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Deployment and evaluation of a wireless sensor network for methane leak detection

Andrey Somov[a,*], Alexander Baranov[b], Denis Spirjakin[b], Andrey Spirjakin[b], Vladimir Sleptsov[b], Roberto Passerone[c]

[a] CREATE-NET, Via alla Cascata 56/D, 38123 Trento (TN), Italy
[b] Department of Radio-Electronics, Telecommunication and Nanotechnology Moscow State Aviation Technological University, Orshanskaya 3, 121552 Moscow, Russia
[c] Dipartimento di Ingegneria e Scienza dell'Informazione, University of Trento, Via Sommarive 5, 38123 Trento (TN), Italy

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ABSTRACT

Wireless sensor networks (WSN) have been adopted in various monitoring applications. However, due to the high power consumption of catalytic gas sensors, which enable reliable gas detection, there is a lack of real WSN deployments aimed at the monitoring of combustible gases. This work reports on the evaluation of a WSN deployed in a real operational boiler facility. The WSN consists of nine battery-powered wireless sensor nodes (with an onboard catalytic sensor) controlled by a network coordinator. In this safety critical environment our objective is twofold: (i) guarantee precise and fast sensor response, and (ii) deliver the sensed data from the sensor nodes to the network coordinator safely in case of methane leakage. We first describe the deployment of the WSN and then evaluate the catalytic sensor response under various conditions. Besides, we evaluate the wireless links using the received signal strength indicator (RSSI) and link quality indicator (LQI) metrics. Finally, the experimental results demonstrate that during 5 months of deployment the sensor nodes have been discharged for 22–27%.

1. Introduction

Wireless sensor networks (WSN) [1] are collections of resource constrained sensing and processing devices that have a variety of different successful applications, including environmental monitoring (monitoring of floods [2], an active volcano [3], monitoring of zebras migration [4]), safety and security (monitoring of radioactive materials [5], wildfire [6], and buildings [7]), assisted living (smart medication system [8]), control (light control in tunnels [9]). Among these, hazardous/combustible gas monitoring, e.g., ethylene [10] and methane [11], is particularly promising for WSNs, since it requires capillary sensing capabilities in often difficult or harsh environments, favoring the adoption of simple, low-maintenance units. Until recently, however, hazardous/combustible gas monitoring with WSNs has lacked real deployments and experimentations in real scenarios. The reasons are found in the many limiting factors of this kind of deployments: (i) the high power consumption of catalytic [12] and semiconductor [13] sensors which fails to meet the long-term operation requirement of WSNs; and (ii) the long response time of colorimetric sensors which consume low power, but do not meet safety standards [14]. Hence, today the monitoring of hazardous gases in industrial premises or living apartments is typically carried out by wired systems [15] which can employ accurate and power 'hungry' sensors, and fast and powerful processors.

There are many reasons why one would like to replace the available wired solutions for gas monitoring in favor of a WSN approach. The principal one is that the major drawbacks of wired monitoring systems are their maintenance cost and their large demand in terms of cables, which constrain the way the system can be deployed. The WSN paradigm, in contrast, enables easy deployment of sensor nodes *anywhere* they are required and provides high flexibility and ease of maintenance. The use of this technology is possible today thanks to semiconductor and catalytic sensors with low power consumption on board of a WSN node that are able to meet the standard [14] of gas monitoring and energy-aware sensing [16] requirements, in terms of accuracy and response time.

In this work we present a novel application where a WSN is used to monitor methane levels in an operational boiler facility in Moscow. In particular, we evaluate and characterize the response of the sensors with respect to environmental conditions. To avoid dangerous situations, we emulate the leakage of methane in lab conditions and evaluate the sensor performance at 0.26% and 2% of methane concentration in the environment. In such a safety-critical application, the system must ensure the highest control quality, which strongly depends on reliable measured data delivered in time by the wireless communication channel. For this reason, our results include an estimation of the wireless link quality between

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[*] Corresponding author. Tel.: +39 0461 408400x406; fax: +39 0461 421157.
E-mail address: andrey.somov@create-net.org (A. Somov).

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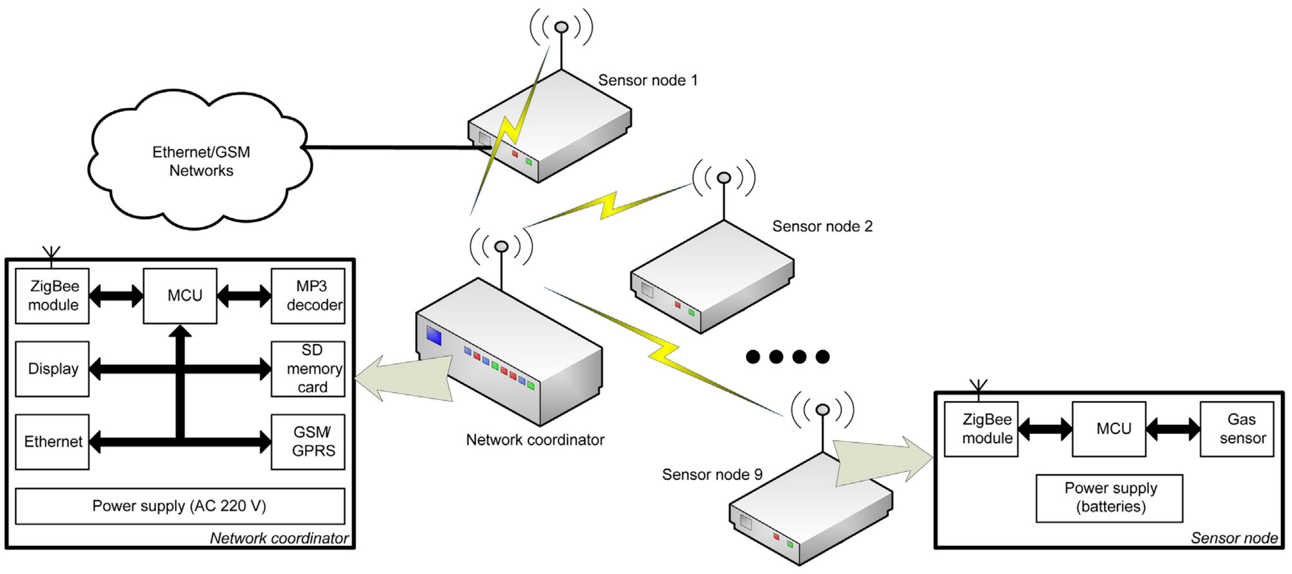

