# Prototypes of Opportunistic Wireless Sensor Networks Supporting Indoor Air Quality Monitoring

Petros Spachos *, Liang Song*,§ and Dimitrios Hatzinakos*
*Department of Electrical and Computer Engineering, University of Toronto, Toronto, ON M5S 3G4, Canada
E-mail: {petros,songl,dimitris}@comm.utoronto.ca
§OMESH Networks Inc., Toronto Ontario, Canada

***Abstract*—In this demonstration proposal we describe a prototype of a Wireless Sensor Network (WSN) for monitoring the air quality of an arbitrary indoor infrastructure environment. Specifically, the proposed demonstration deals with an application of wireless mesh networks for monitoring the carbon dioxide ($CO_2$) levels of an indoor environment, supporting guaranteed real-time data acquisition and display. In the proposed demonstration we will illustrate a number of advantages of opportunistic routing, including dynamic node deployment and dynamic routing path selection, opportunistic resource utilization, robustness to interference and guaranteed multi-hop QoS (Quality of Service) for an indoor gas concentration monitoring network.**

## I. INTRODUCTION

Environments monitoring and control represents the next evolutionary development step in building, utilities, industrial, home, shipboard, and transportation systems automation. First and foremost it relies on sensory data from the real world, which comes from multiple sensors of different modalities in distributed locations. As a consequence, environments monitoring and control needs information about its surroundings as well as its internal workings.

The challenges of detecting the relevant quantities, monitoring and collecting the data, assessing and evaluating the information, formulating meaningful user displays, and performing decision-making and alarm functions are enormous. Therefore, a lot of human, financial and material resources have been invested in gas monitoring during the last decade. Traditional gas monitoring systems use wired sensor networks. Under the condition that the same information can be delivered, processed, and received properly, modern Wireless Sensor Networks (WSNs) are more desirable to have little human interaction to eliminate human errors (such as misuse of equipment and carelessness during operation), reduce risks and increase efficiency.

The proposed demonstration shows that the technology of cognitive networking, [1], along with opportunistic routing, [2], and the potential of an easily deploying and inexpensive wireless sensor network can alleviate the problem.

## II. DEMONSTRATION PROTOTYPE

The proposed demonstration is a prototype based on the cognitive networking technology for WSNs, supporting real time data collection. It is implemented with Zigbee radio (IEEE 802.15.4) [3], which contributes to a practical demonstration space requirement due to the much smaller radio range.

This work was supported in part by the Natural Sciences and Engineering Research Council of Canada (NSERC), and by the MRI-Ontario under an ORF-RE grant.

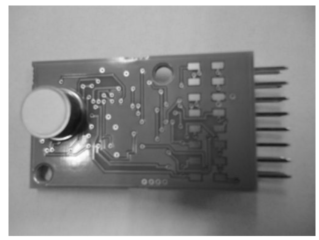

Fig. 1: iAQ-2000 sensor

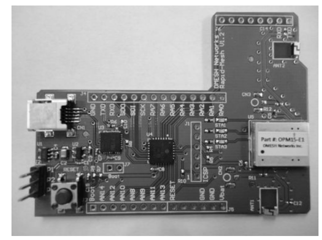

Fig. 2: OPM15 radio.

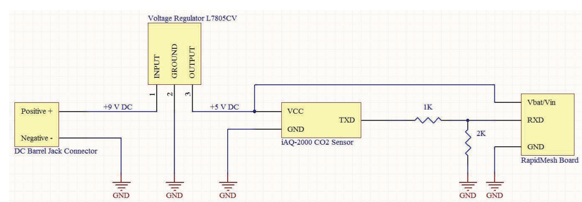


Fig. 3: Circuit schematic

A number of prototypes are located in an indoor environment, monitoring the gas concentration. The transmission range of each prototype can vary between 10 to 50 meters, according to the network configuration. For an office environment, with many obstacles and the non-line-of-sight (NLOS) problem, a small transmission range is preferable, because the communications can be conducted through reflections and diffractions. The purpose of the demonstration is to have a control room which monitors in real time the gas concentration in different locations of the office.

The system consists of the following three modules:

*i) Sensor module:* Indoor air quality sensor nodes, by Applied Sensor, are used for data collection. iAQ-2000 sensors can measure temperature, humidity and carbon dioxide ($CO_2$) levels. It is a sensitive, low-cost solution for detecting poor air quality in an indoor environment. Figure 1 shows an iAQ-2000 sensor node.

The node keeps monitoring the gas concentration ($mol/m^3$) in the environment. The collected data are feeded to the radio node, through a electronic circuit, shown in Figure 3, to properly form data packets and transmit them to the control room.

