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A Wireless Based Environment Monitoring Design Taking Parameters Such As Power Consumption, Portability, and System Cost Into Consideration

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Abstract:

Power consumption, portability, and system cost are important parameters in designing pervasive measurement systems. With these parameters in mind, wireless environment monitoring system with a capability to monitor greenhouse gases, such as CO, CO2, SOx, NOx, O2 with environmental parameter is developed. In order to achieve the target design goals, the communication module, the wireless smart transducer interface module, and wireless network capable application processor module were developed based on the IEEE 802.15.4, IEEE 1451.2, and IEEE 1451.1 standards, respectively. The low cost and energy efficient gas sensing modules were successfully developed with improved tolerance to EMF/RFI noise. We defined recalibration of the system at time intervals to ensure that the desired accuracy is maintained. This paper presents the undertaken design detailing solutions to issues raised in previous research.

Index Terms:
Smart sensor, smart transducer interface module, network capable application processor, IEEE 802.15.4 standard, electrochemical gas sensor array.

I. INTRODUCTION:

WIRELESS sensor networks (WSNs) are being deployed in many real-life applications, such as environmental monitoring, security and surveillance, industrial automation and control [1]. This has been possible due to the advent of: (i) the IEEE 802.15.4 standard [2], which defines the physical and medium access control (MAC) layers of the protocol stack; and (ii) the ZigBee specifications [3], which cover the network and application layers.

A major concern in WSNs is energy conservation [4], although reliability is also very critical [5]. Indeed, it has been shown that WSNs based on IEEE 802.15.4/ZigBee suffer from serious unreliability issues, especially when power management is enabled for conserving energy [6], [7]. Therefore, effective and efficient mechanisms should be provided to achieve reliability with a low energy expenditure. Now, different WSN applications have different reliability requirements. For instance, industrial control or military applications might require nearly 100% reliability. On the other hand, environmental monitoring applications might tolerate message loss, leading to a trade-off between energy conservation and reliability.

For energy efficiency, the WSN protocol stack needs to be tuned according to the actual needs. The traffic and network conditions in a WSN are often very dynamic, due both to the noisy wireless channel and the failure probability of sensor nodes (e.g., when they run out of battery power). Thus, energy-aware and reliable data collection mechanismsshould be able to adapt to the actual operating conditions [8]. In addition, they should be flexible enough to support a wide variety of operating scenarios, without any prior or global knowledge on the network topology and the traffic pattern. All these requirements make the design of energy-efficient adaptive schemes for reliable data collection a significant challenge.

To this end, a cross-layer approach is definitely beneficial, since it can exploit the knowledge provided by the different layers of the protocol stack to minimize the energy expenditure [9].In this paper we propose an adaptive and cross-layer approach for reliable and energy-efficient data collection in WSNs based on the IEEE 802.15.4/ZigBee standards.

Our approach involves an energy-aware adaptation module that captures the application's reliability requirements and autonomously configures the MAC layer, based on the network topology and current traffic conditions. Specifically, we propose the ADaptive Access Parameters Tuning (ADAPT) algorithm, based on an analytical study of the IEEE 802.15.4 standard. ADAPT is simple and lightweight, and uses only information local to the sensor nodes. As a result, it is fully distributed, and has a very low complexity, thus being well suited for resource-constrained sensor nodes. Furthermore, it can be integrated into WSNs based on IEEE 802.15.4 without requiring any modification to the standard. We show that ADAPT is effective, in the sense that it can satisfy a target reliability constraint while consuming low energy, and its performance is near-optimal for a wide range of operating conditions, for both single-hop and multi-hop networks.

II. RELATED WORK:

There exists literature about cross-layer frameworks and adaptive approaches to data collection in WSNs. This section briefly reviews the related work. As mentioned, energy efficiency is one of the major concerns in WSNs [4]. In addition to providing optimized solutions specific to a single layer of the protocol stack, various cross-layer approaches have been proposed in the literature [9]. Most of these approaches focus on the joint optimization of the physical and MAC layers, or the MAC and networking (e.g., routing) layers. For instance, the activity management scheme presented in [10] jointly exploits the MAC and the physical layer. In addition, only a limited number of works specifically deals with the IEEE 802.15.4/ZigBee standards.