Fig. 1. Schematic diagram detailing the network operation and internal architecture of the sensor nodes and network coordinator.

the network coordinator and the sensor nodes in varying environmental conditions.

This paper is organized as follows: we introduce the reader to the used WSN in Section 2 where we describe the catalytic sensor, the battery-powered gas sensor nodes, and the network coordinator which enables remote sensor calibration. The details on the deployment scenario are shown in Section 3. The experimental results on the sensor response in a real boiler facility, the evaluation of wireless links and the sensor node long-term operation are demonstrated in Section 4. Finally, we discuss the related work and provide our concluding remarks in Section 5 and Section 6, respectively.

2. Wireless sensor network description

For this deployment, we have upgraded and improved the wireless gas sensor network (WGSN) research platform we introduced in our previous work [17]. For example, our current, commercially oriented platform supports remote sensor calibration (see Section 2.2) of sensor nodes and employs external antennas.

The WGSN consists of 9 battery-powered wireless sensor nodes and 1 network coordinator (see Fig. 1). The network topology is of star configuration. The network coordinator sets up the network parameters automatically. Communication within the network is implemented using the IEEE802.15.4 standard and the low-power wireless specification ZigBee. The network coordinator, however, has access to the Ethernet and GSM networks, so that, in case of alarm, it can notify a network operator or a boiler service team by sending a message through the Internet. All devices used in the deployment are customized, so we could easily adapt them to our needs.

2.1. Sensor nodes

The full block diagram of the sensor node is presented in Fig. 2. The sensor nodes are based on an AtXmega32A4 microcontroller and use an ETRX3 communication module (IEEE802.15.4, ZigBee, 2.4 GHz). The chosen communication module supports convenient self-configuration functions, at the expense of the power consumption which is slightly higher than other traditionally used solutions. Our choice does not degrade significantly the performance of the network, since the module power consumption is still very low compared to the rest of the system (especially the sensor heating) and considering also the duty cycle of the application. The nodes are supplied by two 2D-type batteries, wired in series. The input voltage from the batteries to the sensor node is regulated by a DC–DC converter. The sensor nodes can operate autonomously for more than 1 year [16]. To support the stable communication between the nodes and the coordinator, all wireless devices have an external antenna. The sensor node includes the gas sensor, which is described in Section 2.1.1. A picture of the sensor node is shown in Fig. 3.

The sensor node performs the catalytic sensor heating every 30 s. The heating voltage is adjusted by a built-in Digital-to-Analogue Converter (DAC) in the microcontroller and by an output amplifier. The measurement circuit is disabled by a MOSFET switch when it does not perform the sensing of the environment. Apart from the methane measurement, the wireless sensor nodes perform also self-diagnostics which includes the monitoring of the voltage level of the batteries and the sensor heater status.

2.1.1. Sensor

The sensing circuit, shown in Fig. 2, consists of an *active* (R4) and a *reference* (R5) catalytic sensor. In this work we use planar catalytic gas sensors by NTC-IGD, Russia. The sensor is manufactured on gamma alumina membranes with a thickness of 30 μm and has low power consumption [16]. The active sensor has a platinum micro-heater covered by porous gamma alumina oxide material that is used as catalyst support for catalytically active metals (mixture of Pd and Pt). In order to impregnate the catalyst support by the catalytic metal, salts of palladium chloride ($PdCl_2$) and platinum acid (H_2PtCl_6) are used. The noble metal clusters are formed on the catalyst support after annealing. The reference sensor has only a microhotplate covered by porous gamma alumina oxide material without catalytically active metals and is used to compensate for environmental factors such as temperature and humidity. The sensors are arranged in a Wheatstone bridge configuration, where the resistance of R1 and R2 is 1 kΩ each. The resistance of R3 is 1 Ω and is wired in series to the bridge to measure the heating current by measuring its voltage drop and applying Ohm's law. The resistance of the active and reference sensors is 12 Ω each under normal condition. During the heating process the resistance of the sensors changes, but does not do so equally for both sensors. This effect will be discussed in Section 4.1.

