Crowd-sourcing: Citizens as scientists for air pollution monitoring

Beti Angelevska[1], Igor Andreevski[2], Vaska Atanasova[3]

Abstract – **The architecture of crowd-sourced monitoring based on sensor - smart phone - server platform is analyzed for the town of Bitola, Republic of North Macedonia. Recommended crowd-sourcing possibilities include integration with current monitoring system, creation of air quality management system and regulation of urban traffic in the town.**

Keywords – **Crowd-sourcing, Air pollution, Monitoring.**

I. INTRODUCTION

Mobile participatory sensing or crowd-sourcing is a new monitoring approach where individuals participate voluntarily and actively in collecting data and contribute for creation of mobile monitoring system. Each single participant has a key role for building a citizen observatory with an extended spatial and temporal range.[1] This approach is also more acceptable for being a more cost-efective.[2]

The presented analysis elaborates participatory sensing framework for air pollution monitoring for the town of Bitola, Republic of North Macedonia. Proposed crowd-sourced monitoring platform resides on sensors, smart phones and server. This architecture allows mobile sensing to upgrade non-mobile and expensive monitoring equipment contributing for comprehensive range of air pollution monitoring.

The current monitoring system in Bitola town consists of two fixed monitoring stations: Bitola 1 is located in the town's periphery; Bitola 2 is in the town's centre. Bitola 2 is very often out of order. Both stations measure: O_3, NO_2, SO_2, CO и PM_{10}. Results from Bitola 1 are used in the regularly published reports of the Ministry of environment, NGOs, health organizations and others.

This traditional approach for air pollution measurement based on fixed monitoring stations is inflexible, cost-intensive and with insufficient spatial resolution. Without monitoring network to completely cover the urban centre and surrounding residential areas in the town of Bitola, it is obscure to have real-time and valid information for air pollution levels. In this situation, local decision makers are unsupported with scientific facts to analyze, propose and undertake appropriate measures for reduction of air pollution. Changes and modernization of the current monitoring system are necessary and are a first step towards the air quality management in the town.

Hence, comprehensive monitoring system should be supported by actively participating citizens. Crowd-sourcing is characterized with flexibility for smart applications in urban monitoring. Other possibilities that crowd-sourcing offers are numerous and have been successfully applied for real-time monitoring in smart city environments.[3] For the town of Bitola are recommended and elaborated the most necessary ones at the moment: integration with current monitoring system, creation of air quality monitoring system and regulation of the urban traffic. Being a feasible solution for air pollution problem in the town, each of these possibilities is analyzed in detail.

II. ARCHITECTURE OF THE CROWD-SOURCED MONITORING

The proposed innovative crowd-sourcing for air pollution monitoring for the town of Bitola consists of three units: sensors, smart phones and a server. The system should provide measurement of different pollutants like PM, CO, CO_2, NOx, HC, O_3, additionally temperature and humidity as well. The focus should be put on particles PM_{10} and $PM_{2.5}$ being the main air pollutants in the town and region with frequently measured values 10 (and more) times above the permitted limits.

The architecture of crowd-sourced monitoring should be based on low-cost but reliable sensors in order to precisely measure pollutants and other parameters. Today, accurate, portable and personal sensors are easily wearable and with promising functions (Fig. 1).

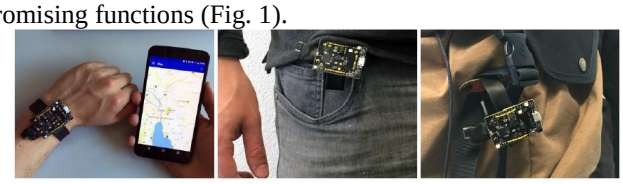

Fig. 1. Citizens wearing sensors

Source: [4]

The concept of crowd-sourcing is the following: the sensor communicates with the person's smart phone that gathers the measured data, marking them with additional information regarding the GPS coordinates, along with the time and date. Then, the server receives and stores large amounts of information from multiple users as they finish pollution recording and upload the gathered data over the Internet. The server will then analyze and interpret all the data in order to generate a pollution map and make that map available online

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on the website.[5] This concept of the proposed crowd-sourcing monitoring is presented at Fig. 2.

