ekoNET system architecture and service for environmental monitoring

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***Abstract*— The ekoNET system is developed for a real-time monitoring of air pollution and other atmospheric condition parameters such as temperature, air pressure and humidity. The ekoNET service is based on EB800 device integrating low-cost gas, Particluate Matters (PM) and meteorological sensors providing cost-efficient, simple to deploy, use and maintain solution targeted for the usage within the IoT domain of smart cities and smart enterprises. This paper gives an overview of the overall system architecture, ekoNET device, back-end cloud IoT infrastructure mapped to the IoT-A Architecture Reference Model (ARM), data handling and visualization engine as well as the application-level components and modules.**

Keywords: *Smart City, IoT, low-cost sensors, environmental monitoring, CoAP*

I. INTRODUCTION

The Internet of Things (IoT) concept envisages smart environments connecting with the citizens and shaping the cities around the world by offering smart services and concepts with aim to increase the quality of life in these cities. Connecting the environments with people requires an interface with rich user experience able to engage the users and present the relevant information that will fulfill the goal of the service.

Currently, more than 50% of people live in cities and the UN estimates that by year 2050 cities will be home to 70% of the world's population [1]. Consequently, significant effort is directed towards accommodating this growing trend utilizing smart city concepts and ideas and relying on ICT. Furthermore, the citizens expect more from the cities: to have better quality of life and to have detailed information about the city's environmental conditions. For example, although cities occupy only 3% of the world's geography, they generate about 80% of CO_2 emission. Additionally, being a "green" city is important for cities to attract tourists, investors and business and to provide additional information to citizens about the environmental conditions at different areas of a city. At the same time the enterprises are continuously trying to optimize the work processes and at the same time act in a socially responsible manner. To achieve these aspirations, remote monitoring of processes including hazardous gas levels at different locations of the facility, industrial safety, personal exposure and eco-friendly solutions play an important part, in particular in the oil and gas industry. In the developed countries there is a trend of lowering tolerance to the air polluting and all other factors that influence the environment. This goes in hand with improvement of monitoring services and putting in place polices, which as consequence for not following the regulations impose adequate penalties. Companies increasingly have a need to monitor environmental conditions and take corrective actions much before any inspections takes place in order to avoid strong sanctions.

Ultimately, the main goal is to raise an awareness of the community of importance of the environmental issues, in particular the air quality and related air pollution. This task is not simple and requires innovative methods and approaches in attracting large community that will participate and get engaged in the activities related to these issues. This work is part of the comprehensive study and in this paper we present some interesting results regarding ekoNET solution, while the complete results and integration with AR (Augmented Reality) platform will be published in [2].

The paper is organized as follows. In the section II principles of air quality monitoring in smart cities are presented. ekoNET service and system architecture are described in the section III an IV respectively. Section V concludes the paper.

II. AIR QUALITY MONITORING

Currently, the air pollution within the cities is monitored by networks of static measurement stations usually operated by the public authorities. These fixed stations are highly reliable and able to accurately measure a wide range of air pollutants. However, they are very large, expensive and require significant amount of maintenance. Subsequently, the extensive cost of acquiring and operating these stations severely limits the number of installations.

As a result of this problem, low-cost solid-state gas sensors have started to be used for measuring the pollutants in the atmosphere. One of the most popular types of these sensors, have an electrochemical reaction, when exposed to a specific gas. The gas concentration is determined by measuring either the sensor's output current or the resistance of the sensor's tin dioxide layer. These solid-state gas sensors are inexpensive, small, and suitable for mobile measurements.

In the recent years the activities related to environment monitoring are becoming more intensive and are in the focus of many research projects. Special attention is devoted to projects targeting development of smart cities and smart societies in general. Distributed sensing systems for environmental parameters and portable and personal monitoring are emerging as a potential novel solution for data collection with enhanced with computational tools for a real time analysis. Projects such as the European SmartSantander project [3], the Japanese DOCOMO Project [4], and the Copenhagen wheel project [5] use portable sensors to measure a number of parameters including air pollution, UV, noise and/or meteorological conditions. The portable sensors are placed around the city and/or on vehicles or bicycles.