A cross-layer optimization framework is proposed in [11] based on an experimental analysis of interference in IEEE 802.15.4 networks. However, the focus is mostly on the physical layer in the form of power control. Finally, only limited literature jointly evaluates the impact of the network/application layer on the performance of IEEE 802.15.4 networks.For instance, the impact of different sleep/wakeup scheduling policies in multichip WSNs is investigated in [7], with special focus on ZigBee networks. Although the authors provide hints on how to tune the IEEE 802.15.4 MAC layer, the investigated solution is not adaptive, nor does it support application-specific reliability requirements.

Alongside, relatively less attention has been paid to reliability guarantees in WSNs. In the context IEEE 802.15.4- based WSNs, many papers [12], [13], [14] highlighted that a significant share of transmitted messages may be lost due to contention, especially when the number of sensor nodes and the message size are large. In addition, [6] and [7] have shown that serious reliability issues arise when power management is enabled, even in networks with a small number of sensor nodes. It is also shown that a suitable setting of the MAC parameters can alleviate the problem, such that it is possible to achieve a target level of reliability, as well as a higher energy efficiency. However, [7], [6] are based on static (i.e., pre-defined) settings for the MAC parameters, hence they are not flexible enough to support dynamic operating conditions.

In addition, a static parameter setting typically results in an energy consumption higher than necessary. An adaptive mechanism for reliable and adaptive data collection in IEEE 802.15.4-based WSNs has been proposed in [15]. This solution is based on an optimization problem built on top of an analytical model of the IEEE 802.15.4 standard [16]. As a result, the proposed approach has significant computational and storage overheads, which make it unsuitable for implementations on real sensors.

A. Our contributions:

In this paper we design and develop an adaptive and crosslayer approach for data collection in IEEE 802.15.4/ ZigBee WSNs. Different from most solutions available in the literature, our approach is specifically suited for the IEEE 802.15.4 and ZigBee standards. In contrast with many approaches such as [12], our scheme does not require any modification to the IEEE 802.15.4 MAC protocol, and hence can be implemented in real sensors even when the MAC protocol cannot be altered. Furthermore, unlike [7], [6], our scheme is adaptive, hence it can tailor the operating parameters – e.g., the backoff window size and the number of (re)transmissions – according to the actual traffic demands. In addition, it is flexible since it supports diverse policies for enforcing the required level of reliability. In this paper, we extend the work in [8] by considering the message loss due to a noisy channel. Furthermore, we explicitly address multi-hop scenarios, also in contrast with most

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of the existing solutions which are limited to single-hop (star) networks [6], [15]. Simulation results show that our proposed approach is effective, in the sense that it can satisfy a target reliability constraint while achieving low energy consumption (and low latency) in both single-hop and multi-hop scenarios, even when the message loss is high. At the best of our knowledge, this is the first solution tailored to IEEE 802.15.4/ZigBee WSNs which is able to effectively tune the MAC parameters and overcome the reliability problem of the MAC protocol [17] in an energy-efficient way.

II. DEVELOPED WIRELESS ENVIRONMENT MONITORING SYSTEM:

Wireless environment monitoring (WEM) system is an on-line data recording and measurement embedded device which is mainly able to perform the measurements of air quality [9], [10]. Fig. 1 depicts the block diagram of the WEM system. The wireless transducer interface module (WSTIM) is linked to wireless network capable application processor (WNCAP) through zigbee communication. The developed WEM system can be used of detecting the concentration level of greenhouse gases such as SO2, NO2, CO, CO2 , O2 with environmental parameter (temp. and humidity). The sensors output are processed through signal conditioning circuit and the integrated signals are connected to the inbuilt ADCs channel of the processor.

After processing and integration, the sensors results are sent to a network capable application processor (NCAP) PC through zigbee module and are also saved in micro memory card (MMC) according to transducer electronic data sheet. The results are displayed on the graphical user interface (GUI) running on a PC. The mentioned design of WEM system is a self-contained unit which makes it relatively easy to add extra sensor nodes.

III. IMPLEMENTATION OF WSTIM:

A wireless smart transducer interface modules (WSTIMs) or wireless sensor nodes consist of several components such as sensor with signal processing circuit, a power supply unit, memory, and a transceiver unit [21]. The wireless sensor node is designed based on the IEEE802.15.4 and IEEE1451.2 standards and an array of electrochemical sensors are used [22]–[24]. developed wireless sensor module is capable of communicating with NCAP through zigbee, handling the actuators interface, and supporting transducer interface electronic data sheet (TEDS). The developed seven sensing modules are connected to the seven channels of the proposed design node and used the ADC bus. Also, three channels are free for the used in the near future. A PIC 18F4550 microcontroller is chosen to support all above functions and to support the development of the node. The power consumption of the developed sensor node in transmission (TX) mode was measured to be 83.6241mW. The block diagram and photograph of the developed WSTIM or wireless sensor node is shown in Figs. 2 and 3 respectively. In the next section, all components are described in details.

