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# Safe delivery of sensed data in wireless sensor networks for gas leak detection: a boiler facility scenario

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## Abstract

In this work we share our experience in the deployment of a Wireless Gas Sensor Network (WGSN) in an operational boiler facility. Our setup is based on a state-of-the-art WGSN platform which ensures reliable gas detection and long-term operation of the network. We first describe the deployment of the network and then evaluate its wireless links using Received Signal Strenght Indicator (RSSI) and Link Quality Indicator (LQI) metrics.

*Keywords*: wireless sensor network; communication; catalytic gas sensor; gas leak; WSN deployment; WSN performance.

## 1. Introduction

Nowadays, methane monitoring in boiler facilities is performed by wired systems [1]. The major drawbacks of wired monitoring systems are their maintenance cost and their large demand in terms of use of cables which constrain the way the system can be deployed. Recently, the trend has been to shift towards the application of the Wireless Sensor Network (WSN) paradigm for gas monitoring, which can easily be deployed anywhere it is required and provides high flexibility and ease of maintenance. The use of this technology is today possible thanks to semiconductor and catalytic sensors with low power consumption on board of a WSN node that are able to meet the standard [2] of gas monitoring and energy-aware sensing [3] requirements.

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In this paper we present a novel application where a WSN is used to monitor methane levels in an operational boiler facility in Moscow. Since the sensing capabilities have been evaluated in our recent work [3][4] this contribution focuses on the evaluation of wireless communication between the network coordinator and the sensor nodes. In such a safety-critical application, the measured data must arrive in time as well as the quality of control strongly depends on the quality of wireless communication.

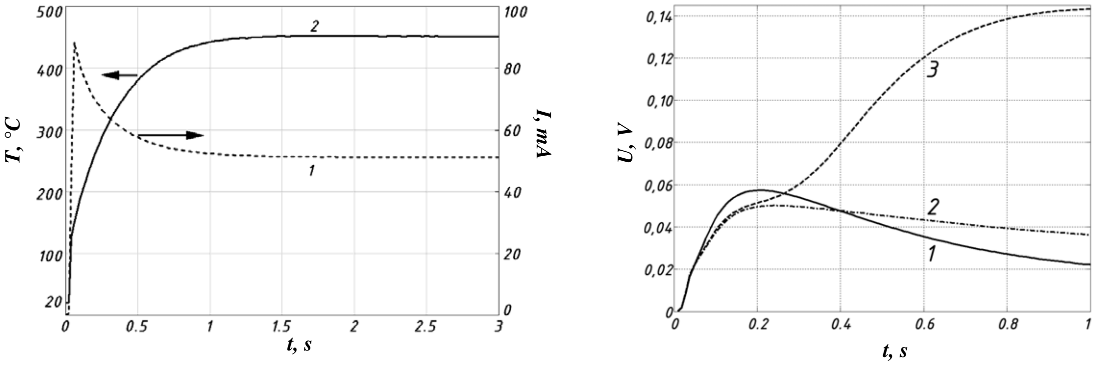
## 2. Hardware and Network Operation

The WGSN consists of 9 sensor nodes (Figure 1a) and 1 network coordinator (Figure 1b). The network coordinator is based on a STM32F102C6 microcontroller, uses a ETRX3 communication module (IEEE802.15.4, ZigBee, 2.4 GHz), and is plugged into the main power supply (220 V). The wireless sensor nodes are based on a AtXmega32A4 microcontroller and have the same communication part. The nodes are supplied by two 2D-batteries, wired in series. The sensor nodes can operate autonomously more than 1 year [3]. To support the stable communication between the nodes and coordinator, all wireless devices in the network have an external antenna.


(a) (b)

Fig. 1. (a) Wireless gas sensor node in the casing. Visible parts: antenna, power supply (2 x D-batteries, 1.5 V), and catalytic sensor (on the right side of packaging); (b) Network coordinator. LCD display shows the status of the sensor nodes in the network.

Figure 2a shows the current flowing through the sensor and the sensor temperature during its heating till 450 °C which is the normal operation temperature for the sensor. The time necessary to heat the sensor to enable its operation is approximately 1 s. Figure 2b shows the sensor response at different environmental conditions. 2% $CH_4$ can be detected in approximately 0.35 s.



(a) (b)

Fig. 2. (a) Heating temperature ‘2’ and heating current ‘*1*’ of the sensor w.r.t. heating time; (b) Sensor’s respons in volts (heating pulses are 2.8 V) w.r.t. environmental conditions: ‘*1*’ - air, ‘2’ – 0.25% $CH_4$ in the atmosphere, ‘*3*’ – 2% $CH_4$ in the atmosphere.

Apart from the methane measurement, the wireless sensor nodes perform self diagnostics which includes the monitoring of voltage level of the batteries and the sensor heater status.