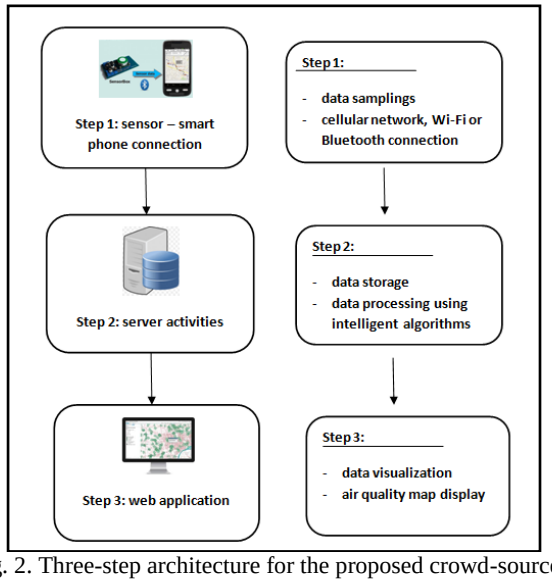

Fig. 2. Three-step architecture for the proposed crowd-sourced monitoring

The first step is based on citizens' participation using sensor connected with their smart phone. The sensor samples air quality data from the citizen's mobility through the town, and then sends the data to the smart phone through Bluetooth. The smart phone displays the data to the user and sends it to the server for processing, visualization and web publishing. Hence, smart phones are used only for raw data collection and distribution to the central server using various communication networks such as cellular networks (3G/4G/5G), local/public Wi-Fi or Bluetooth.[6] Therefore, the demands for wireless network bandwidth, as well as for server capacity needed for data storing, processing and analysis are very high.[7]

In the medium step, air quality data from individual submission at different locations, different dates, and different times are collected, stored, and processed in real-time at the server.[5] By using intelligent algorithms the server will perform automatic categorization and analysis of the collected data obtained by the end-users.[2] Platforms, datasets, data management and processing categories are elaborated in detail in [8, 6] and should be used as a scientific base when developing crowd-sourced monitoring in the Bitola town.

The third step comprises the creation of a web-based network. Air quality maps based on Google Earth will provide data visualization. Using color patterns the collected data in real-time can be mapped showing the pollutant distribution and identifying pollution hotspots. Crowd-sourced map visualizes the data in terms of the location, date, and time that the data were collected.

The citizens will have free access to data gathered in real-time through an online web interface. The maps will be used for real-time information of the citizens. For that purpose, a support by popular social networks (Facebook, Twitter and blogs) is desirable to provide availability to a wide range of potential users (not just to those actively involved in data collection).[2]

Hence, citizens are both the producers of air quality data, and the consumers of important information, notifications and recommendations based on processing and analysis of the massive amount of crowd sensed data at the server.[7]

III. CROWD-SOURCED MONITORING: APPLICATION POSSIBILITIES FOR THE BITOLA TOWN

A. Integrated monitoring system

For obtaining an extensive database of urban air quality, data from crowd-sensing must be joined with measurement data from official air quality monitoring system. Hence, for creation of integrated monitoring network for air quality (Fig. 3), various sources of different types must be used for data collection: [1]

a) *fixed reference monitoring stations*, this equipment has to be standardized, calibrated and certified for legally valid results, and if financial situation allows, their number should be increased at urban level
b) *medium-sized sensor nodes*, that can provide information for air pollution at street level in residential areas or more localized places like road intersections; their costs and accuracy should be acceptable
c) *mobile crowd-sourcing*, provided by the participation of citizens using sensor and smart phone; this could be extended with sensors placed on public transport vehicles that have regular movement across the town.