A. Sensor Unit:

The sensing unit is the main components of a wireless sensor node that differentiates it from any other embedded system with communication capabilities. The sensing unit is also a combination of several sensors known as sensor array [8]. In this section, focus is placed only on energy efficient gas sensor array. A gas sensor is a device that transforms the concentration of the gas into an electric signal [9]. Generally, five technologies are used for monitoring the concentration of gases such as catalytic bead, infrared, photoionization, solid

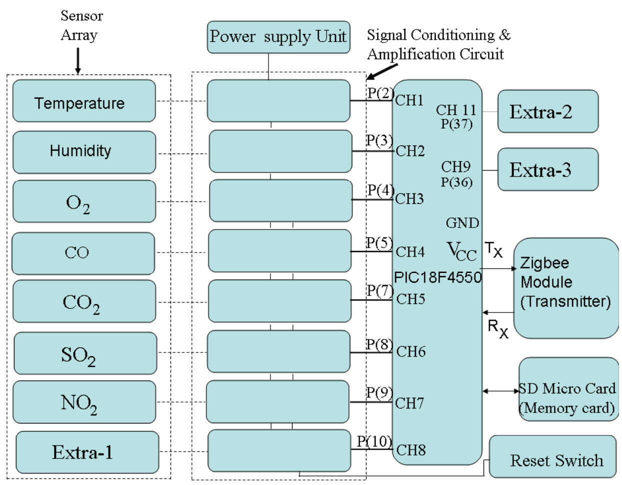

Fig. 2. Block diagram of WSTI module or wireless sensor node.

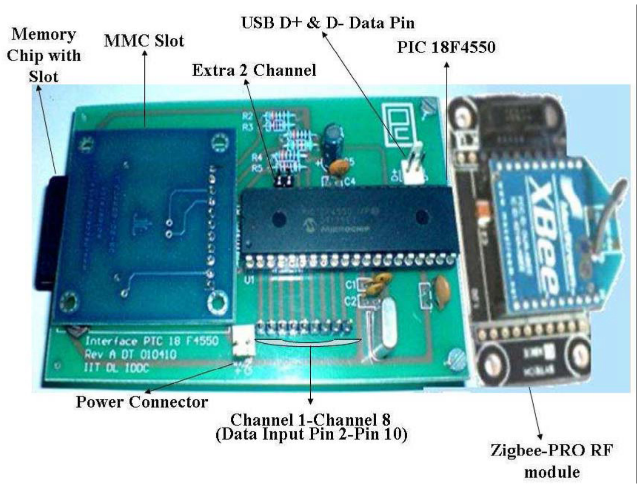

Fig. 3. Photograph of WSTI module or wireless sensor node.

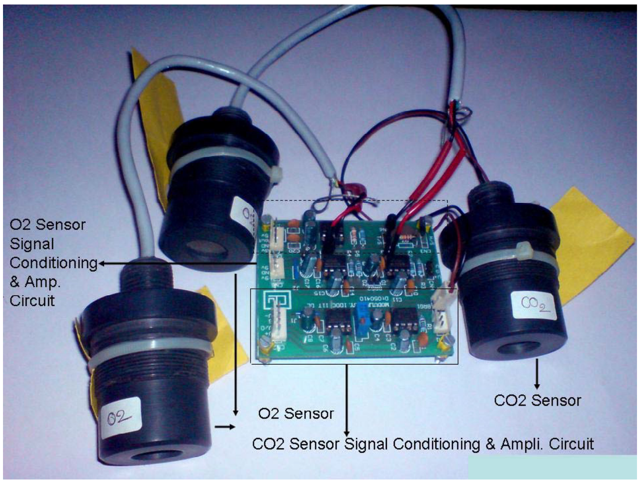

Fig. 5. Photograph of O2 and CO2 sensor module.

