Poster – Cognitive Networking in a Self-Powered Wireless Sensor Network Testbed

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ABSTRACT

Scalability and sustainability are two fundamental requirements in Wireless Sensor Networks (WSNs). Inch scale sensor nodes can operate unattended for long periods if they have sufficient energy sources. In this work, a Self-Powered Sensor Network (SPSN) testbed is introduced. SPSN is cost-efficient and has large-scale deployability. It combines cognitive networking principles with efficient routing approaches and energy harvesting techniques. SPSN is used for indoor CO_2 monitoring as well as for outdoor gas leak detection. The performance of the system for channel estimation at an outdoor environment is examined. Experimental results show that SPSN can be used for a plethora of other applications as well.

Categories and Subject Descriptors

C.2.1 [**COMPUTER-COMMUNICATION NETWORKS**]: Network Architecture and Design—*Wireless communication*

Keywords

Cognitive radio networks; Testbeds; Self-powered wireless sensor networks; Routing protocols;

1. INTRODUCTION

Characterized as one of the key technologies contributing to the so-called "digital evolution", modern Wireless Sensor Network (WSN) platforms are endowed with the ability to create networked artifacts (human and non-human) to sense their environment, and accordingly adapt their behaviour in beneficial manners. The potential applications are numerous, including effective monitoring and sustainable governance in structural health, disaster relief, transportation, law enforcement, and public safety and security.

A major rationale for these WSN technologies is that they can enable the users to make decisions in a "smarter", more "aware" and "responsive" manner [3]. Indeed, a distributed monitoring capacity gives us a "novel" visualization of our environment that allows more effective planning: the ability to respond in a more timely fashion, and to develop more effective actions to resolve environmental problems. The social and economic implications can be enormous, not only for public but also for private organizations. Evidently, this technological innovation impacts many aspects of human life: health and safety, information and communications, energy and environment, as well as security, to name a few.

However, while there are irrefutable advantages to be reaped with the WSN infrastructures, these strategic values are not without caveats. On the one hand, the larger a sensor network becomes, the smarter and more responsive we become, as our visualization becomes more global and informative. On the other hand, as the size of the network increases, so does the associated complexity and management [2]. To facilitate deployment and acceptance of such networks, the sensor nodes must be inexpensive, non-intrusive, and communicate effectively. Together, these conditions imply two fundamental requirements that influence the operation of the network: scalability and sustainability. Without these two requirements, the operation and impact of the WSN would be questionably limited, if not short-lived.

Motivated by the WSN tremendous potentials, coupled with the technological limitations affecting the current WSN platforms as described above, in this work a Self-Powered Sensor Network (SPSN) testbed is introduced. The SPSN testbed consists of self-powered wireless sensor nodes. The nodes can operate indoor with batteries and outdoor with a solar system [1], depending on the application requirements.

2. SYSTEM FRAMEWORK

In this section, an application scenario is given followed by the system requirements and the system models of the introduced SPSN framework.

2.1 Application scenario

A self-powered WSN monitoring application is considered. The application can be indoor or outdoor. A number of wireless sensor nodes along with a number of simple relay nodes are deployed in the monitoring area. Each node is equipped with a sensor module and a wireless transmission module. The data from the sensor module are passed to the transmission module which forwards all the necessary data to the control room, through the relay nodes. The relay nodes have the same wireless transmission module with the sensor nodes however, they only have communication capabilities. Both the sensor units and the relay nodes are battery powered for indoor applications. For an indoor application, a monitor-

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ing system of CO_2 levels in a building is considered. For outdoor systems the units are equipped with solar panels and perform energy scavenging. For an outdoor application a gas leak detection system is studied.

2.2 System requirements

A monitoring system has a number of requirements, depending on the application scenario. Apart from general system requirements, such as the size of the units and the cost per unit, at the network level, the proposed system has the following requirements:

- *Real-time data aggregation.* The packets related to the CO_2 levels or the gas leakage, should be delivered to the destination on time with a minimum delay.

- *Energy efficient sensor units.* The units should operate unattended for long periods of time and hence, the network lifetime is important. An energy conserving routing protocol should be applied.

- *Drop-and-play units.* The units should be able to join or leave the network at any time.

