# Wireless Sensor Network Based Infrastructure for Experimentally Driven Research

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*Abstract*—**The availability of suitable infrastructure represents one of the key factors for sustainable development of society and economy. The concept of smart cities exposed the importance of sensorial infrastructure combined with powerful analytical data processing to enable deep insight and better understanding of natural and social processes to provide various services to citizens. The aim of this paper is to present the LOG-a-TEC sensor network and its role in experimentally driven research and development. The LOG-a-TEC testbed is based on wireless sensor network technology and its initial phase was deployed on public infrastructure in Logatec, Slovenia, subsequently being complemented with additional locations for different application areas. In all cases the wireless sensor network implementation is based on the VESNA platform, a versatile platform for sensor network applications. To support the evaluation of different principles and solutions, the VESNA platform allows remote reprogramming as well as expansion with new sensors and other functional modules. As an example we present LOG-a-TEC experimental infrastructure based applications for radio spectrum occupancy sensing, environmental monitoring, smart grids and the sensors as a service concept making sensors and their measurements directly accessible for ad hoc use.**

***Keywords—LOG-a-TEC; wireless sensor network; VESNA platform; experimentally driven research; smart infrastructure and services***

## I. INTRODUCTION

We are witnessing a rapid increase in the number of devices connected to the internet and the emergence of direct communication between such devices also referred to as machine-to-machine (M2M) communication, complementing traditional people-to-people and people-to-device communications. In this context, Wireless Sensor Networks (WSN) allowing interconnection of devices equipped with sensors without expensive wired infrastructure are expected to play an important role. The integration of WSNs into the future Internet architecture is facing a series of challenges resulting from the network scale, diversity of devices and their constraints such as processing capacity, energy independence, data rate, etc. Existing solutions are typically functionally closed and intended for use in a specific area, providing interoperability only between similar sets (i.e., vertical integration) [1].

The adoption of a reference architecture, which is based on the use of standardized protocols and interoperability of available resources in various application areas (i.e. horizontal integration), appears to be the key to broader deployment of WSNs in real life. The development of WSN solutions, however, typically calls for an interdisciplinary approach with collaboration between application domain experts and technology solutions providers. In order to test, develop and amend the system, the establishment of realistic test environments is necessary. Such environments should allow experiments for the (i) assessment of individual approaches to solve a particular problem and (ii) evaluation of heterogeneous technological building blocks. This approach is particularly important for research on complex and/or large scale concepts which cannot be evaluated only in a laboratory environment or using a computer simulation. Some of the foreseen concepts for evaluation in test environments include the Future Internet, cognitive radio, Internet of Things and smart cities.

The trend in the Future Internet research area is to establish experimental infrastructures consisting of several testbeds, which will enable more accurate evaluation of research results in a realistic environment. An important role in this context play the research framework FIRE (Future Internet Research and Experimentation) in the EU [2] and GENI (Global Environment for Network Innovations) in the USA [3], under which a set of heterogeneous infrastructures have been established considering Future Internet as a common denominator [4].

The availability of suitable infrastructure represents one of the key factors for sustainable development of society and economy, as well as for the introduction of new services which meet the different needs of business, administration and private entities. The term infrastructure traditionally referred to transport, utility and energy infrastructure, but over the last two decades the information and communication infrastructure started gaining in importance. While broadband Internet access infrastructure is by now already understood as something obvious and omnipresent, the concept of smart cities exposed also the importance of acquisition and monitoring of various quantities, phenomena and events, and of emerging technologies that will enable the integration of the information

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infrastructure into uniform system to provide various services to the citizens.

The aim of this paper is to outline the basic requirements in designing sensorial infrastructure both in terms of hardware and software, and discuss functionalities that must be supported for the effective execution of experimentally driven research. As an example implementation, we present the experimental infrastructure LOG-a-TEC and the VESNA platform as its basic building block. The concluding part of the article deals with examples of current experimentally driven research in WSNs.

## II. Sensorial Infrastructure

Sensorial infrastructure combined with powerful analytical data processing enables deep insight and better understanding of natural and social processes in cities. Consequently, these enable more efficient use of resources and sustainable urban development. Sensorial infrastructure is thus becoming indispensable in applications dealing with energy saving, efficient use of natural resources, monitoring and protection of environmental conditions, reduction of noise, light and harmful chemicals pollution, transportation efficiency, independent living of elderly, sick or disabled, security, and protection against floods, fires and earthquakes.