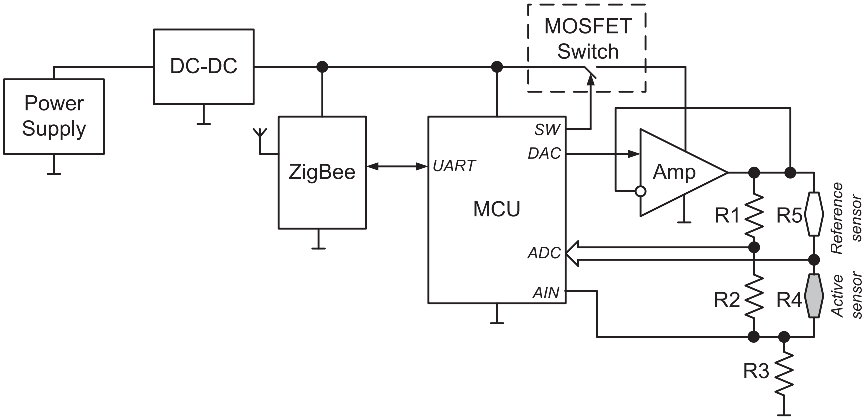

Fig. 2. Schematic diagram of the wireless gas sensor node.

The choice of catalytic sensors in our WSN is dictated by their better selectivity and sensitivity to methane in the 0.1–5% gas concentration range [18] in comparison to semiconductor sensors, and by their lower power consumption in comparison to optical solutions (see Table 2).

The sensing circuit is enabled by applying a supply voltage to the Wheatstone bridge. The sensors rapidly reach the temperature at which gas combustion occurs (450 °C) due to the high current which flows through the sensors. Both sensors must be heated up to 450 °C to reach standby mode. To meet this requirement a 2.8 V pulse supply voltage is applied.

Fig. 4 shows the current flowing through the sensor in the active portion of the pulse and the sensor temperature during its heating till 450 °C which is the normal operation temperature for the sensor. With the increase of the sensor temperature, the sensor resistance also increases. This, therefore, leads to the decrease of the heating current given that the heating voltage is kept constant. The time necessary to heat the sensor and to enable its operation is approximately 1 s, the heating interval is 30 s, the heating period is 30 ms, and the pulse width modulation duty cycle is 60%.

2.2. Network coordinator

The network coordinator (see Fig. 5) is based on a STM32F102C6 microcontroller, uses the same ETRX3 communication module as the sensor node (IEEE802.15.4, ZigBee, 2.4 GHz), and is plugged into the main power supply (220 V). The communication module has the option of automatically configuring the network, which simplifies and shortens the time of deployment.

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, the nodes send an acknowledgement to the network coordinator every 30 min, which then updates their statuses: a green

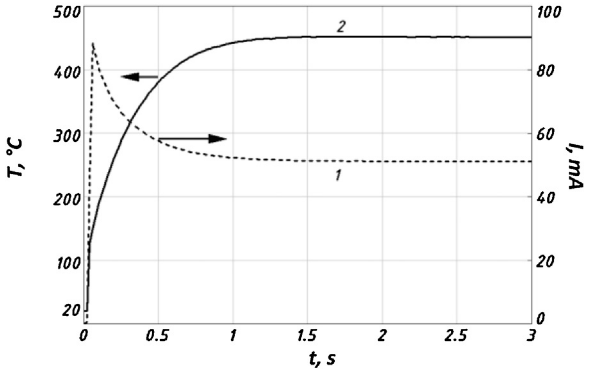

Fig. 4. Heating temperature '2' and heating current '1' of the sensor w.r.t. heating time.

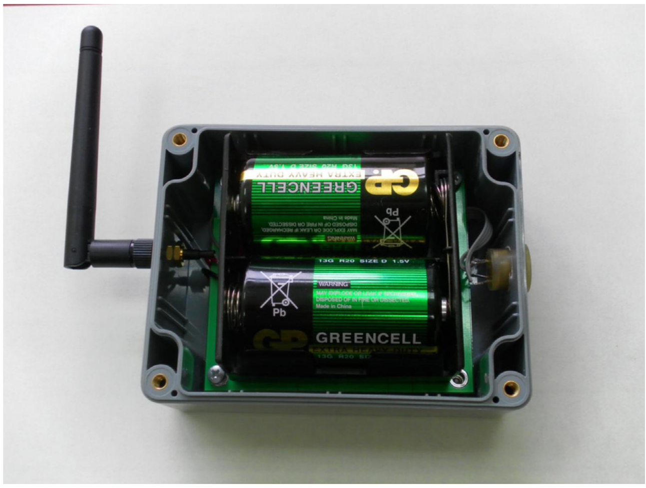

Fig. 3. Wireless gas sensor node in the casing. Visible parts: antenna, power supply (2× D-batteries, 1.5 V), and catalytic sensor (on the right side of packaging).

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Датчик 000D6F000180CF5C вне сети
  Батарея:  Не известно
  Метан:    Не известно
Датчик 000D6F000180D6A2 вне сети
  Батарея:  Не известно
  Метан:    Не известно
Датчик 000D6F000180D5C3 вне сети
  Батарея:  Не известно
  Метан:    Не известно
Датчик 000D6F000180CE44 в сети
  Батарея:  Заряжена
  Метан:    Норма
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Fig. 5. Network coordinator. LCD display shows the status of the sensor nodes in the network.

colour means that the sensor node is in the network, a grey colour means it is out of the network (see Fig. 5).

- *Battery charge* status can take the values: 'charged', 'voltage below 2.2 V', 'discharged' (voltage below 2.0 V).
- *Current methane concentration*. The WGSN operates according to two thresholds (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 highlighted with red colour.