- *Location information.* The location of the even should be included in the packet towards the destination. Location information can be acquired with the use of a number of techniques.

- *Coexistence problem.* The system should have minimum interference with other infrastructures. Especially in the indoor case, the system should be flexible in the spectrum selection and not interfere with other WLANs.

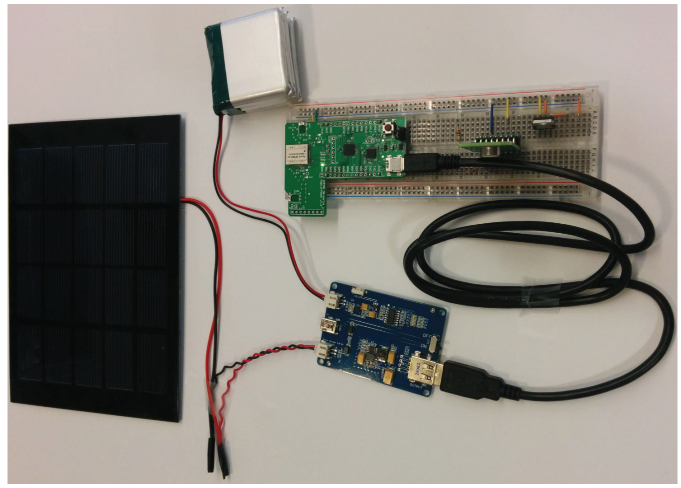
2.3 System Modules

SPSN framework has three important modules: the *sensor units*, the *relay nodes* and the *control room*. In the following, a brief description of each module is given.

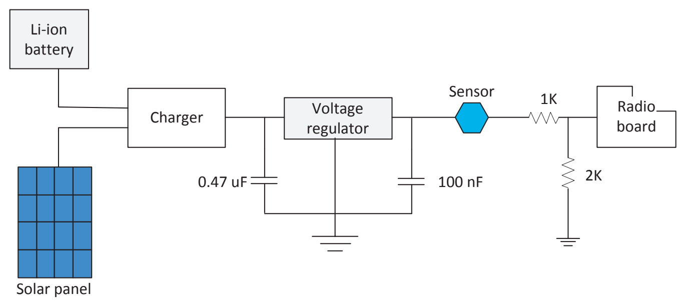
- **Sensor unit.** The sensor unit is the monitoring module. It consists of a prototype radio board [4] that has two antennas and performs the spectrum sensing and the routing protocol. Also, it has a sensor node attached. The sensor can monitor the concentration of CO_2 as well as gas leakages, temperature and humidity. The development board (the sensor and the radio), is connected either to a $9V$ battery (indoor) or to a solar system (outdoor), depending on the application. The solar system consists of a photovoltaic solar panel with operating voltage $5V$ and operating current $560mA$. The panel is connected to the rechargeable battery through a charger. The battery is a polymer lithium ion battery of $6600mAh$ and $3.7V$. The sensor unit with the solar system is shown in Fig.1(a) along with the schematic diagram with the connection of the different components in Fig.1(b). For the indoor system, a battery is connected right before the Voltage regulator in Fig.1(b).

- **Relay node.** The relay node has the same radio board with the sensor unit. This module however, does not have a sensor. Hence, the total energy consumption is lower. It performs the main packet forwarding and uses either $2AA$ batteries or a solar system. Periodically, the relay nodes broadcast advertisement packets. In this way, the network maintains location information about the sensor units, through Received Signal Strength Indication (RSSI) values and information about nodes which joined or left the network. The relay node is shown in Fig.2 its specifications are shown in Table 1.

- **Control room.** This is a radio board connected to a computer. This radio board is the destination of all the packets. When a packet arrives, the radio decomposes it and forwards the necessary information to the GUI. The GUI displays location and monitoring information regarding the relay nodes and the sensor units in real time. For the location we use the RSSI values of the different packets and a simple triangulation method.



(a) Sensor unit for outdoor applications.



(b) Circuit Schematic.

Figure 1: SPSN can operate both indoor and outdoor. In (a) is an example of an outdoor sensor unit along with its circuit schematic in (b).