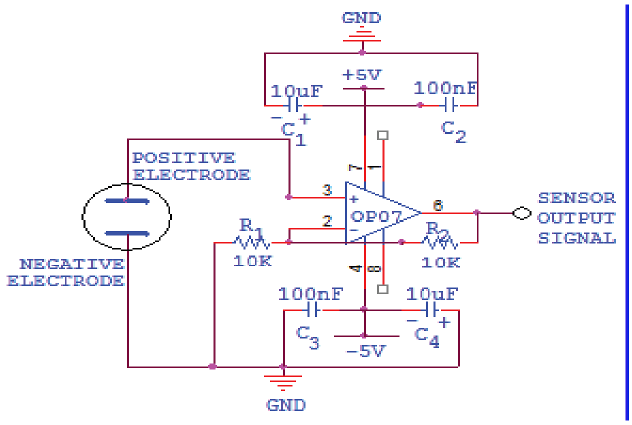

Fig. 6. Schematic diagram of O2 sensor module.

state, and electrochemical [9], [10]. Detailed information on these technologies and gas sensors, such as, advantages, disadvantages, usage, and life time is reflected in [25] and [26]. We may note that the electrochemical sensor have low cost, low power consumptions, single gas detection property with high accuracy, good selectivity, no effect of the environmental parameter fluctuations, excellent repeatability, and miniature as compared to solid-state, photoionization, catalytic bead, and infrared. The major drawback of the electrochemical sensor is extremely sensitive of the EMF/RFI. In this sense, these sensors are attractive for use in different areas such as space, environment, forestry, agriculture, and automobile [27]–[29]. The sensor specifications of the used in the development of WEM system could be found in [29]–[31].

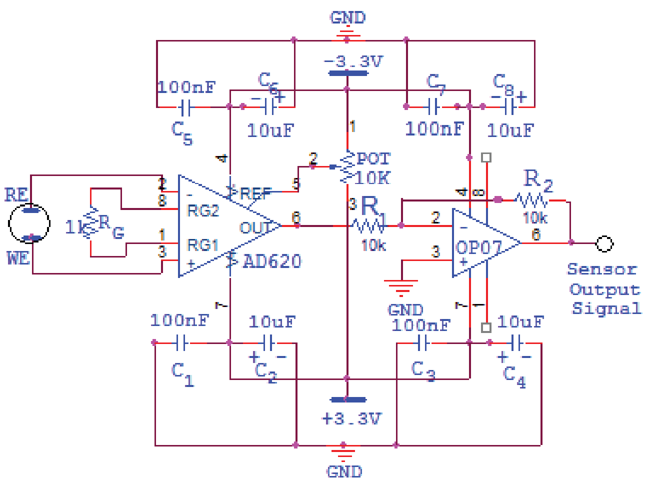

Fig. 4. Schematic diagram of CO2 sensor module.

negative electrodes. This circuit consists of a non-inverting amplification circuit based on OP07 with a fixed gain of 2. The schematic and a photograph of the developed module are shown in Figs. 5 and 6, respectively. The operating voltage range of the developed module is from ±5.0V to ±9.0V. It is operated at a fixed voltage of ±5.0V and the proportionality factor is fixed at 13.93. The response time and power consumption of the developed sensor module were

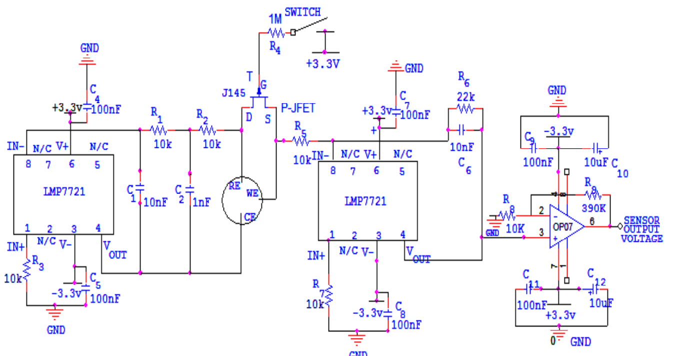

Fig. 7. Schematic diagram of SO2-D4 sensor module.

