoors, air may be 2–5 times more polluted than outdoors. An indoor off-the-shelf system for AP monitoring, developed in UBT laboratory, is presented in [18]. The data acquisition module is based on Arduino Uno platform, which utilizes Atmel ATmega328P microcontroller and interfaces a MQ2 gas sensor, DHT temperature/humidity sensor, and a ZigBee transceiver (Fig. 5a). In order to cover a larger indoor area, the data dissemination is performed in multi-hop manner (Fig. 5b).

Although the proposed system provides a satisfying accuracy for the measurement of LPG, CO, and smoke, it shows some of the general aforementioned weaknesses related to the implementation of low-cost gas sensors. For instance, current drain in active mode is ≈140mA. With a specific duty cycle, system can achieve power autonomy of a few weeks. The system should be thoroughly tested and improved in accuracy.



(a) (b)

Figure 5: A system for indoor air quality monitoring.
(a) Sensor node, (b) Multi-hop wireless network.

3.2 A VSN-based AP Monitoring System

A number of VSN-based systems for AQM have been proposed in literature. They are either implemented as standalone VSNs or combined with SSNs. Different vehicles have been used to carry nodes, and different technologies have been used to sample, process, and transmit data. Some examples are given in [19, 20].

An experimental study has been conducted in the area of Prizren, Kosovo [21]. The MQ gas, temperature and humidity sensors are interfaced to the Arduino Uno board and are attached on roof of the Taxi vehicles (Fig. 6). Data are sent to the server via GPRS technology and are stamped in space and time with GPS. The system combines SSNs and VSNs to collect data for real-time visualization, historical view, and further analysis. The nodes are powered-up from the vehicle's power supply system. Hence, the system is not power constrained. Micro SD card module is installed on the board to store samples when the GPRS connection is unavailable.

A server receives data and stores them in a database for further web-based visualization and data analysis. Google API and JQuerry library are used for map and value entries visualization (Fig. 7a). The interface also provides the preview of the historical data (Fig. 7b)

The system shows satisfying performances in terms of overall functionality and continuity, with a small number of transmission errors. It provides

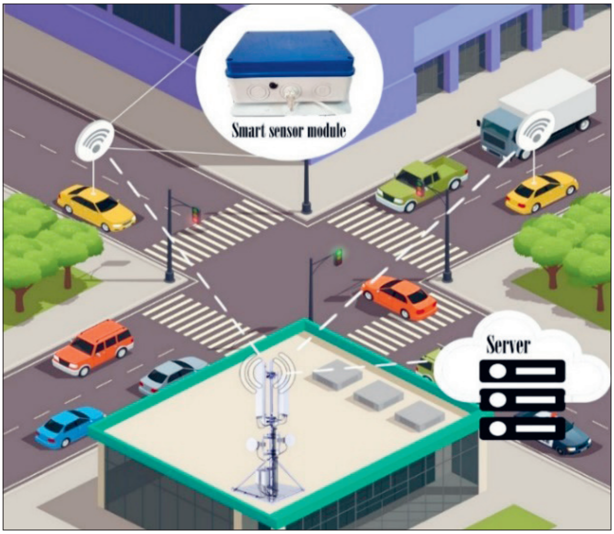


Figure 6: Sensor are installed at the roof of the taxi vehicles and are power supplied from the vehicles' battery. The readings are combined with those obtained from a conventional AP monitoring station in the region of Prizren, Kosovo.

