Demo: MegaSense: Megacity-scale Accurate Air Quality Sensing with the Edge

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ABSTRACT

This demo presents MegaSense, an air pollution monitoring system for realizing low-cost, near real-time and high resolution spatio-temporal air pollution maps of urban areas. MegaSense involves a novel hierarchy of multi-vendor distributed air quality sensors, in which accurate sensors calibrate lower cost sensors. Current low-cost air quality sensors suffer from measurement drift and they have low accuracy. We address this significant open problem for dense urban areas by developing a calibration scheme that detects and automatically corrects drift. MegaSense integrates with the 5G cellular network and leverages mobile edge computing for sensor management and distributed pollution map creation. We demonstrate MegaSense with two sensor types, a state of the art air quality monitoring station and a low-cost sensor array, with calibration between the two to improve the accuracy of the low-cost device. Participants can interact with the sensors and see air quality changes in real-time, and observe the mechanism to mitigate sensor drift. Our re-calibration method minimizes the error for NO_2 and O_3 81% of the time (vs single calibration) and reduces the mean relative error by 25%–45%.

CCS CONCEPTS

• **Applied computing** → **Environmental sciences**; • **Networks** → *Mobile networks*;

KEYWORDS

Air Quality, 5G, Artificial intelligence, Edge computing, Data fusion

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1 BACKGROUND

Air pollution is a global challenge that needs to be urgently addressed. According to the World Health Organization, air pollution exposure resulted in the death of nearly 7 million people in 2012. More recently, the Global Burden of Disease (GBD) project reports that air pollution exposure kills 5.5 million people prematurely each year[1]. To make matters worse, we are witnessing exponential growth of urban areas and emergence of megacities. Today more than half of the world's population live in cities and it is forecasted that this will increase to 66% by 2050. The population living in megacities will grow from 3.2 to 5 billion already by 2030[2]. This hyperdensification results in compact energy consumption, more waste and traffic congestion, adversely affecting air quality, and further increasing the pollution levels of cities.

2 STATE OF THE ART IN CITY-SCALE AIR QUALITY MONITORING

Cities typically have a small number of sophisticated monitoring stations to measure urban air quality caused by heterogeneous sources (i.e. traffic, domestic heating, industry, agriculture, shipping, natural sources and emissions in distant areas). However, the high costs of installation and maintenance of reference monitoring stations results in relatively sparse monitoring, which provides good data on background sources, satisfying the legislative requirements but not providing information about localized gradients of critical importance to citizens.

[1]http://www.healthdata.org/news-release/poor-air-quality-kills-55-million-worldwide-annually
[2]https://esa.un.org/unpd/wup/

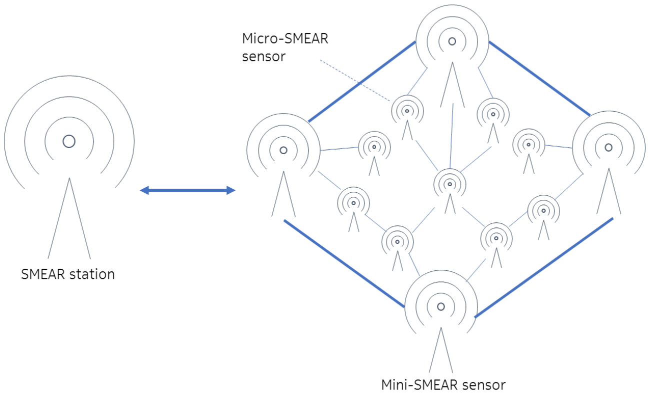

Figure 1: Overview of hierarchical air quality monitoring for detecting pollution hot spots.

Several projects investigate this issue by deploying numerous sensors within cities [2]. For instance, sensors attached to street lights are piloted in Chicago's Array of Things[3] and the Barcelona Lighting Masterplan[4]. The OpenSense research project supports mobile measurement stations with GSM/GPRS and WiFi[5]. Sensors attached to 5G base stations are tested by the LuxTurrim5G project of Espoo, Finland[6].