2.3. *Remote programming and sensor calibration*

A brand new sensor is typically calibrated by the manufacturing company and is accompanied by the technical documentation which provides the calibration values. In this case a user should program these values into the memory of the sensor node. Nevertheless, the sensor degrades with time and requires periodical (1–1.5 year) calibration. Calibration consists in measuring the output response voltage for a defined and known methane concentration in the environment and recording the obtained values in the memory of the sensor node.

To perform the sensor calibration using the wireless channel we must first wake up the sensor node and set it in calibration mode by a command within 20 s after it is awoken. As soon as the sensor node is in calibration mode, the user can remotely adjust the thresholds for gas detection as well as set other parameters such as the address of the device and the measurement time.

To set up the gas detection thresholds we identify two points in the sensor characteristics (see Fig. 6):

(i) The sensor response in the air.
(ii) The sensor response at 1% of methane concentration in the atmosphere.

Fig. 6 shows that the dependency of the sensor response w.r.t. methane concentration in the atmosphere is almost linear. Therefore, the sensor response at 0.5% of methane concentration in the atmosphere, which we need to set one of the thresholds, is calculated automatically.

It is essential to achieve a stable sensor response during the calibration. For this reason, if the difference between the last two measurements is more than a predefined value specified in the sensor documentation, the system automatically repeats the measurements of the sensor response (controlling its input parameters) until the response meets the requirements. Upon achieving a stable response, we programme this value in the microcontroller of the sensor node.

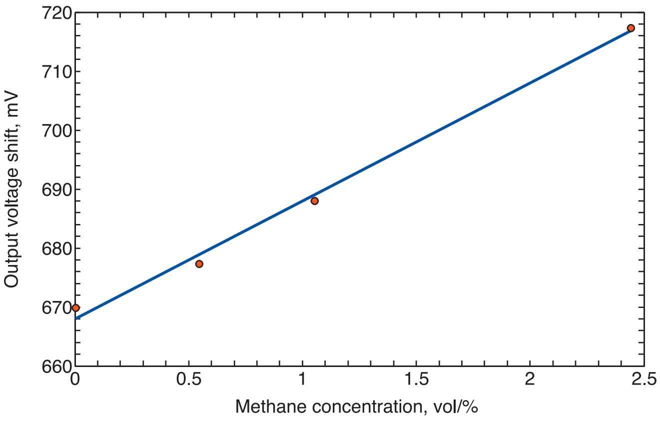

Fig. 6. Output signal of the sensor in mV with respect to methane concentration in the atmosphere.

3. Deployment scenario

The access to a real boiler facility gives us the opportunity to experimentally evaluate the features of this kind of environment, which were not investigated in WGSNs before. The WGSN, comprising 9 sensor nodes and 1 network coordinator (see Fig. 7a), is deployed in the boiler facilities (service rooms and the main hall) on a territory of over 2000 m^2. Each node with external antenna is packed in a plastic box and fixed at a height of approximately 10 m. One of the nodes is placed near boiler B3 as shown in Fig. 7b. The thickness of the brick walls is approximately 50 cm.

This deployment of sensor nodes helps us evaluate the wireless links between the network coordinator and sensor nodes in different parts of the boiler facility. In particular, we evaluated the sensor performance of sensor node no. 6, which is placed near boiler B3.

4. Experimental results and discussion

We have conducted three types of experiments to evaluate the network deployment. Our first set of measurements is oriented to the estimation of the sensor response amplitude and time. We then focus on the evaluation of wireless links between the network

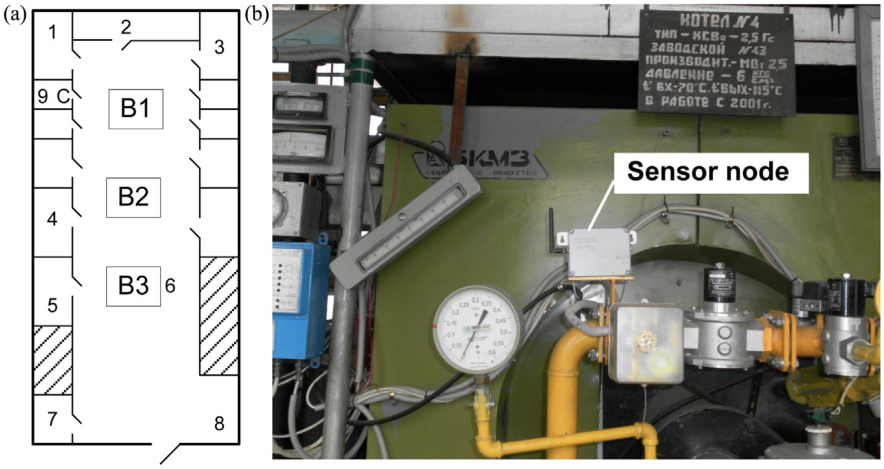

Fig. 7. (a) WGSN deployed in an operational boiler facility (30 m × 70 m) where C is the network coordinator, 1–9 are the sensor nodes, B1–B3 are the boilers; (b) sensor node no. 6 near boiler B3.

