MegaSense: 5G and AI for Air Quality Monitoring

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Abstract. Air pollution has become a global challenge during the growth of megacities, which drives the deployment of air quality monitoring in order to understand and mitigate district level air pollution. Currently, air pollution monitoring mainly relies on high-end accurate reference stations, which are usually stationary and expensive. Thus, the air quality monitoring deployments are typically coarse grained with only a very small number of stations in a city. We propose scalable air quality monitoring by leveraging low-cost air pollution sensors, artificial intelligence methods, and versatile connectivity provided by 4G/5G. We describe pilot deployments for testing the developed sensing technologies in three different locations in Helsinki, Finland.

Keywords: Internet of Things · Air pollution sensing · Smart cities

1 Introduction

In recent years, we have witnessed unprecedented growth of urban areas. Future smart cities are characterized by high density, versatile connectivity requirements, localized processing, and mobile sensors. Citizens are expecting to experience personalized, anticipatory, real-time, clean and safe city services supported by digital services, autonomous vehicles, Artificial Intelligence (AI), and robots. Hundreds of thousands of smart street lights, base stations, and sensors support near real-time decision making and optimization.

During the growth of urban areas, we have also witnessed the degradation of air quality in developing countries. Urban air pollution has become a global challenge for human health, ecosystem, and the climate. The recent study by the Global Burden of Disease (GBD) project reported 5.5 million people worldwide are dying prematurely each year as a result of air pollution [1]. Air pollutants are conventionally measured by expensive high-end stationary stations. However, high cost and needs for constant maintenance of such stations prevent large-scale dense deployments. The recent advances in sensing technologies and wireless communications enable a complementary approach with large scale sensing solutions with low-cost sensors.

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In the MegaSense research program, we introduce a scalable and intelligent real-time air pollution monitoring system by developing and deploying a hierarchical sensing architecture with low-cost sensors and leveraging machine learning for sensor calibration and versatile connectivity provided by 4G/5G. Our goal is to achieve near real-time air quality sensing with high spatial resolution. We propose calibration of a large number of low-cost sensors with a small number of accurate reference stations by using machine learning techniques. 5G offers unification by supporting versatile connectivity options and a framework for managing smart city deployment. Scalable real-time air quality sensing is expected to enable many applications.

We present pilot deployments carried out in the EU UIA HOPE project [2] in Helsinki, Finland. The experimental results from three large urban test areas indicate that crowd sourcing of air quality measurement is feasible, data validity can be significantly improved through calibrating the low-cost sensors with higher quality stations, and crowd-sourced air quality data can serve as a basis for new applications, such as green path routing.

The chapter is organized as follows: Sect. 2 presents the vision of the scalable air pollution sensing in megacities. We describe the low-cost sensors used in our sensing platform in Sect. 3 and present our pilots currently running with these sensors in Sect. 4. Section 5 concludes this chapter with discussing future research.

2 Spatio-Temporal Air Quality Sensing

In this section, we present the vision of the scalable spatio-temporal air quality sensing.

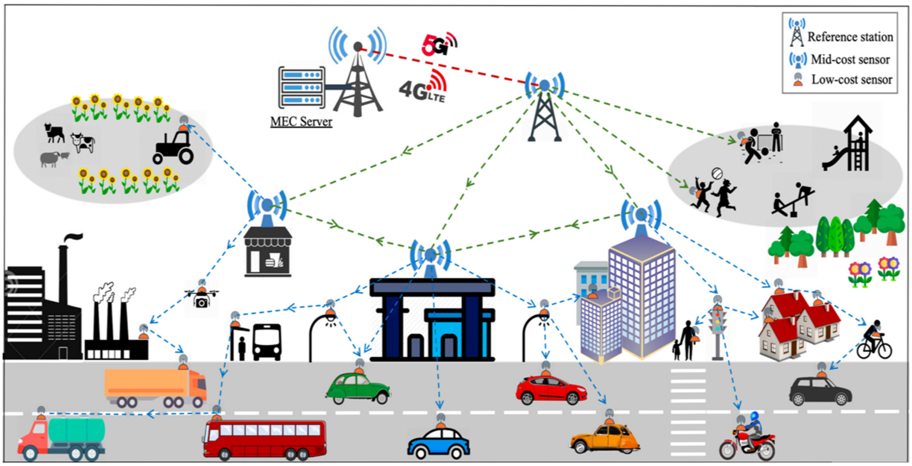


Fig. 1. Vision of spatio-temporal air quality sensing.

Figure 1 gives an outline of our vision of spatio-temporal air quality sensing. A number of different types of sensors are deployed for monitoring the air quality, including low-cost mini-sensors, middle-cost sensors, and high-cost reference stations. The low-cost and medium-cost sensors can be mobile and can be integrated into vehicles or carried by citizens [3].