While they can be based on similar or even same type of sensor nodes, sensorial infrastructure purposely developed and optimized for the targeted application and experimental sensorial infrastructure differ in many aspects. Unlike for targeted applications, which include hardware and software to deliver a set of selected services taking into account the constraints of the operating environment, experimental sensorial infrastructures are typically more generic and biased towards instrumentation. They usually require the inclusion of advanced network monitoring and management functionality, possibly some alternative communication solutions, onboard memory for storing the collected data on the node and subsequent retrieval if necessary, detailed insight into the devices that are part of the experiment, and for reliability reasons possibly permanent powering.

Due to all these requirements most experiments were until recently limited to controlled laboratory environments. But now there are appearing new experimental testbeds in real environments in outdoor urban areas with full remote access [5, 6]. This usually requires the inclusion of management hardware interfaces, which control and monitor the experimental devices through appropriate interfaces. Typical remote management functionalities include (i) remote reprogramming of experimental devices for the needs of particular experiments, (ii) collecting data for remote debugging, (iii) exchange of control commands for monitor and control of the experiment course and triggering external events associated with the experiment.

It is often necessary for the realization of all these features to select a hardware which is much more powerful than the sensor device needed in the experiment or final application. The exchange of control information requires provision of additional communication interface with high bandwidth. Such approach is appropriate in a controlled laboratory environment, but usually turns out to be unfeasible for operation in real outdoor environment, where it is often impossible to provide supporting infrastructure such as the uninterrupted power supply or redundant communication interface. These limitations require either to develop new management hardware, or to include its functionality in the same device as used for carrying out experiments. The latter approach has been selected in the implementation of an experimental sensor network LOG-a-TEC.

## III. Experimental Sensor Network LOG-a-TEC

The initial phase of a large scale outdoor experimental sensor network LOG-a-TEC has been deployed on the public lighting infrastructure in the city of Logatec in Slovenia and represents the baseline for different basic and applied projects. It is primarily intended for experimentally driven research and development with an emphasis on the evaluation of technologies, devices, algorithms and protocols. It has been deployed in a close cooperation between the Jozef Stefan Institute, the Municipality of Logatec and the utility company Komunalno podjetje Logatec.

In the initial phase, the wireless sensor network consists of two clusters; one cluster of 25 nodes is located in the industrial zone and another cluster of 25 nodes in the town centre. Most of the sensors are installed on street lamp lighting poles while others are mounted on buildings or roofs. The wireless communication between the nodes in both clusters is based on the ZigBee standard and operates on 868 MHz. In each cluster there is a coordinating node which is connected to the Internet via a gateway. The nodes are accessed and controlled via a Web application. Coordinating nodes are installed at locations with fix Internet access and are thus equipped with an Ethernet module. Alternative connection to the Internet could be