Fig. 3. Integrated monitoring system for the town of Bitola

Integration of different monitoring types in one system will provide regular monitoring of air quality levels in the town of Bitola and will generate relevant information to citizens and authorities. For that purpose, the proposed placement of the sensor nodes and crowd-sourcing participants in Fig. 3 was carefully planned. The most relevant parts of the town are covered: major crossroads, central and peripheral residential areas, as well as green area for public recreation. For small towns such as Bitola, two urban reference stations would be sufficient, as well as maximum seven sensor nodes for street level measurement. Referring the crowd-sourcing participants, the more the better for the reduction of statistical divergence. For starting the crowd-sourcing monitoring, 80-100 volunteers would be enough sending the data from different parts of the town at least three times on a daily level.

Collection of the data from these three various monitoring sources in one integrated system allows the implementation of advanced quality assurance and quality control methods [1]: first, the measurements of the medium-sized sensor nodes can be validated by the data from reference stations. Then, the measurements obtained from the sensors used in crowd-sourcing, being the least accurate, can be validated by the measurements data of the sensor nodes. Hence, techniques for data validation can be automated, with the system receiving and integrating information from these three monitoring sources, as shown in Fig. 3.

Integrated monitoring system provides data with higher spatial and temporal accuracy that will strengthen the opportunity and preparedness for prevention and mitigation of air pollution. Development of integrated monitoring system in the town of Bitola is a first step towards the development of air quality management system.

B. Creation of air quality management system

Air quality management system is an integrated system for assessment and management of air quality, which consist of three crucial components: monitoring, modeling and GIS (Fig. 4). In this structure the role of monitoring is twofold: real-time information and validation of the modeling results.

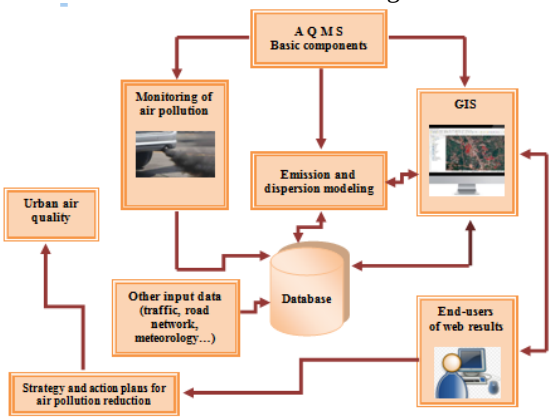

Fig. 4. Structure of integrated air quality management system proposed for the town of Bitola

As part of the air quality management system, the monitoring system will provide continuous air quality measurements and availability of real-time data which is important and useful for the citizens. In a situation when pollution concentrations reach a critical level and represent a health hazard, a timely warning to the general population, regardless of their health condition can be issued.[9] Also, monitoring provides real-time information for local authorities about the short- and long-term changes in air quality, thereby supporting the planning and decision making process.

Integration of monitoring and modeling supported with GIS will provide selection of the effective decisions for pollution reduction in the town when permitted levels are exceeded. Using monitoring data an assessment can be performed at implemented reduction/mitigation measures, thereby providing feedback to the action plans and strategies.[10] Here, crowd-sourced monitoring provides support for the proper selection of the planned measures, through detailed environmental profiling, for example, of the location of urban pollution hotspots.

C. Regulation process of urban traffic

Crowd-sourcing could be used for development of dynamic road traffic control in the town of Bitola. The basic idea is development of strategies for traffic control that contribute for maintaining air quality level. The relationship between traffc flow and pollutant emission provides important data as a base for design process of traffic management strategies for urban road networks.[11]

Traffic regulation process is based on data gathered from integrated monitoring system and must be adapted to user needs, considering that they will continually increase over time. At the same time, all input factors should be taken into account and different data sources should be effectively processed: mobile devices, meteorological data, road network data etc. All these inputs feed the process, which can use advanced intelligent algorithms for analyzing and obtaining results to provide the needed performance.[12]

The generated results are used to define the most environment-friendly routes which are less-polluted and shortest at the same time, and also to create other notifications to traffic participants or citizens in general. The main aim is to avoid the most polluted areas of the urban road network. Fig. 5 illustrates an overview of the structure of traffic process regulation.