The emerging 5G-based technologies are expected to enable efficient data collection, reliable sensor connection, less energy consumption, and intelligent sensor management. Building on massive connectivity, sensing and distributed data processing capabilities, the next-generation air quality monitoring networks can automatically identify the operational environment of each sensor and optimize sensor parameters in order to minimize errors and sensor drift.

Air quality sensors are hindered by many environmental factors and need to be placed in suitable locations, where network connectivity and power supply issues are taken into account. We introduce flexible and short-term placement of the mini-sensors to optimize the coverage and accuracy of the pollution detection process and study urban mobility patterns to improve coverage using portable micro-sensors carried by citizens. We envisage that multi-vendor and open-source sensor devices of different accuracy and capabilities can form a self-optimizing mesh network. In our current work, we investigate the integration of low-cost (tens to hundreds of euros) air pollution sensors, mid-cost sensors (thousands of euros), and the high accuracy Measuring Earth Surface-Atmosphere Relations (SMEAR) [4] stations that monitor a high number of pollutants every second.

Low-cost sensors are typically limited in accuracy compared with city monitoring reference stations. We have designed a calibration model that maps the measurements of low-cost sensors to measurements of reference stations using machine learning algorithms to improve the performance of the low-cost sensors. The low-cost sensors are co-located near to the reference station for a sufficient period of time to collect the data for performing the sensor analysis and calibration. This corresponds to other research work related to sensor calibration [5–7]. Periodic re-calibration of sensors is necessary during the air quality monitoring process due to its high instability, sensor drift phenomenon [8], and other errors that reduce the accuracy.

The current solutions for sensor calibration have limited support for large-scale and very dense deployments. It is not practical to bring thousands of sensors to the reference stations for performing the calibration. Our key insight is to support calibration through a hierarchical mesh of sensors with both stationary and mobile sensors (Fig. 1). We are exploring the possibility of using opportunistic re-calibration, collaborative re-calibration, and transfer re-calibration [9] with hierarchical sensor mesh networks.

Near real-time wide-area air quality sensing is expected to support the development of many applications. Reliable and fine-grained air quality data and insights are helpful in pinpointing pollution hot-spots and gaining understanding of the root causes of the identified pollution problems [10]. The insights can then help in mitigating pollution. For example, a smartphone map and navi-

(a) Portable low-cost device. (b) Device attachment. (c) Measurement application.

Fig. 2. Pilot devices.

gation application provide suggestions and directions regarding the paths and routes with the best estimated air quality.

The MegaSense system is designed to provide information on multiple levels from the city and district levels to the level of personal exposure to pollution. On the city and district levels, it is possible to detect pollution sources and provide suggestions for stakeholders to take actions for mitigating pollution. Such information can be used to improve fitness and health applications as well as control air ventilation systems. For example, the car ventilation system can be controlled based on the current and predicted outside air quality to maximize indoor air quality. The air quality information can also be used for building a predictive model for early warning, which is very important especially for people with respiratory problems.

3 Low-Cost Sensors

To evaluate the capabilities of low-cost crowd-sourced micro-sensors, we designed a portable air quality sensing platform based on a BMD-340 system on a module and mobile phone application (Fig. 2c). The portable platform connects to the citizen's Android smartphone over Bluetooth Low Energy, and the smartphone reports the readings and GPS location to a collecting server. The measurements are calibrated using the data from reference stations and machine learning techniques before being displayed in the mobile app. The mini-sensor platform component for measuring the Particulate Matter (PM) is a Sensirion SPS30. Table 1 presents a list of all the sensor components available on the portable device. The platform is powered with a 3500 mAh battery and enclosed in a 3D-printed case made of ESD-PETG filament. The form dimensions are: width 75 mm, depth 33 mm, height 127 mm, with weight 165 grams. The front is protected by an aluminum mesh. General battery life before recharging via micro USB interface:

26 h. Figure 2a presents a portable low-cost sensor that was carried by one of the voluntary citizens in his bag for tracking the measurements of air pollutants (Fig. 2b).

Table 1. Sensor types available in the low-cost portable device.

Sensor	Type
BME-280	Temp, Humidity, Air Pressure
Battery	Voltage
Sensirion SPS30	PM
SI1133-AA00-GM	UV
MiCS-4514	CO, NO_2
MQ-131	O_3

To evaluate the practicalities of low-cost mini air quality sensors, we designed a Raspberry Pi HAT with the same sensors (Table 1) with Nb-IoT modem encased in water-proof rugged casing suitable for fixed outdoor stationary locations having constant power. This allows us to experiment with edge computing as we can have more computation power with the sensors in comparison to the portable sensor.

4 Pilot Deployments

We are running multiple pilot deployments with the university designed sensors, including three pilots with portable micro-sensors and one pilot with stationary mini-sensors in Helsinki, Finland.