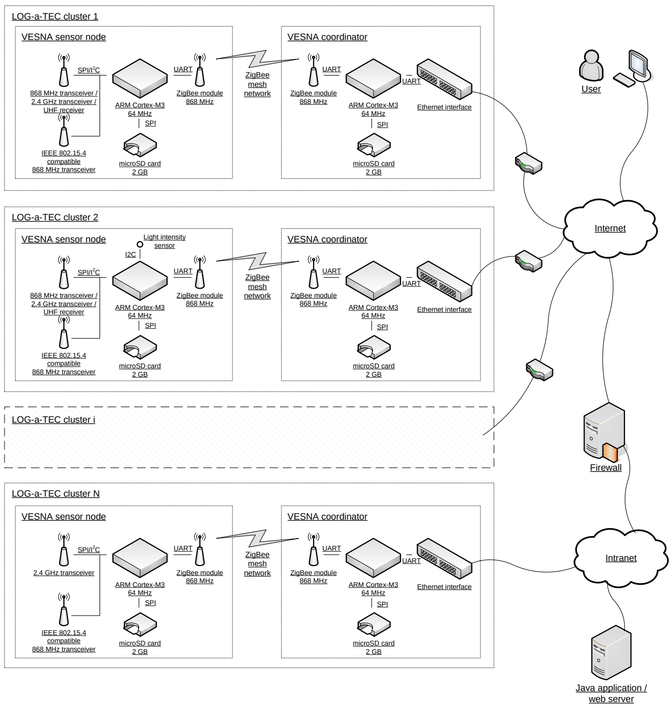


Fig. 1. A logical block diagram of LOG-a-TEC experimental sensor network

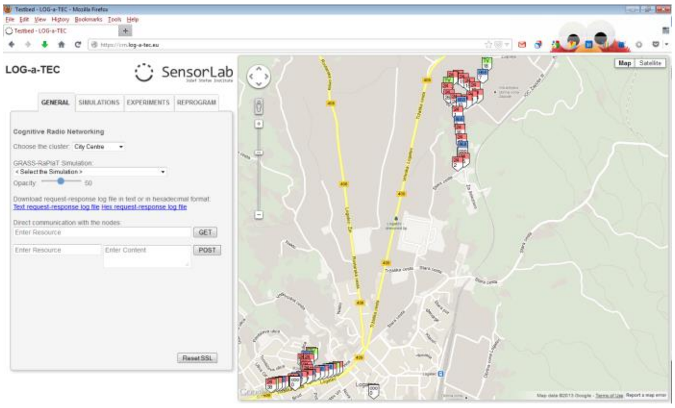


Fig. 2. Web interface to access experimental sensor network LOG-a-TEC

provided with a readily available GPRS module. A logical block diagram of the LOG-a-TEC sensor network and its connections with the control application is shown in Fig. 1.

The user interface to the physical experiments is provided by a web application illustrated in Fig. 2, where also the two clusters of nodes deployed in Logatec can be seen. Sensor data and the status of the node are obtained by clicking on the respective marker. Further interaction with the nodes and their available resources can be established either using GET and POST commands, which can be entered directly in the web interface (baseline mode) or by using Python scripts based on the prepared library of available resources (advanced mode). The web application also includes administration tab for scheduling of experiments, management of user rights, cluster management and implementation of tasks for remote upgrading of the infrastructure. An example of the latter application is the remote reprogramming of an individual node or entire cluster with firmware for the planned experiment.

An overview of available features of the application and implementation of infrastructure links with sensor is illustrated in Fig. 3.

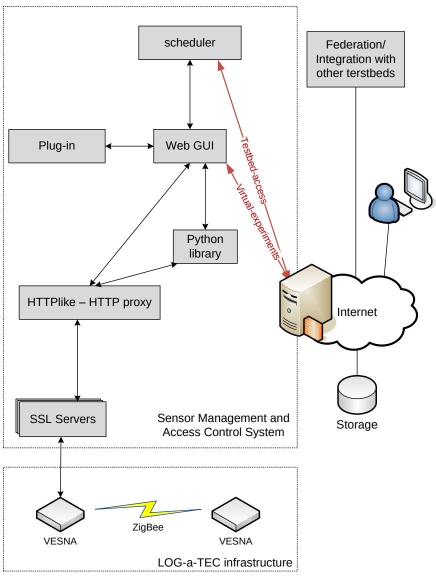


Fig. 3. Application functional blocks

## A. *VESNA platform*

The VESNA platform represents the basic building block of the experimental sensorial infrastructure LOG-a-TEC. The modular design of the platform provides support and flexibility for different applications. Hardware solutions typically consist of:

- Sensor Node Core (SNC) module based on a powerful ARM microprocessor with Cortex-M3 core.
- Sensor Node Radio (SNR) module supporting different implementations of a variety of communication interfaces, technologies and operating frequency ranges.
- Sensor Node Expansion (SNE) module enabling the realization of application related functionality, additional power supply solution and/or gateway functionality in order to connect to other communication networks.

Through a set of digital and analog interfaces the platform supports a wide range of sensors and actuators. The core and radio modules of the VESNA platform are depicted in Fig. 4 [7].

# IV. EXAMPLES OF EXPERIMENTALLY DRIVEN RESEARCH

In the current version, sensor nodes of the LOG-a-TEC experimental infrastructure are mostly mounted on the public light poles. A number of configurations adjusted to various project requirements are applied for research and development of various applications and scenarios. Some of them are briefly presented below.