Also, the recent literature covers a number of devices for air pollution monitoring in urban and rural areas that utilize low cost sensors and wireless systems for transmission of measured data. A system that measures concentrations of gases, such as CO, NO_2, SO_2, and O_3 using semiconductor sensors is presented [6] where the measurement station is static and there is no possibility of remote data reading. In [7] the authors present a wireless distributed mobile air pollution monitoring system which is implemented and tested using the GPRS public network. The system utilizes city buses to collect pollutant gases such as CO, NO_2 and SO_2. In [8] the concept of a mobile monitoring system for chemical agents control in the air is presented (CO, CO_2, NO, NO_2 and VOC). The proposed system can be applied to measure industrial and car traffic air pollution. Data transmission uses the GPRS/EDGE radio link to transfer measurement results to the server with database. ekoNET system, presented in this paper, contains the greater number of sensors than other devices, and have ability to perform measurements both at a static location and as a mobile platform.

In paper [9] authors present an approach based on the mathematical statistics methods towards significant reduction of the number of necessary measuring points, as well as the number of required sensors while still providing reliable estimation of environment parameters across the monitored area. The paper shows that proposed solution works quite well in the areas with slowly-changing weather conditions. Solution is verified on the mobile platform mounted onto public transport vehicles and used for measurements of environmental parameters.

The environmental monitoring solution ekoNET aims to provide a simple and cost-effective solution that can be deployed both within the cities and enterprises wishing to monitor the air pollution and atmospheric parameters. This paper presents the overall system architecture encompassing the ekoNET device, back-end cloud infrastructure.

III. EKONET SERVICE

The ekoNET service is designed in such a way to provide a complete end-to-end solution for the environmental monitoring following the design concepts used within the IoT domain. The system comprises all necessary components namely: devices (EB800), back-end infrastructure and client applications (web and mobile).

The back-end infrastructure and the overall system follows the design principles of IoT architecture reference models such as IoT-A ARM so that the overall design methodology can be easily compared and potentially integrated to the other IoT platforms.

The exact functionality in terms of the environmental monitoring is defined with types of sensors used within the device itself. Currently, the system is designed to support two types of sensors: more accurate ones that can be used for air quality measurements and less accurate sensors that can be used to provide indications of the levels of the gases in the air. The devices with both variants can be used indoor and outdoor and it is planned to develop personal devices as well, which will be used to monitor personal exposure.

The device is designed in modular fashion, making it possible to use different sensor packs, adapted to suit different industries and associated use-cases, while the core processing and communication part of the device remains the same. This is of particular importance for the industries where specific requirements and regulations are in place.

The devices can be mounted on the public transportation vehicles (buses and trolleybuses) and on the trucks in coal mine in order to monitor air quality in different parts of coal mine. End users can query the system using a web or mobile application to get the real time measurements as well as locations of the vehicles. The EB800 devices are designed in a modular fashion enabling connection of different sensors according to the requirements. The central part of the device is the main board which block diagram is shown in Figure 1.

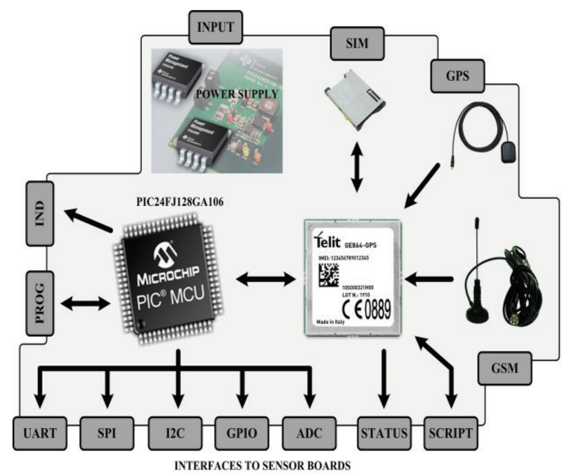

Figure 1. Block diagram of ekoNET device main board

It essentially provides the core functionality of the system such as GPRS/GPS connectivity as well as the digital and analog interfaces for the external sensor boards. All the components have been carefully selected in order to minimize the intrinsic noise generated by the internal electronic circuitry and also to prevent any noise injection into the sensitive sensor driver circuitry. The main design philosophy that has been adopted it to connect all the sensor boards via the digital I2C or SPI interface. This decision has been undertaken in order to minimize the interference with the low-level analogue signals that sensors provide. In this way, each of the sensors has its own driver board with associated ADC that is directly connected to the main board via the I2C interface. In this way, the length of the analogue line (susceptible to the noise interference) is minimized and therefore the signal to noise ratio is greatly increased.