*ii) Radio module:* Radio nodes from OMESH networks are

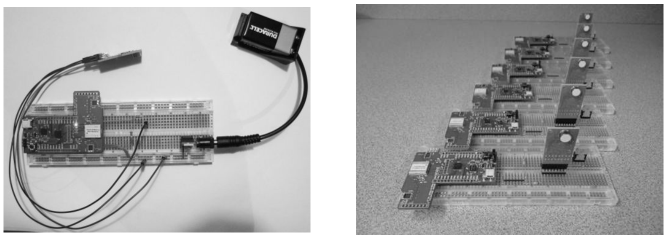

Fig. 4: Prototype

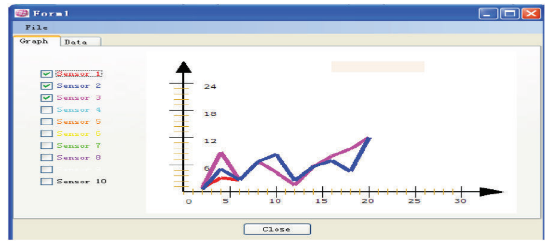


Fig. 5: Graphical User Interface.

used for the wireless data transmission. RapidMesh OPM15 Development Platform is an open-source embedded platform that provides the tools for rapid wireless application development with the OPM15 radio module. Figure 2 shows an OPM15 radio node while the operation parameters can be seen in Table I.

The node process the gas data that are reported from the sensor and forms the DATA packet that will be transmitted. Its packet consists of the gas data, the reported time and a unique ID. When the data packet has been formed, it will remain in the buffer of the node, waiting to be transmitted.

At communication level, the radios have been implemented with multi-channel collision avoidance method [2]. When the radio is idle, the node will opportunistically transmit the data to the best available neighbor node at that time. At application level, the radios works on unicast mode, following an opportunistic routing protocol, [4], with opportunistic spectrum access. Each node will keep transmitting the DATA packet toward the control room.

*iii) Data aggregation interface:* The graphical user interface (GUI) module run at a workstation in the control room. The workstation is connected with a radio, through serial port, and receives the real-time data from the different nodes and feed them into the data tables and graphs. Figure 5 shows an instance of the GUI. The interface will report the gas concentration in real time and can perform special actions, i.e. require more data from a node that report a gas concentration that over exceeds a predefined threshold.

The development board of the prototype can be seen in Figure 4. The iAQ-2000 sensor requires a $5V$ power supply. Each prototype is powered by a $9V$ battery, which provides a $5V$ output to the RapidMesh board and iAQ-2000 sensor via the L7805CV voltage regulator. The radio at the control room which is connected to the workstation is powered via USB.

During the demonstration, $5$ prototypes are distributed in an indoor environment, monitoring the gas concentration. The distance between the prototypes can vary between 2 to 20 meters. The collected data are transmitted through OPM15 radio nodes to a laptop, where the data are stored, processed and displayed in real-time with a developed graphical user interface.

| Parameter | Value |
|---|---|
| $Frequency\ Ranges$ | $2405MHz$ $to$ $2483MHz$ |
| $Bandwidth$ | $5MHz$ $per$ $channel$ |
| $Peak\ Input\ Power\ to\ Antenna$ | $3mW$ |
| $Antenna\ Pollarization\ and\ gain$ | $2dBi\ Vertical\ Polarization$ |
| $Waveforms$ | $QPSK$ |

TABLE I: Operational Parameters

## III. TECHNOLOGY ADVANTAGES

The technological advantages of the proposed demonstration are summarized in the following:

*i) Dynamic node deployment and dynamic routing path selection*. The network topology is random while all the prototypes have a dynamic "drop-and-play" nature which is of high importance in cost-saving infrastructures. For instance, in a large-scale indoor network, the installation or replacement of sensitive sensor nodes would not require to reconfigure the whole network.

*ii) Opportunistic resource utilization*. DATA packet transmission follows an opportunistic routing protocol. Opportunistic routing is an energy efficient and reliable dynamic routing protocol, especially for indoor environments, [4].

*iii) Robustness to interferences*. The use of the opportunistic routing along with the opportunistic spectrum access, can provide the necessary robustness toward interference. Operation within unlicensed bands can result in large network capacity.

*iv) Guaranteed multi-hop QoS*. Cognitive networking can guarantee dataflow over multiple hops, in terms of throughput and end-to-end delay. These factors are crucial in a wireless sensor network for gas detection. It is only requires sufficient network resources being deployed to cover the monitoring area. After testing the prototype, the error rate is less than $3\%$ and the delay is minimized, less than $0.5s$.

## IV. CONCLUSION

A demonstration of opportunistic routing in wireless sensor networks is introduced, along with the technological advantages that can be shown. WSNs have become an attractive solution for a plethora of communication applications, especially for event monitoring and tracking. Opportunistic routing can provide multiple advantages for higher performance in WSNs.

## REFERENCES


[1] Liang Song and Dimitrios Hatzinakos, "Cognitive networking of large scale wireless systems," *Int. J. Commun. Netw. Distrib. Syst.*, vol. 2, no. 4, pp. 452–475, June 2009.

[2] P. Spachos, Liang Song, and D. Hatzinakos, "Opportunistic multihop wireless communications with calibrated channel model," *IEEE International Conference on Communications (ICC)*, 2012.

[3] IEEE Standard for Local and Metropolitan Area Networks Part 15.4 (802.15.4), ," *Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (LR-WPANs) (Amendment of IEEE Std 802.15.4-2003)*, 2006.

[4] P. Spachos, F.M. Bui, Liang Song, Y. Lostanlen, and D. Hatzinakos, "Performance evaluation of wireless multihop communications for an indoor environment," *IEEE PIMRC*, pp. 1140 –1144, Sept. 2011.