## A. *Spectrum sensing and cognitive radio*

In the context of the European FP7 project CREW [8] the LOG-a-TEC testbed represents one of the five federated experimentation networks for spectrum sensing and cognitive radio related research. As part of FIRE initiative, these testbeds are made available for a variety of experimental investigations and experiments within a project as well as for external researchers. For the purpose of the project, we designed SNE modules for the VESNA platform, which measure the radio spectrum occupancy in (i) unlicensed industrial, scientific and medical (ISM) frequency bands at the frequencies 433 MHz, 868 MHz and 2.4 GHz and in (ii) licensed UHF frequency band, which is allocated primarily for TV broadcasting (i.e. 470-862 MHz) but also used for wireless microphones.

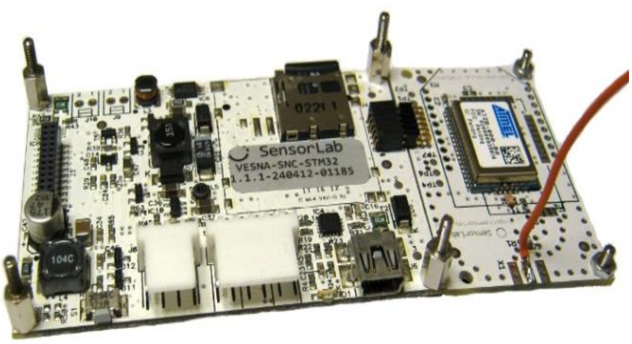


Fig. 4. VESNA platform SNC and SNR modules

Each of the sensor nodes consists of a SNC module, SNR module intended for communication within the network, and SNE module with one of the following communication interfaces:

- The transceiver radio interface for ISM band at 868 MHz based on the Texas Instruments CC1101 radio chip. It is primarily intended for detection of radio signals, but it can also be used as a communication interface to connect to other nodes or as a transmitter of test signal sequences.
- The transceiver radio interface for ISM band at 2.4 GHz based on the Texas Instruments CC2500 radio chip. It is primarily intended for the detection of radio signals, but it can also be used as a communication interface to connect to other nodes or as a transmitter of test signal sequences.
- The receiving radio interface for UHF frequency range based on NXP TV tuner chip TDA18219HN. It can be used only as a radio signal detector.

Each SNE module is further equipped with an additional radio interface based on Atmel radio on chip AT86RF212 for setting up the IEEE 802.15.4 compliant management network at the frequency of 868 MHz. The experiments carried out on the sensor nodes include testing different protocols and algorithms. Measurement results are stored in the local memory for retrieval and later processing. This is an easy way for verifying and evaluating solutions for dynamic spectrum allocation and cognitive radio in a realistic environment.

### *B. Air quality monitoring*

The European FP7 project CITI-SENSE [9] addresses environmental monitoring in cities, public spaces and inside buildings, particularly focusing on air quality. Its aims are to raise environmental awareness, promote participation and involvement of users by complementing purposely developed and deployed sensor nodes through the integration of applications and sensors embedded in smart phones, and providing possibility for citizens' feedback on the impact of individual phenomena.

A prototype system of air quality monitoring and assessment of environmental pollution by noise will be developed within the CITI-SENSE project. The VESNA platform together with a new extension module was chosen as one of the sensor platforms for air quality monitoring. The newly developed SNE module will be hosting sensors for (i) gases, such as carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds, VOC, (ii) other environmental parameters, including air pressure, temperature and humidity, and (iii) the intensity of noise.

The LOG-a-TEC experimental infrastructure will be used for the initial test and validation of the prototype system. The final pilot system is planned to be installed in selected cities participating in the pilot study.

### *C. Semantic sensor network*

In the national basic research project APRICOT, we are concerned with applying SOA principles to develop advanced procedures for the interactive composition of sensor networks on demand and thus exploit shared heterogeneous sensor resources assuming the knowledge of their characteristics, functionality, the context and accessibility. We are using semantic technologies to annotate and subsequently search for, discover, and reason upon sensor and associated communication resources, and on demand compose those resources into dynamic sensor infrastructure. By having data on shared sensors instead on available sensor data, we make possible a direct interaction with sensors, so we can reuse them and set their parameters according to the needs of a particular application.