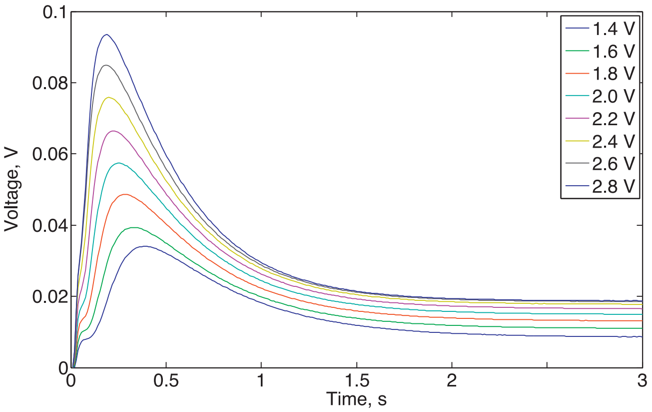

Fig. 8. Impact of environmental conditions: sensor response in the boiler environment (air) at −7 °C.

coordinator and each sensor node. In our third experiment we check the battery status of each sensor node and discuss the results. The next sections describe these experiments in details.

4.1. Sensor response

As stated above, in this work we evaluate the performance of the sensor node no. 6, since it is located close to the boiler (see Fig. 3). In this work, we use the sensor 'response voltage' and 'output voltage' terms interchangeably.

The catalytic sensor is in standby mode when it is heated up to 450 °C. To guarantee this we conducted a number of experiments in boiler conditions when the microcontroller on board of the sensor node generated the heating voltage in the range of 1.4–2.8 V. For example, Figs. 8 and 9 demonstrate the response of the Wheatstone bridge (sensing circuit) with respect to the applied heating voltage at −7 °C and +20 °C, respectively. Table 1 summarizes the experimental data of the average sensor temperature in standby mode with respect to the applied heating voltage of the sensor and at +20 °C in boiler conditions.

The sensor standby mode (450 °C) is achieved at 2.8 V supply voltage in normal boiler conditions (+20 °C) and the amplitude of the response signal is around 57 mV. At the same time, Fig. 8 shows that the same response amplitude in a colder environment can be achieved even with a 2 V supply voltage. This situation may happen during the nights in northern countries in the spring, when the heating of the boiler facilities is already off or in the fall when the heating is not yet on. That is why it is highly important to monitor the temperature and apply the remote sensor calibration procedure described in Section 2.1 to avoid false alarms.

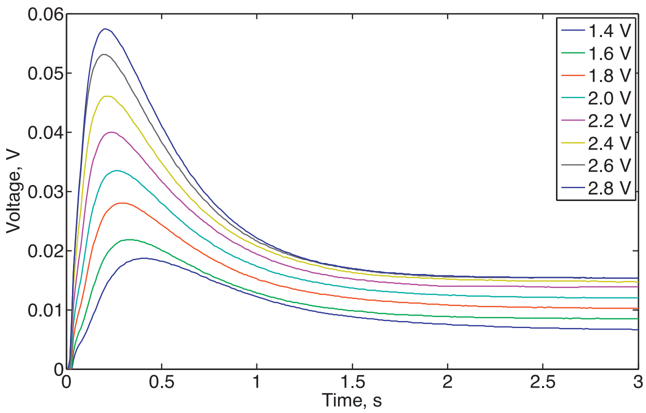

Fig. 9. Impact of environmental conditions: sensor response in the boiler environment (air) at +20 °C.

Table 1
Average sensor temperature in standby mode at +20 °C with respect to supply voltage.

Supply voltage, V	Sensor temperature, °C
2.8	450
2.6	388
2.4	330
2.2	277
2.0	229
1.8	186
1.6	146
1.4	113

In our next experiment we evaluate the sensor response in the case of methane leakage. Since it is dangerous to emulate this situation in the boiler facilities we carried out this experiment in the lab conditions with 0.26% and 2% of methane concentration in the atmosphere at 20 °C. We then compared the obtained results with the two previous experiments shown in Figs. 8 and 9. Fig. 10 shows the sensor response under four conditions (at 2.8 V supply voltage): at +20 °C (curve 1) and −7 °C (curve 2) in boiler (air) conditions; presence of 0.26% (curve 3) and 2% (curve 4) of methane in the environment (lab conditions). Curve 1 and curve 2 have similar shape, but different response voltage amplitude.

In contrast, curve 3 and curve 4 have different shapes. Curve 3 has one critical point 'A' whereas curve 4 has two critical points 'A' and 'B'. This effect can be explained due to the application of a pulsed heating mode to two sensors in the sensing circuit, where the active sensor is covered by a catalyst, while the reference sensor is not. Fig. 11 explains this effect.

The figure shows that the change in resistance of the sensor during the sensors heating with 2.8 V is different due to the

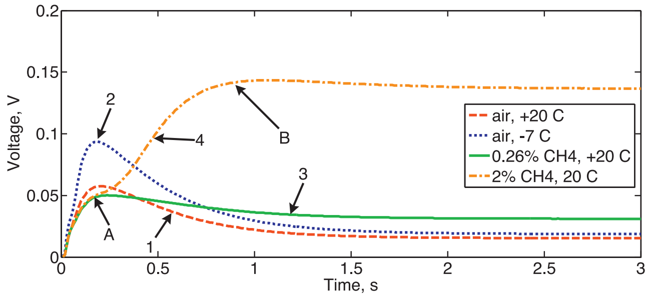

Fig. 10. Sensor response in deferent conditions.