The sensors that are connected the main board are of different types, namely electrochemical gas sensors, atmospheric conditions sensors, particulate matter and noise.

The ekoNET device presented in this paper is equipped with the following atmospheric condition sensors:

- The sensor for atmospheric pressure measurements MPX4115 (15-115 kPa) [11]
- The sensor for temperature and humidity measurements CC2D23S (-40°C–123°C, 0-100%) [12]

Sensors used for the measurements of concentration of gases in the air are Alphasense's B4 family electrochemical types and infrared type IRC-AT for CO_2:

- CO_2-IRC-AT (0-5000ppm) [13]
- O_3-B4 (0-2ppm) [14]
- NO -B4 (0-20ppm) [15]
- NO_2-B4 (0-20ppm) [16]
- CO-B4 (0-50ppm) [17]

Alphasense B4 series sensors are intended for air quality monitoring in urban, rural and indoor areas, while D4 are industrial sensors. In this paper we are presenting results for urban air quality monitoring based on B4 sensors.

Furthermore, EB800 device is also equipped with the noise sensor measuring the sound pressure up to 105 dB.

As for the particulate matter monitoring Alphasense OPC-N1 [17]is used as particulate matter sensor, measuring PM1, PM2.5 and PM10, as well as measuring the particle size distribution in real time. This sensor solution uses SPI interface and can easily be attached to the main board. Alphasense OPC-N1 already has microcontroller for local signal processing and therefore it is connected to the main board via SPI connector.

Figure 2. shows the ekoNET device with mounted electrochemical gas sensors and packaged in the waterproofed box which makes this set-up suitable for the outdoor usage.

Figure 3. shows the EB800 components inside of the box with electrochemical gas sensors on the right, CO_2 at the top, main board in the middle of GPS/GPRS antenna at the left.

Figure 2. ekoNET device with low-cost electrochemical gas sensors mounted in the box

Figure 3. ekoNET device with low-cost electrochemical gas sensors

Each of the available devices is initially registered into the Resource Directory (RD) which stores the meta information about all resources and services within the IoT platform.

Subsequently, the collected data from the EB800 sensors are packaged into appropriate format and sent to the back-end cloud infrastructure via the mobile network (GPRS) channel utilizing Constrained Application Protocol (CoAP). The data is stored in the appropriate database which then service layer components use to provide the data to the applications.

The data is visualized in a real-time using the appropriate web or mobile application such as shown in Figure 4. The applications can also be used for the visualization of historical data which was gathered over longer period of time. In addition, as each ekoNET device comprises GPS module, the exact location of the sensor pack is known, so the network of environmental conditions can be built, pin pointing the "best" areas for the public, as well as indicating the areas where the pollutant levels are higher.

Figure 4. Web application for ekoNET data visualisation

IV. EKONET SYSTEM ARCHITECTURE

Figure 5. shows the high-level architecture of the ekoNET system mapped to the IoT-A Architecture Reference Model (ARM) [18]. The aim of the IoT-A ARM is to provide an architectural reference model for the interoperability of IoT systems, outlining principles and guidelines for the technical design of its protocols, interfaces and algorithms. Following the outlined principles ensures that the implemented and instantiated architecture complies with the standards related to the interoperability in terms of the protocols and functional specification of the building blocks of the resulting IoT system.