As they are developed, the procedures for dynamic composition of sensor networks are being evaluated and validated in a semantic sensor network testbed at JSI campus, which also represents part of LOG-a-TEC experimental sensor infrastructure and complements the outdoor testbed in Logatec. The JSI campus testbed consists of VESNA platforms equipped with Contiki OS and used for experimentation with cognitive networking on MAC and higher layers using the ProtoStack tool [10] for remote composition, reconfiguration and reprogramming of CRime protocol stack.

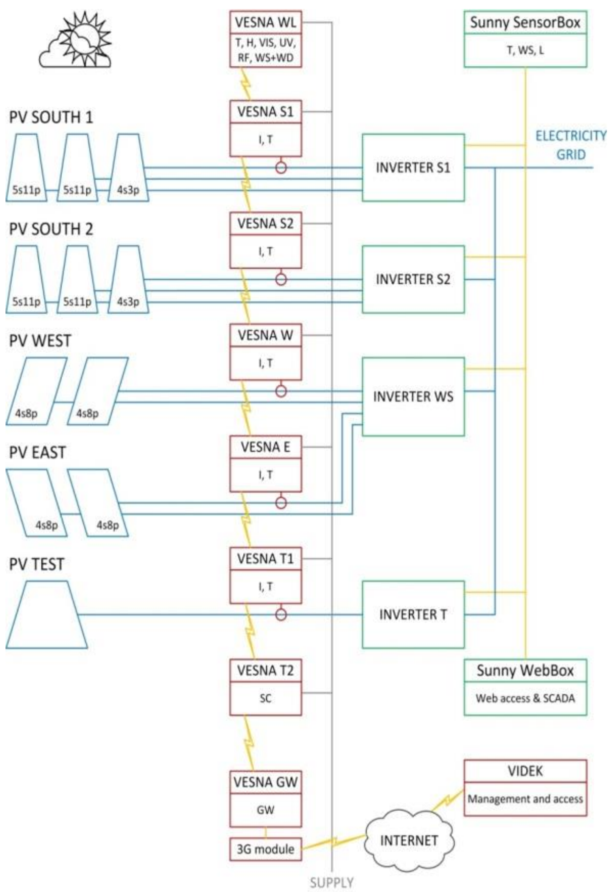


Fig. 5. VESNA based WSN for real time monitoring of PV system

### D. Photovoltaics system monitoring

In collaboration with Telekom Slovenije, we also used the VESNA platform as a baseline for the development and implementation of a sensor network for detailed real time monitoring of operating parameters in a photovoltaic system.

The wireless sensor network consists of eight sensor nodes as depicted in Fig. 5. The communication between nodes is based on ZigBee at 868 MHz, while the backhaul connection to the remote server is implemented via the mobile network (3G). Sensor measurement data and associated metadata are collected in a database, and is accessible via a web user interface [11] or directly via HTTP REST interface.

The deployed sensor nodes incorporate sensors for monitoring weather conditions (air temperature, relative humidity, wind strength and direction, precipitation), the intensity of solar radiation in the visible and ultraviolet region of the spectrum, an electrical current through each branch of the PV system, and the temperatures of solar panels in different orientations (south, east, west).

This pilot sensor network deployment also forms one distinctive part of the LOG-a-TEC experimental sensor infrastructure.

## V. CONCLUSION

Sensors are being increasingly integrated in our living environment and will, by integration in smart applications, play more and more important role in our lives. Unlike traditional communication networks, which are primarily intended for communication between people or people and devices, sensor networks are mainly intended for communication between the devices of a system. This article discusses the importance of establishing sensor infrastructures in real urban environment for experimentally driven research and development in various areas, which can lead to new solutions and applications. As an example, we present the LOG-a-TEC experimental infrastructure based on the VESNA platform along with examples of applications for radio spectrum occupancy sensing and environmental monitoring.

The modular design of the VESNA platform as well as of the experimental sensor network LOG-a-TEC allows the upgrade and expansion of the sensorial infrastructure to support a wide range of applications.


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