We observe that cities lack low-cost high-resolution massive sensing capabilities to identify pollution hotspots (i.e. traffic junctions, construction sites, compact living areas) in real-time. The deployment of numerous low-cost sensing devices to the cities has been investigated, but low-cost devices suffer from low accuracy and experience drift [1]. Achieving high accuracy with low-cost sensors is an open challenge [3]. We contribute by developing new methods for fine-grained low-cost air pollution sensing with on-demand sensor calibration supported by the network.

3 SYSTEM ARCHITECTURE FOR MASSIVE SCALE SENSING

Our system builds on the Stations for Measuring Earth Surface-Atmosphere Relations (SMEAR)[7] operating in Finland, Estonia and China, which monitor over a thousand parameters pertaining to air quality. We extend this concept by developing new categories of lower cost measurement devices with reduced functionality, namely mini-SMEAR and micro-SMEAR stations. The discovery of pollution hotspots is achieved through a large number of monitoring stations interconnected using 5G cellular networks. Sensor calibration and data rates are optimized using edge computing clusters placed in high-density areas.

The key innovation in this model is to use highly accurate measurement stations to calibrate a hierarchy of 5G connected low-cost and less accurate stations in the field. The systematic calibration of devices is made possible by the deployment of low-cost mobile devices being periodically in the vicinity of higher quality stations (i.e., mini-SMEAR and SMEAR). After the calibration process has been completed for a device, it can also help re-calibrate other devices not in the proximity of accurate equipment, as depicted in Fig. 1.

The calibration of numerous static and mobile measuring stations in near real-time will result in significant data volumes to be transported over the network. It also requires rapid data processing and computation within the network at central servers and at the edge near the sensor deployments. Pushing air quality models to the edge, we can produce near real-time high-resolution air pollution data. We envisage that in the near future, this data will be available for applications and services through data sharing platforms and APIs. The network infrastructure enables the sharing of data, sensors and computing resources to support a new range of services for smart cities and the industry.

4 SYSTEM REQUIREMENTS

The deployment of wide area massive-scale monitoring capabilities requires sensor network planning to forecast how the dense sensor networks will operate, the economic costs, and the technical details of the sensor networks' capabilities. Designing sensor arrays with similar sensing devices is challenging when considering interference, and availability of power supply and network access points. Our concept aims to ease planning by having a centralized tower and strategically located mini-SMEAR measurement devices to correct measurement error and inaccuracies of clusters of low-cost sensors [1, 4].

Our system produces real-time fine-grained air pollution data. According to air quality experts, pollution values can change radically within a distance of 100 meters. To capture these variations, we need to deploy small sensors every 50 meters (400 per km^2) in the area of interest. Future air quality and environmental monitoring may also include hyperspectral cameras and LIDAR instruments for continuous environmental monitoring and mapping. All these sensors produce a large amount of data to be processed in near real-time. Depending on cellular network base station density, this may mean hundreds of megabytes of traffic per base station in fine grained deployment areas, still manageable by current cellular networks. However, the large number of simultaneous connections that need to be handled by a single cellular base station may disrupt current LTE and

[3] http://chicagoinfrastructure.org/initiatives/smartlighting/
[4] https://www.livingmap.com/smart-city/smart-barcelona-its-all-about-people/
[5] http://www.opensense.ethz.ch
[6] https://www.luxturrim5g.com
[7] https://www.atm.helsinki.fi/SMEAR/