3. EVALUATION

SPSN represents our second generation Cognitive Radio Network (CRN) routing testbed architecture. In particular, SPSN testbed composed of:

- 50 relay nodes and 20 sensor units,

- units and nodes can work outdoor with solar panels or indoor with batteries,

Table 1: Radio board specifications.

Parameter	Unit	Value
Radio range	$meters$	20
Frequency range	GHz	2.405-2.483
Bandwidth	MHz/channel	5
Receiver sensitivity	dBm	-94
Transmitting power	dBm	-25
Power Cons. (Sleep)	uA	1
Power Cons. (Work)	mA	25

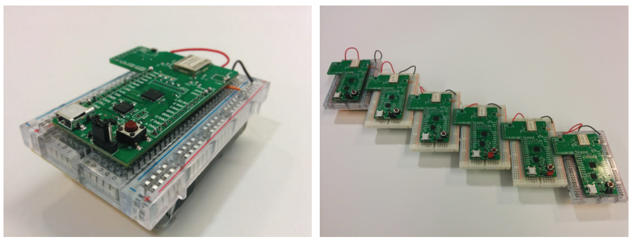


Figure 2: Relay nodes.

- remote access to the testbed for centralized control and management,
- open source protocol library for easy deployment and
- enhanced GUI for localization and monitoring applications.

To evaluate the performance of SPSN, outdoor experiments were performed. A channel estimation at an outdoor environment was conducted. Three channels were used for the radio boards. For the experiment 31 relay nodes were used. The nodes were placed in a straight line with 1 m distance between them. Each unit broadcasted packets for 2 $min.$. From the packets the RSSI value [5] was extracted. 4480 values were collected with an average of 154 values in each distance. For the theoretical calculation of RSSI the following formula was used:

$$RSSI(d) = -10 \times n \times log(d) + A \qquad (1)$$

where n is the propagation path loss exponent, d is the distance from the sender and A is the received signal strength at one meter of distance.

Table 2 shows the theoretical value, the average RSSI value and the standard deviation (SD) for 10 distances. The results for all the distances can be seen in Fig. 3.

As it can be inferred from the results, the experimental results are close to the theoretical for an outdoor application. Hence, SPSN can provide realistic results for channel estimation at an outdoor environment.

4. CONCLUSIONS AND FUTURE WORKS

In this work, a Self-Powered Sensor Network (SPSN) system is proposed. The main components of the system were described. Also, the performance of the system for a channel estimation at an outdoor environment was examined. The experimental results are promising.

Further study on the performance of SPSN at a complex indoor environment should be conducted. Moreover, the performance of the nodes under a non-line-of-sight model should be examined. Finally, some optimizations on the tool should be made before the SPSN testbed becomes publicly available for research projects.

Table 2: Distance, theoretical and experimental RSSI and SD.

Distance	Theoretical [dBm]	Exp. [dBm]	SD
3 m	-52.88	-50.14	1.32
6 m	-61.01	-56.77	1.48
9 m	-65.76	-62.11	1.53
12 m	-69.13	-67.21	1.02
15 m	-71.75	-69.04	1.62
18 m	-73.89	-72.67	1.32
21 m	-75.69	-72.86	1.13
24 m	-77.26	-74.97	1.41
27 m	-78.64	-76.22	1.09
30 m	-79.88	-77.1	1.02

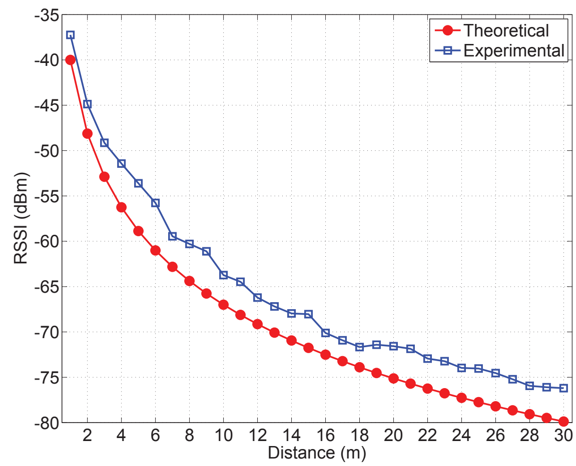


Figure 3: Comparison of theoretical and experimental RSSI.

5. ACKNOWLEDGEMENTS

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