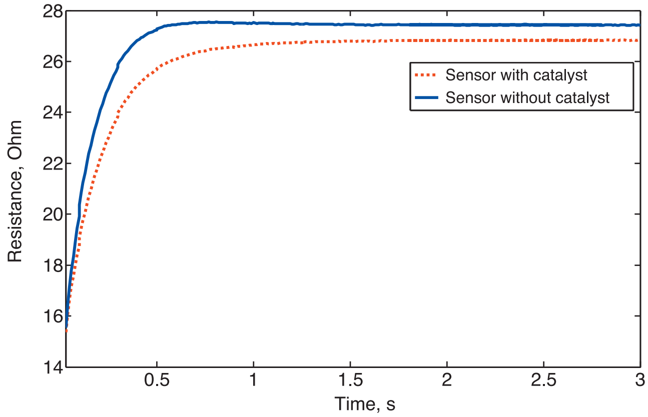

Fig. 11. Sensors resistance (with and without catalyst) change during heating it up with 2.8 V at 20 °C.

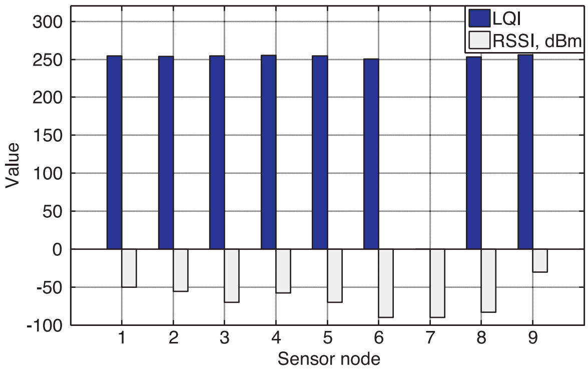

Fig. 12. Wireless link assessment between each sensor node and the network coordinator using LQI and RSSI metrics (average values after 100 measurements).

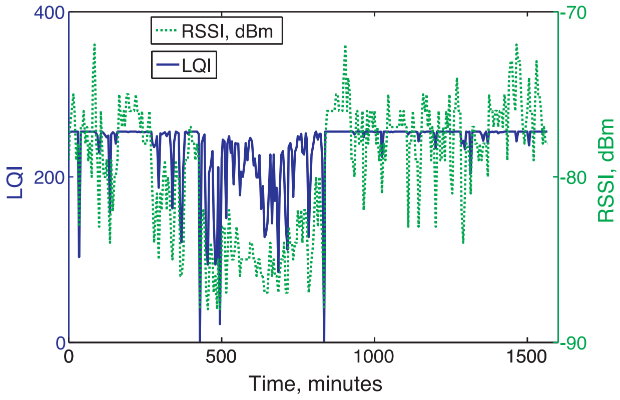

Fig. 13. LQI and RSSI evaluation during 1565 min (approximately 26 h).

presence/absence of a Pt–Pd catalyst layer. Obviously, it takes more time to heat the sensor with the catalyst and, therefore, the active sensor reaches the standby mode some time later than the reference one (without catalyst). The resistance of the reference sensor is stabilized in approximately 0.6 s whereas the active sensor keeps heating. In approximately 1.6 s both sensors have stable resistance and, therefore, their response voltage does not change any more.

Basically, the amplitude difference of curve 1 and curve 2 in Fig. 10 also happens due to the same effect: it takes more time to heat the sensor with the catalyst in a colder environment (see Figs. 8 and 9), which also affects the sensor resistance.

4.2. Evaluation of wireless links

One of the main objectives of this work is to understand the impact that the received signal strength (RSSI) and the link quality (LQI) metrics have on the physical layer of the wireless system and how these metrics depend on the environmental conditions of the boiler facility. The RSSI shows the received signal strength in dBm. The LQI shows the ability of the signal to be demodulated in a scale of 0–255.

For the first experiment, we evaluate the wireless links between the network coordinator and each sensor node. For the evaluation we carry out 100 measurements of RSSI and LQI (200 measurements in total) for each link during the day time. Fig. 12 demonstrates that links with low RSSI might have high LQI. For example, the location of sensor node no. 7 ensures approximately the same RSSI value as for sensor node no. 6, but this signal has the lowest LQI and cannot be demodulated. This means that the RSSI alone cannot accurately identify the link quality in the boiler scenario. In contrast, LQI can do it quite accurately.

For the evaluation of the environmental impact on the LQI and RSSI stability during more than a 24-h deployment in the boiler environment, we measured both metrics between sensor node no. 3 and the network coordinator. This sensor node has stable LQI, but 'borderline' RSSI, making it interesting for evaluation during the full day experimentation. Fig. 13 shows a plot of the measurements. The LQI level is sufficiently stable during the day time (0–250 and 850–1565 min). However, there might be significant LQI drops during the night (9 pm to 7 am or 250–850 min in Fig. 13). 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 that also impacts the level of humidity.

Next, we evaluated the performance of packet delivery from sensor node no. 3 to the network coordinator. The node has sent around 10,000 data packets with 20 s time interval between submissions. Fig. 14a and b plot the packet delivery rate (PDR) values with respect to 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 180.4. It is worth to note that when the LQI is around 210, the PDR reaches almost 100% rate.

The conducted experiments suggest that LQI is a more reliable metric for the evaluation of wireless links in a boiler facility scenario, which is considered as a safety-critical environment: the data delivery may fail due to low LQI even at high RSSI.

4.3. Sensor nodes lifetime

Long-term autonomous operation of wireless sensor nodes is an important requirement in the WSN domain. At the same time the gas sensor calibration has to be performed by a service team no less than once a year. Our objective, therefore, is to guarantee the sensor node operation at least for 1 year.

Each sensor node hosts on board two D-type batteries 1.5 V each (see Section 2.1). The node power management circuit supports its stable operation until the total voltage drops down to 2 V (0% battery charge).