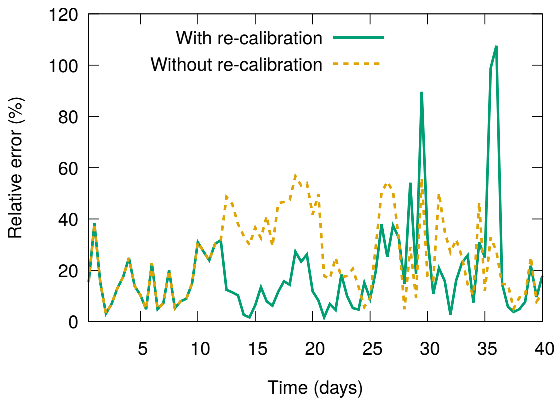

Figure 2: Relative error of mini-SMEAR O_3 measurements calibrated against SMEAR. *With re-calibration* is re-calibrated every 14 days.

4G networks operation. Our system leverages 5G and edge computing, as opposed to the cloud, in order to enable fine-grained real-time air quality measurements.

5 IMPLEMENTATION

Our prototype sensor array measures gases: ozone (O_3), carbon monoxide (CO), nitrogen and sulfur dioxide (NO_2, SO_2); particulate matter $\leq 2.5\mu m$ ($PM_{2.5}$) and $\leq 10\mu m$ (PM_{10}); temperature, pressure, and relative humidity. The O_3 and $PM_{2.5}$ sensors allow us to compare measurements with the SMEAR station and monitor measurement drift.

Our MegaSense prototype consists of multiple sensor arrays, a computer receiving the measurements, and calibration routines programmed in Matlab. Our demo uses Vaisala's AQT400[8] as a mini-SMEAR station to highlight the multi-vendor capabilities of our system. Calibration was performed between mini-SMEAR and the SMEAR stations, and our results indicate that re-calibration minimizes the error for O_3 and NO_2 81% of the time (mean relative error reduced by 25%–45%, results for O_3 in Fig. 2). For NO_2, the best results with linear regression were obtained by using only the raw measurements from the NO_2 sensor. For O_3, multivariate linear regression gave the best results, with the raw O_3 sensor output, temperature, and pressure.

6 DEMO SETUP

The demonstration consists of the full prototype system as described above. We will bring our own extension cord to power our demo devices (laptop and sensor prototypes). For maximum effect, a large screen should be connected to the laptop, so the demo can reach a larger audience.

[8]https://www.vaisala.com/sites/default/files/documents/AQT400-Series-Datasheet-B211581EN.pdf

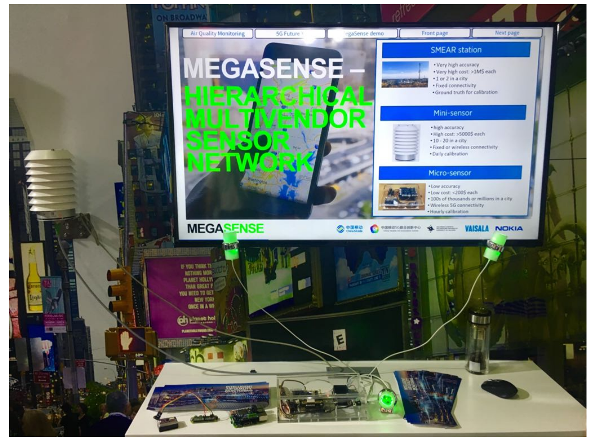

Figure 3: MegaSense demo setup.

Setup time for the demo is roughly 10 minutes.
Interaction: Spectators can inspect the sensors and the network environment and observe how, for example, CO_2 readings change during the interaction. The distributed air quality sensing, calibration, and air quality of the demo room will be analyzed and explained to the audience.
Our Key Contribution is the sensor calibration method, a crucial component of the hierarchical low-cost air pollution monitoring system supported by the 5G network. With the calibration, our sensor prototype demonstrates that accurate low-cost air quality measurement is feasible. We will also explain the signaling aspects and how 5G architecture can be leveraged to optimize it.

7 ACKNOWLEDGMENTS

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[9]https://www.helsinki.fi/en/researchgroups/sensing-and-analytics-of-air-quality