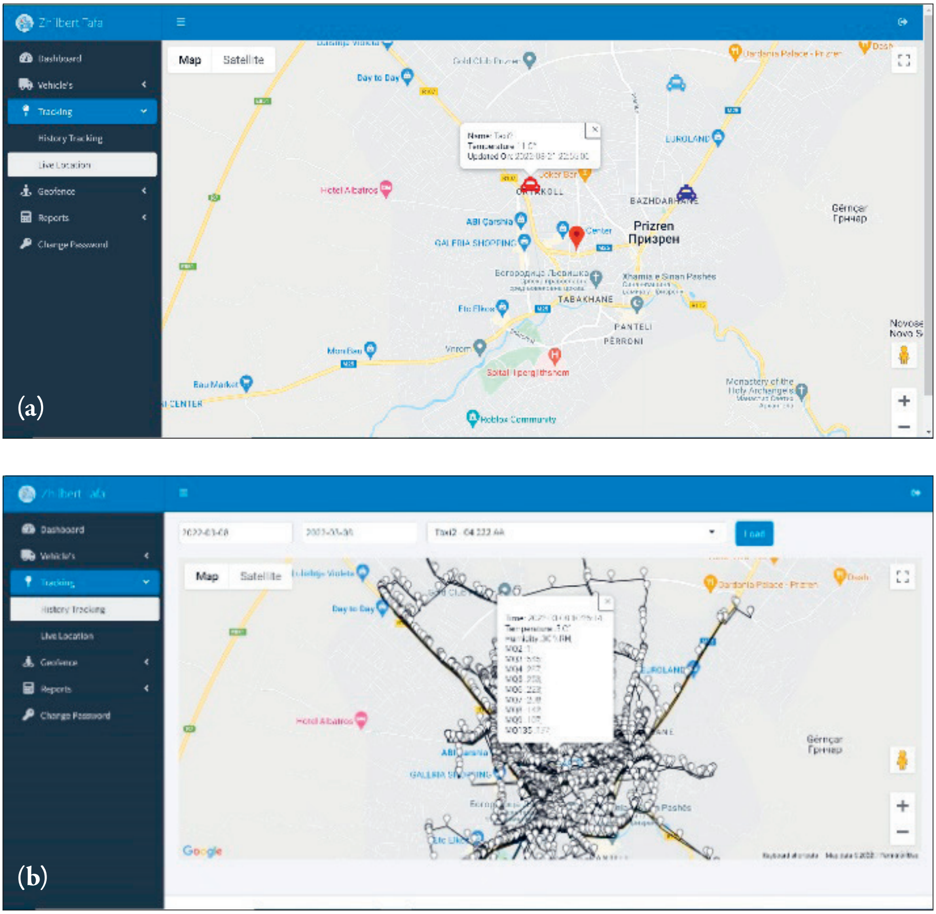


Figure 7: (a) User-friendly interface for real-time AP visualization, (b) Historical view

a satisfying spatiotemporal resolution for the region of Prizren, of an area of cca. 640 km^2. Future work will cover the implementation of ML for accuracy improvement and AP forecasting.

4. ML ALGORITHMS IN EMERGING AP MONITORING SYSTEMS

Calibration consists of setting a mathematical model to describe the relationship between low-cost sensor data and reference measurements [22]. Recently, calibration has been mostly performed by using statistical and ML approaches, such as multi-linear regression, Support Vector Machine (SVM), Artificial Neural Networks (ANN) etc. [23,24]. The ML techniques take into account the influences of the temperature, humidity, air pressure, solar radiation etc. on the deviations of readings.

Machine learning techniques have been also widely investigated for anomaly detection [25], AP estimation [26], and AP prediction [27, 28]. The follow-up of the study presented in [21] will include the aforementioned extensions. Future work will also combine sparse data acquired from fixed and mobile nodes for ML-based estimation of the AP for every point on the map.

5. CONCLUSION

WSNs have a potential to fill the gap between AP data acquisition requirements and the respective economically feasible technological solutions. Although some issues (as presented in this article) have slowed down the wider implementation of these technologies, recent extensive research show that WSNs can successfully improve spatiotemporal sensing resolution at a relatively low cost of implementation. Moreover, ongoing research show that implementation of the ML techniques can greatly contribute to the improvement and optimization of the WSN-based AP monitoring and management information systems.

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Zhilbert TAFA

ZAGAĐENJE VAZDUHA: NADGLEDANJE I UPRAVLJANJE PRIMJENOM BEŽIČNIH TEHNOLOGIJA

Sažetak

Zagađenje vazduha je jedan od glavnih uzročnika raka pluća i moždanog udara. Ono se povezuje i sa drugim bolestima kao što su kardiološke, oftalmološke, psihijatrijske itd. Da bi se smanjio negativan uticaj na zdravlje, zagađenje se mora pratiti. Konvencionalni sistemi za praćenje kvaliteta vazduha su skupi zbog čega se instaliraju u relativno malom broju. Kao takvi, oni ne pružaju željenu vremensko-prostornu rezoluciiju mjerenja. U ovom radu se predstavljaju bežične tehnologije za praćenje zagađenja vazduha u realnom vremenu. Osim infrastrukture, u radu su predstavljene i neke mogućnosti korišćenja mašinskog učenja u nadgledanju i upravljanju zagađenjem vazduha.