The network coordinator shows the status of four sensor nodes at a time on a TFT display. The status includes:

- *Sensor node ID and its availability in the network*. To support this option, every 30 minutes the nodes send an acknowledgement to the network coordinator which updates their statuses: green window means the sensor node is in the network, grey window means it is out of network (see Figure 1b);
- *Battery charge* status can take the values: 'charged', 'voltage below 2.2 V', 'discharged'.
- *Current methane concentration*. The WGSN operates according to two hresholds (0.5% and 1%) of methane concentration in the environment: (i) <0.5%: nothing happens, (ii) 0.5% – 1%: alerting of the network coordinator, (iii) >1%: alerting of the main control system, sound alarm, and the sensor node status highlighte with red colour.

For this deployment, we have upgraded and improved the WGSN research platform we introduced in our previous work in [2]. For example, the current commercially-oriented platform supports remote reprogramming (RR) of sensor nodes and employs external antennas.

## 3. Deployment and Experimental Results

The access to a real boiler facility gives us the opportunity to experimentally evaluate the features of this environment which were not investigated in WGSN before. The WGSN, comprising 9 sensor nodes and 1 network coordinator (see Figure 1), is deployed in the boiler facilities (service rooms and the main hall) on a territory over 2000 m$^2$. The sensor nodes are fixed at approximately 10 m height and one is near the boiler *B3* as shown in Figure 3. The thickness of the brick walls is approximately 50 cm.

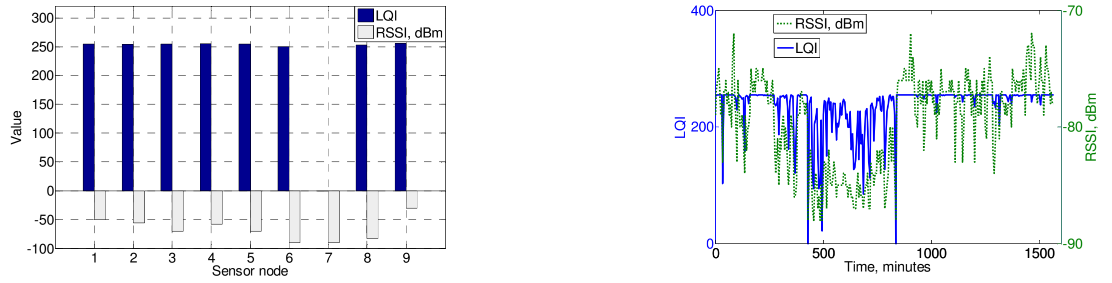
(a)

(b)

Fig. 3. (a) WGSN deployed in an operational boiler facility (30 x 70 m) where *C* is the network coordinator, *1–9* are the sensor nodes, *B1–B3* are the boilers; (b) sensor node №6 near boiler *B3*

The first experiment (see Figure 4a) demonstrates that links with low RSSI might have high LQI and vice versa. For example, the location of sensor node №7 ensures approximately the same RSSI value as for the sensor node №6, but this signal has the lowest LQI and can not be demodulated.

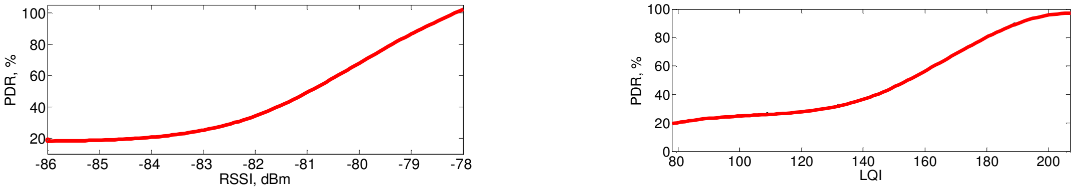
For the evaluation of LQI and RSSI stability during a 24-hours deployment in the boiler environment, we measured both metrics between sensor node №3. The LQI level is sufficiently stable during the day time (0-250 and 850-1565 minutes). However, there might be significant LQI drops during the night (9pm-7am or 250-850 minutes in Figure 4b). The RSSI is less stable even during the day, but is generally around -80 dBm. In night hours, the RSSI may be reduced up to almost -90 dBm. This can be explained by the harsh environment of the boiler facility, e.g., the night temperature in the beginning of May in Moscow can reach 12 °C (26 °C during the day time) that also impacts the level of humidity.



a) b)

Fig. 4. (a) Wireless link assessment between each sensor node and the network coordinator using LQI and RSSI metrics (average values after 100 measurements); (b) LQI and RSSI evaluation during 1565 minutes (approximately 26 hours).

Figures 5a and 5b plot the Packet Delivery Rate (PDR) values w.r.t. RSSI and LQI. A good link (PDR>80%) can be achieved when the RSSI is higher than -79.3 dBm and the LQI is over 200.4.



a) b)

Fig. 5. Relation between (a) RSSI and average PDR; (b) LQI and average PDR

The experimental results show that both the RSSI and LQI metrics should be carefully analyzed before the WSN deployment in a safety-critical environment: the dangerous gas can be detected within 1 s, but the data delivery may fail due to low LQI at high RSSI.

## Acknowledgements

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