Fig. 15 shows the battery charge status of each sensor node from the beginning of April 2012, to the beginning of September 2012. The battery charge status varies from 73% to 78% for all nodes except for node no. 7 whose charge status is 0%. This happened because the sensor nodes and the network coordinator try to establish the communication link at predefined time intervals in automatic mode (see Section 2.2). Due to the poor wireless link quality, both devices attempt to do it until the link is established. The log file accounts only a few successful connections for node no. 7. That is why its

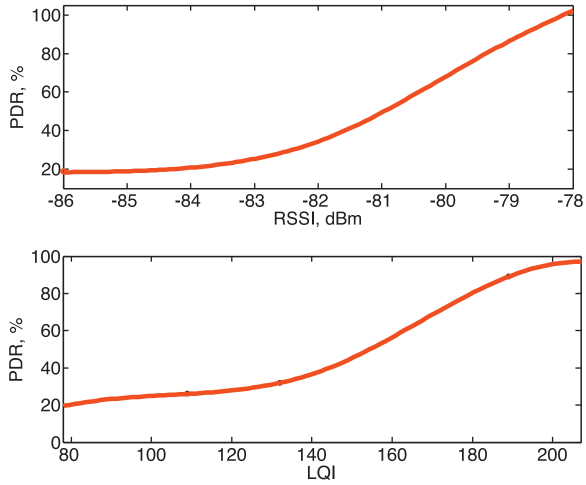

Fig. 14. Relation between (a) RSSI and average PDR; (b) LQI and average PDR.

Table 2
Power consumption of some off-the-shelf gas sensors.

Sensor type	Model	Manufacturer	Power consumption, mW (unless otherwise indicated)
Catalytic	DTK-2 (used in this work)	NTC-IGD	120
	NAP-66A, flammable gases	Nemoto	360
	MC series, combustible gases	Hanwei Electronics	420–600
	KGS 601, combustible gases	Korea New Ceramics	440
Semiconductor	TGS 2610, LP gas	Figaro	280
	AD81, gasoline	GE	620
	MQ-4, methane	Hanwei Electronics	750
Laser spectroscopic	NLK series	NTT Electronics	800 mA

batteries were depleted quickly. With this experiment we can predict the successful network operation for approximately 20 months in total.

4.4. Lessons learnt

In this section we report the difficulties we faced during the WSN deployment and some useful experience we gained.

1. To ensure safe combustible gas monitoring with the sensor nodes, the EN 50194:2000 standard [14] requires that an optical and a sound alarm appear no later than 30 s after the gas detection. Due to intensive noise in the boiler facility caused by the operation of the heating equipment and due to the nodes installation at high altitude, we deployed these alarms on the network coordinator located in a service room. The sensor nodes sense the environment every 30 s and, in case of gas detection, the network coordinator alerts the network operator and/or forwards the alarm signal to a fire crew through the Internet.
2. Since methane is lighter than air, we deployed the sensor nodes at a height of 8–10 m.
3. The transceivers with the integrated antenna could not provide a reliable communication channel among the sensor nodes and the network coordinator. To overcome this problem we used external antennas with 5 dB gain for the network coordinator and 2 dB for the sensor nodes. This solution guarantees 100% of packet collection with RSSI higher than −78 dBm (see Section 4.2).

5. Related work

The research in monitoring of hazardous/combustible gases with WSNs is still fragmented and lacks real deployments. This mainly happens due to the reasons that (i) gas sensors consume high power [17] (see Table 2), (ii) sensor nodes must ensure safe and reliable gas detection in accordance with the safety standards [14].

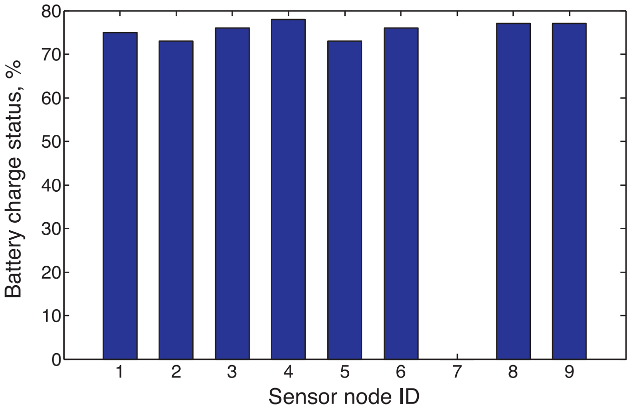

Fig. 15. Battery charge status of the sensor nodes in the network (the numbers are relevant for the period from the beginning of April 2012, to the beginning of September 2012).

In this respect, the state-of-the-art work related to our contribution can be divided into two groups: (1) WSN prototypes for hazardous gas leak detection with a gas sensor performance evaluation and (2) application deployments with the evaluation of wireless links.

5.1. WSN prototypes

Since high power consumption of gas sensors contradicts the WSN philosophy of long-term autonomous operation, just a few WSN platforms for hazardous gas leak detection have been recently proposed in the scientific literature. It is worth noting that this problem has not been resolved in commercial off-the-shelf gas WSNs as well: the operation of some items is limited up to 14 h [19].

Wireless sensor nodes based on silicon bridge-type micro-gas [20] and colorimetric chemical [21] sensing films ensure long-term operation of gas sensor nodes. In this case, the proposed solutions follow the classical WSN scenario where the radio chip is the most power ‘hungry’ component of the device. However, the response time of this kind of sensors may be up to several hundreds of seconds [21], which does not satisfy safety standards [14].