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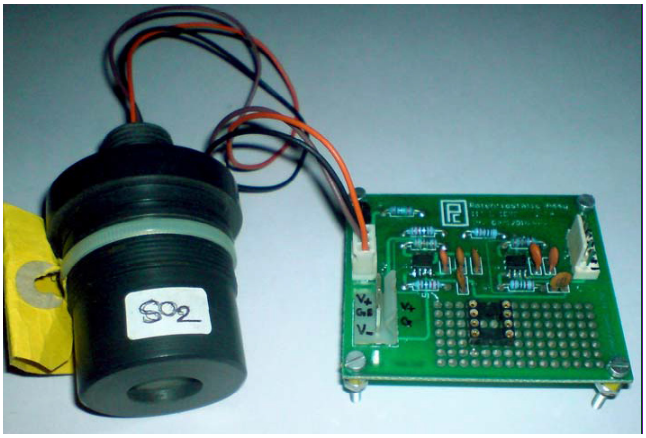

Fig. 8. Photograph of SO2-D4 sensor module.

observed to be 300sec and 3.6292mW, respectively. The gas sensing range of the developed module is set from 15% to 65%.

3) SO2-D4 Sensor Module: In this module, the amplifier LMP7721 is used in the controlling and measuring circuits while the OP07 is used in the amplification circuit. The guarding and multi-core PCB techniques are used in potentiostatic circuit layout to reduce the parasitic current. The input pins of LMP7721, are fully guarded (a guard is a low impedance conductor that surrounds an input line and its potential is raised to the input line voltage).

The operating voltage range of the developed module may vary from ±2.0V to ±3.3V. It is operated in this application at fixed voltage of ±3.3V and also the proportionality factor is fixed 0.55. The load resistance (R5) is fixed at 10.0K_ in the measuring circuit. The output of the measuring circuit is applied to the input of the non-inverting amplifier with a fixed gain of 40. The response time and power consumption of the developed sensor module were observed to be 40sec and 0.72mW, respectively. The gas sensing range of the developed module is set from 0.04ppm to 2ppm. The schematic diagram and a photograph of the developed module are shown in Figs. 7 and 8, respectively.

4) CO Sensor Module: The CO-CF sensor module is built in the same manner as the SO2–D4 module. The load resistance (R5) is fixed at 33.0_ for the measuring circuit and the output of the measuring circuit is applied to the input of a noninverting amplifier with a fixed gain of 48. The response time and power consumption of the developed sensor module were observed to be 60sec and 9.0936mW, respectively. The gas sensing range of the developed module is set from 0.5ppm to 20ppm and the proportionality factor is fixed at 4.1.

5) NO2 Sensor Module: The NO2 sensor module is built in the same manner as the SO2–D4 module. The load resistor (R5) is fixed at 20.0_ for measuring circuit. The output of the measuring circuit is applied to the input of the non-inverting amplifier with a fixed gain of 33.0. The response time and power consumption of the developed sensor module were observed to be 60sec and 11.2712mW, respectively. The gas sensing range of the developed module is set from 0.01ppm to 0.5ppm and the proportionality factor is fixed at 0.1046.

6) Temperature Sensor Module: The response time and power consumption of the developed sensor module were observed to be 2sec and 1.7673mW, respectively. The temperature range of the developed sensor module is set from 15°C to 70°C.

7) Humidity Sensor Module: The response time and power consumption of the developed sensor module were observed to be 15sec and 1.0mW, respectively. The humidity range of the developed sensor module is set from 0% to 100%.

VII. CONCLUSION:

In this paper, we present a low cost, and energy efficient prototype of a wireless environment monitoring system. The prototype system consists of the communication module, the wireless smart transducer interface, and wireless network capable application processor modules. These modules are successfully developed based on the IEEE802.15.4, IEEE1451.2 and IEEE1451.1 standards. This prototype system is tested for the monitoring of greenhouse gases and environmental parameter in-situ and open environment. In the signal processing circuits, the PVC holder based sensors, low (<5nA) input bias current amplifiers, multicore PCB, and calibration switch are used for the requirement of low power consumption, low cost, ease of operation, low EMI/RFI noise, and miniaturization. The total power consumption of the developed WEM system is found to be 83.6241mW. The power consumption and cost of the developed WEM system is far less than the existing systems. In addition the performance and quality of measurements of the developed system is better as compared to the existing systems.

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For further study, the RF interference in the 2.4 GHz can be alleviated by considering other frequency bands such as the 433 MHz which can be achieved through the new DASH7 [38] communication technology.

This technology presents better penetration through walls, which is important for indoor applications. In addition, the WSN will be explored in the area of green building such as built environment monitoring management, elder carrying, and harvesting power management.

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