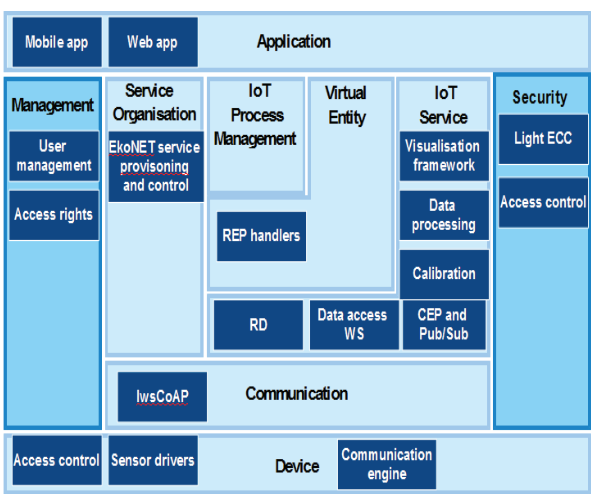

Figure 5. ekoNET system architecture mapped to IoT-A ARM

The ekoNET devices are connected to the ekoNET platform serving as the back-end cloud infrastructure. There are several variants of the ekoNET devices depending on the deployed location (indoor/outdoor), type of sensors used (air quality/safety) and usage (stationary/personal) but their deployment is same in the context of the connection to the cloud infrastructure. Each of the sensor has its Sensor driver board**.** Access to sensor data is controlled using the Access Control component which is also used for controlling the access of devices to the cloud infrastructure. This ensures that only authorized users can access the data as well as only authorized devices can access the cloud infrastructure. The collected data from the sensors is transmitted to the back-end infrastructure via the mobile network using the CoAP [19] utilizing the Communication engine component. CoAP is an application layer protocol designed to lower the complexity for the constrained networks but, also, to enable communication over the existing internet infrastructure. CoAP is a light-weight application protocol based on UDP that supports multicast requests, cashing and REST web services between the end-points, and is seen as a future protocol for IoT. CoAP is still work in progress of the IETF CoRE Working Group [20]. This system utilizes light weight secure CoAP (lwsCoAP) that is designed for secure data transfer using CoAP where the encryption is based on Elliptic Curve Cryptography (ECC) which significantly lowers the required computational effort for data encryption which is essential for the constrained IoT devices such as EB800. This component is also utilized on the server side to enable the creation of the secure communication channel between the devices and rest of the platform.

The cloud platform and associated building blocks enable the core features such as the permanent storage and access to the data (Data Storage and data access web services component) within the Data Server component). Search and discovery of resources and services is performed using the Resource Directory (RD) component. Complex Event Processing and Publish/Subscribe broker enable detection of complex events from multiple heterogeneous data sources. Once these events are detected, they are forwarded (published) to the users or components that consume them (subscribers). data cleaning and processing functionality (Data Server and Data Processing components) as well as a set of visualization widgets (Visualization Engine component). Calibration component is very important module in the context of the environmental monitoring sensors as it provides functionality for continuous correction of acquired data using the empirical models derived during the laboratory calibration phase. Data processing component is responsible for providing various levels of data analysis, used by the Visualization Framework for example (e.g. data interpolation, data averaging, medians, trends etc.). Visualization framework enables the application-level components to display the measured values utilizing set of widgets capable of showing real-time, historical and other statistical data sets. REP handlers provide the top-level entry points for accessing the EB800 devices provide that the access is allowed by the authentication and authorisation procedure. Service provisioning and control component is responsible for handling the creation of various services that can be provisioned on the system. For example a service can be created that provides temperature measurements every minute which only specific users are allowed to access. User management component provides functionality for the creation of users, access rights based on the access rights rules defined for the entire platform.

On top of the architecture stack there are web and mobile applications that are used to access then services provided by the platform. Furthermore, additional web applications are used for the administrative purposes.

V. CONCLUSION

In this paper we have presented the environmental monitoring service ekoNET, based on the low-cost electrochemical gas sensors. The ekoNET system is developed for a real-time monitoring of air pollution and other atmospheric condition parameters and is intended for the usage within the IoT domain of smart cities and smart enterprises. Overview of the overall system architecture, ekoNET device, back-end cloud IoT infrastructure mapped to the IoT-A Architecture Reference Model (ARM), data handling and visualization engine as well as the application-level components and modules are given and discussed in details. In the future work ekoNET will be integrated with AR Genie, augmented reality platform. By extending the AR Genie platform with the ekoNET IoT service, we will able to demonstrate usage of real-time environmental data within AR mobile applications.

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