The authors of [22] integrated a laser spectroscopic sensor into a wireless sensor node. The hazardous gases detection using photoacoustic spectroscopy is a promising approach in terms of accuracy and short time response of the sensor. Another advantage of this approach lies in the application of a single sensor in a sensing circuit, while the sensing circuits based on catalytic or semiconductor sensors [13] require two items to realize the Wheatstone bridge where one sensor is active and the other one is for reference. In spite of this, the laser spectroscopic sensor consumes up to 800 mA that is too high for wireless sensor nodes.

In [23], a field-effect-transistor sensor has been used in a sensor node prototype for hydrogen detection. The sensing circuit, implemented as a Wheatstone bridge, can detect the presence of gas at room temperature, but as in [21] the response time is long. To overcome this problem the sensor is heated up to 100 °C within several seconds, so that the response time decreases up to approximately 1 s. The authors do not report the sensor or sensor node power consumption. We may infer however that the power consumption should be high enough since the sensing circuit contains two sensors and employs constant heating for them. In our work, we heat the catalytic sensors up to 450 °C with pulses instead of applying a constant current.

The platforms listed above have been tested in laboratory conditions. In contrast, in this work we deployed the WSN for methane detection proposed in [17] in a real boiler facility.

5.2. Application deployments

A number of application deployments with the analysis of wireless links have been described recently in the literature.

For example, in [24] the authors study the wireless link quality in real office environments. The goal of the study is to develop a link cost metric that minimizes the necessary measurements of communication channel. The effects of obstacles and various moving objects in factory environments have been studied in [25] from an experimental point of view.

A comparative study on operational and non-operational road tunnels is presented in [9]. The authors investigate spatio-temporal characteristics of wireless links and performance of link quality estimators. For example, it was established that temperature does not significantly affect packet delivery rates, but humidity does. Besides, as in our work, the authors also suggest that the link quality indicator (LQI) is a better predictor for communication reliability in WSN deployments.

6. Concluding remarks

In this paper, we have presented a novel application where we evaluated the deployment of a wireless sensor network (WSN) in a real boiler facility. In this safety critical environment, we carried out a number of experiments on evaluation of quality of wireless links to ensure the safe delivery of sensor data and performed the analysis of the catalytic sensor response under various conditions. The experimental results demonstrated that both RSSI and LQI metrics must be carefully considered in a boiler environment to ensure the quality of wireless links. At the same time, the response amplitude of catalytic sensors may vary greatly under different ambient temperature. To ensure the precise analysis of data from the gas sensors it is important to be aware of temperature measurements as well.

In our future work, we plan to investigate the operation of our system by studying the collected data (sensor response time, level of methane concentration, battery status) from a statistical point of view. At the moment we keep storing the collected data in the network coordinator.

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Biographies

Andrey Somov received his BS degree in Electronic Engineering and the diploma of Electronics Engineer from Moscow State Aviation Technological University, Russia in 2004 and 2006 respectively. Before starting his PhD, Andrey worked as an electronics engineer in space technology for 2 years. He subsequently undertook research in the area of wireless sensor networks in which he gained a PhD degree from the University of Trento, Italy in 2009. In the fall 2008 Andrey was a visiting scholar at the University of California, Berkeley, USA, where he conducted research in energy efficient sensor networks. Dr. Somov holds the position of researcher at CREATE-NET, Italy. His work is focused on the Internet of things.

Alexander Baranov is a Professor at Moscow State Aviation Technological University, Russia. He received a PhD in Physics and Mathematics in 1994 from Moscow Institute of Electronics & Mathematics (Technical University) and the Doctor of Technical Science degree in 2003 from Moscow State Aviation Technological University. Prof. Baranov is the project leader on several research projects, some with international partners. His current research interests include the development of thin film nanocomposite catalysts for gas sensors by plasma deposition methods, catalytic and semiconductor sensor characterisation, and wireless sensor networks.

Denis Spirjakin is presently a PhD candidate at the Department of High Tech Radio-Electronics of Moscow State Aviation Technological University, Russia. He obtained his BS and MS in Electronics in 2005 and 2007 both from Moscow State Aviation Technological University, Russia. His research interests are in digital signal processing, data transmission system, and wired/wireless sensor networks.

Andrey Spirjakin graduated with a BS and MS degrees in Electronic Engineering from Moscow State Aviation Technological University, Russia, in 2007 and 2009, respectively. He works towards his PhD in wireless sensor networks (WSN) at the same university. Andrey's research is focused on power management and signal processing of semiconductor gas sensors for WSN applications.

Vladimir Sleptsov is the Head of the Department of Radio-Electronics, Telecommunications and Nanotechnology at Moscow State Aviation Technological University ("MATI"), Russia. Professor Sleptsov is the project leader on several National and International research projects. His current research interests include the development of thin film nanocomposite materials by ion plasma methods for energy storage systems and wireless sensor networks.

Roberto Passerone is Assistant Professor at the Department of Information Engineering and Computer Science at the University of Trento, Italy. He received his MS and PhD degrees in Electrical Engineering and Computer Sciences from the University of California, Berkeley, in 1997 and 2004, respectively. Before joining the University of Trento, he was research scientist at Cadence Design Systems. His current research interests include formal models for system design and the development of design methodologies for embedded systems, with particular attention to wireless sensor networks.