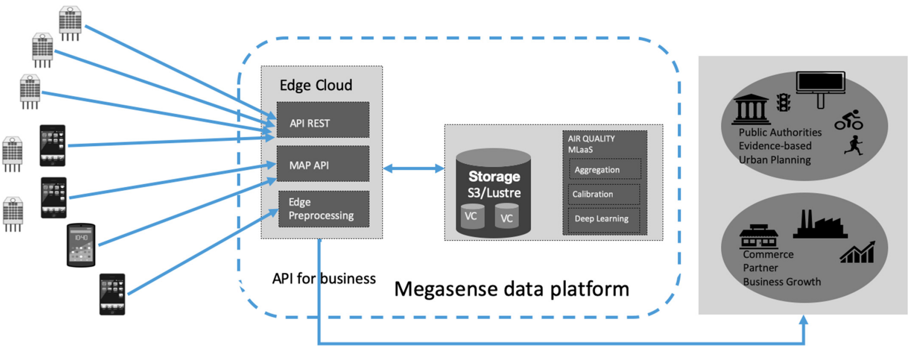
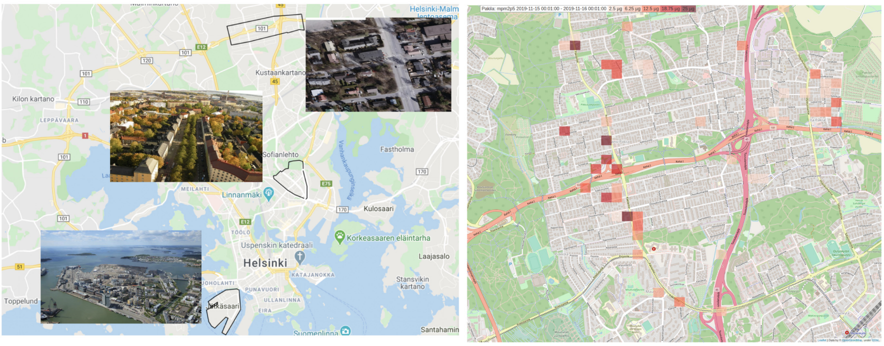


Fig. 3. The MegaSense platform architecture.

One hundred portable micro-sensors are loaned to voluntary citizens in the UIA HOPE project [2] for measuring their own daily air pollution exposure using the HOPE mobile application and crowd-sourcing data gathering. The citizen exposure readings are based on measurements from the portable sensors, city reference stations and an air quality model. The mini-sensors are deployed in a small Nb-IoT network as part of a 5G testbed at the Kumpula area with support from the City of Helsinki.

Both the portable micro-sensors and stationary mini-sensors upload air quality measurements and download data to/from the MegaSense Edge/Cloud data services. This is aligned with the MegaSense research program focuses on addressing significant challenges towards scalable air quality sensing using low-cost sensors with 5G technology and realizing big data analytics with machine learning for supporting wide-area air quality monitoring applications. As presented in Fig. 3, sensors and mobile devices are connected to Edge/Cloud with available 5G/4G connections via Rest API. Air quality MLaaS (machine learning as a service) offers machine learning tools as a part of Edge/Cloud services to support business analytics. Specifically, low-cost sensors are periodically calibrated to provide reliable air quality data, data can be saved and processed on Edge/Cloud depending on the application purposes.



(a) Pilot monitoring areas in Helsinki, Finland. Top-down: Pakila, Vallila, and Jätkäsaari.

(b) Pollution hotspot map created from Pakila using portable low-cost sensors.

Fig. 4. Monitoring areas.

Early results from the UIA HOPE monitoring areas support the MegaSense approach for optimising the spatial coverage and accuracy of the pollution detection through loaning citizens portable low-cost micro-sensors living in three districts of Helsinki for a period of 3 months, and each district having a different source for the emitted air pollutants (Fig. 4). Jätkäsaari is a new maritime inner city district with a busy passenger port in the area which has high levels of traffic pollution (see Fig. 4a). Pakila is an old suburban housing area and has mostly been single-family housing burning wood which had lead to high black carbon emissions. Vallila is an old densely built residential district at the edge of the inner-city with major traffic routes and street canyons recycling high street dust pollution. An example of citizen crowd-sourcing data is the pollution hotspot map presented in Fig. 4b based on the measurements from Pakila. The emissions data on the map consist readings for one day. On the map the PM2.5 scale ranges from light red (2.5 μg) to dark red (25 μg).

5 Conclusion

MegaSense addresses significant challenges pertaining to scalable air quality sensing by developing and using low-cost sensors with 5G technology in a hierarchical mesh network environment, and implementing big data analytics with machine learning. MegaSense utilizes the designed sensing data platform and reliable atmospheric data from SMEAR reference stations to field calibrate low-cost sensors that can be integrated into vehicles or carried by users for scalable and near real-time air pollution monitoring. In future research, we will continue to explore runtime calibration of the hierarchical sensor mesh as well as investigate approaches for processing real-time image and video data from hyperspectral cameras for air pollutant detection.

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