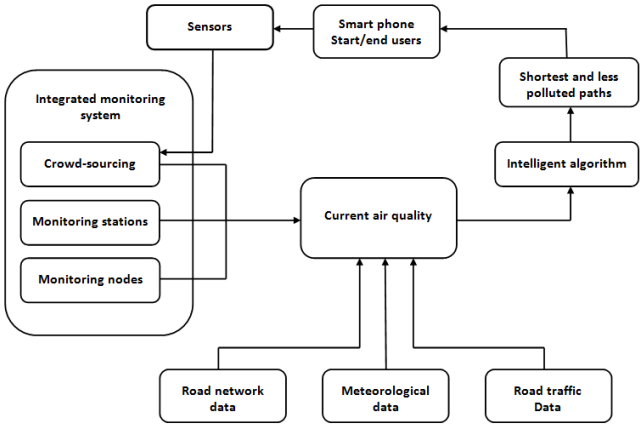

Fig. 5. Structure of the process of traffic regulation

The main features of this process are the following: [12]

- real-time data processing and analysis of pollution levels for each urban road segment
- integration and management of high amounts of data coming from different sources (monitoring, road network, meteorology, traffic)
- effective communication with the start users and end users: crowd-sourcing participants provide data as start users; then recommendations for selected route that comply the preferences of end users (e.g. time of travel) are provided.

Also, an important aspect is the problem dynamics taking into consideration the unknown number of potential users who demand and expect recommendations for redirection to alternative paths.[12]

Crowd-sourced monitoring can contribute for significant improvements in traffic regulation and management:

- understanding of the extent of impacts that urban traffic has on air quality
- behavioral change of citizens in everyday urban journeys towards more sustainable transport modes (public transport, cycling and walking)
- attractiveness of green transport policies and travel choices which contribute for public health improvement at the local level, both in the short and long term [13]
- support for evaluation of the effectiveness of transport measures undertaken for mitigation/reduction of air pollution, since monitoring data are necessary starting point in the evaluation process.

The traffic regulation process proposed for the town of Bitola, whenever implemented has result of around 75% reduction of pollutants concentrations, achieved by avoiding the traffic congestion and providing efficient routing in urban areas with less traffic and lower emission levels.[11]

IV. Conclusion

The measurement of air quality in urban areas has become an important issue for management of air pollution. Crowd-sourcing of air quality is an emerging technology which gathers local air quality data mobilizing the time, willingness and mobile devices from the citizens. Urban mobility of citizens provides higher spatial and temporal range and better awareness compared to traditional monitoring networks.[14,8] Hence, crowd-sourcing encourages citizens to become active participants for air pollution monitoring within their city.

Considering the advantages of crowd-sourced monitoring, this innovative approach is proposed for the town of Bitola, where current monitoring system consists of only two fixed stations. Elaborated system architecture includes three main components: sensors, smart phones and server. Also, an analysis of the application possibilities of crowd-sourcing in the town is presented, emphasizing its capabilities and contributions for urban life quality. Recommendations include integration with current monitoring stations, creation of air quality management system and regulation of urban traffic.

The benefits of implementing crowd-sourced monitoring in the town of Bitola will be numerous: real-time information for pollution levels in the town or specific areas, supported policy decisions in urban transport planning and management, assistance to the citizens to make informed travel choices that are less polluted, evaluation of the effects of implemented measures against air pollution. In the current situation where all this is lacking, this proposed monitoring approach will make a significant improvement towards the needed air quality management.

As a feedback, citizens could receive real-time information for air quality and relevant recommendations for their everyday mobility. The town authorities will have assistance to make proper decisions, which is of great importance because pollution cannot be tackled by policy makers alone, as it requires consideration of the behavior of all citizens.[15]

Collective participation of citizens with the technology they own is irreplaceable in management and assessment of urban air pollution. As soon the crowd-sourcing will be implemented in the town of Bitola, the mobile participatory involvement will contribute for a creation of a citizen science network with benefits for everyone.

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