Self-Powered IoT Device for Indoor Applications

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Abstract— **This paper presents a proof of concept for self-powered Internet of Things (IoT) device, which is maintenance free and completely self-sustainable through energy harvesting. These IoT devices can be deployed in large scale and placed anywhere as long as they are in range of a gateway, and as long as there is sufficient light levels for the solar panel, such as indoor lights. A complete IoT device is designed, prototyped and tested. The IoT device can potentially last for more than 5 months (transmission interval of 30 seconds) on the coin cell battery (capacity of 120mAh) without any energy harvesting, sufficiently long for the dark seasons of the year. The sensor node contains ultra-low power sensors for temperature, humidity and light levels, with the possibility of adding several more sensors.**

I. Introduction

Recent developments in semiconductor technology, integrated circuit (IC) technology and advancements in wireless technology enables the development of several applications related to wireless embedded systems and Internet of Things (IoT) devices. Wireless embedded systems such as wireless sensor networks (WSNs) has several applications, such as health care applications [1] and monitoring of industrial processes [2]. Internet of things (IoT) is essentially networking of smart embedded electronic devices which sense and exchange data without human intervention, with applications ranging from smart homes to industrial automation. It is expected that approximately 50 billion IoT devices will be connected by 2020. In majority of the WSNs and IoT applications, devices are powered by batteries with limited life time, ranging from hours to years. When these batteries are depleted, they need to be replaced or recharged. For devices in remote locations and harsh environments, it may not be possible to either recharge or replace the batteries. Energy harvesting from ambient sources is a viable solution to overcome these issues, especially for outdoor applications, however, it imposes many challenges in indoor applications, as the available ambient energy is drastically reduced. This paper presents a solution for an IoT device which is self-powered through energy harvesting from ambient sources for indoor applications.

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The paper is organized as follows. Section II describes the brief overview of the system level design. Section III presents the energy harvesting and power management. Prototyping, testing, measurements results are described in section IV and section V concludes the paper.

II. System Level Design

The design consists of sensor nodes communicating with a gateway node by using ultra low power (ULP) wireless communication as shown in Fig. 1. The sensor nodes consist of Arduino Pro Mini with nRF24L01 as 2.4GHz transceiver. An ESP8266, which also uses an nRF24L01, is used as a Wi-Fi gateway. A Raspberry Pi 3 receives data from the gateway through MQTT protocol, as well as storing and displaying the data.

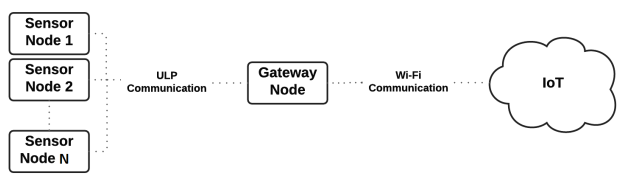

Fig. 1. Wireless data flow (Top level).

III. Energy harvesting and power management

In order to power the wireless sensor network (WSN), an energy harvesting (EH) module is designed. Power available from different EH sources varies greatly with different environments. Therefore, Proof of Concept models are made to test how much energy is available in the indoor environment at University of Agder. These results will define how often the sensor node can measure and transmit the data to the IoT server. The most viable sources for EH for this project are Photovoltaic (light) and RF (electromagnetic energy).

A. Photovoltaic energy harvesting

Harvesting electrical energy from light is commonly done with Photovoltaic (PV) Cells. Most PV cells are designed to be most efficient in natural light, with the sun as the source. Sunlight has higher intensity and provides a wider spectrum than what is found in artificial lightning, as shown in Fig. 2. Fluorescent light, illustrated as blue, covers a very narrow spectrum, while LED light covers a broader spectrum, but peaks at a shorter wavelength.

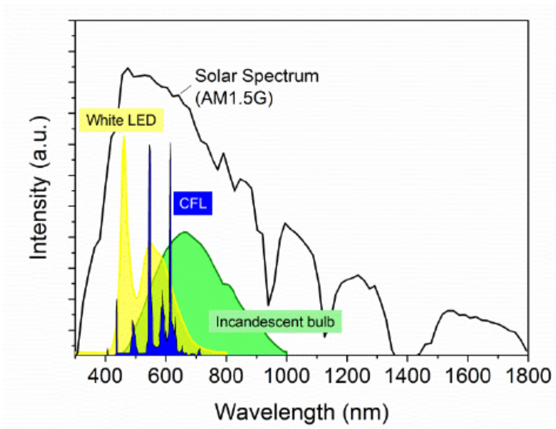

Fig. 2. Spectrum of different light sources

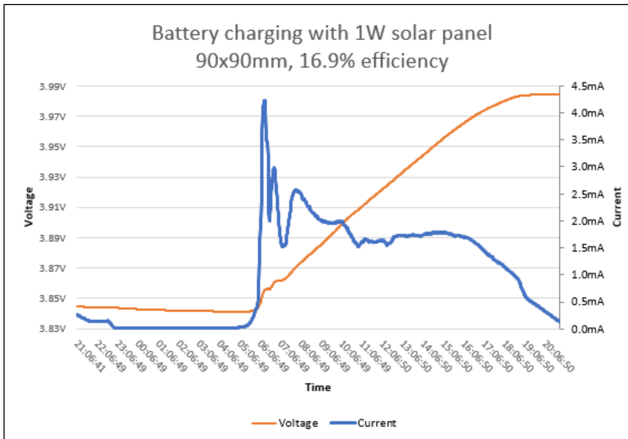

Fig. 3. Indoor test of 1W solar panel

B. Improving the output of PV cell

The output of a solar cell varies depending on light, load and temperature. To get the most of a PV-system, it is necessary to monitor output power and adjust load continuously through Maximum Power Point Tracking (MPPT). MPPT can be done with the open circuit voltage method, which can reach efficiency levels of more than 95% [3]. This involves measuring the open circuit voltage of the panel, and then regulating the load so that the output voltage of PV is set to a predefined percentage of an open circuit voltage.

A 90x90mm 1W epoxy-coated polycrystalline silicon cell panel is used for this prototype. Characterization of the panel at the Photovoltaics lab of University of Agder showed an efficiency of 16.9%. The maximum power point was measured at 80% of open circuit voltage.

C. RF energy harvesting

RF harvesting is the concept of collecting energy from electromagnetic signals in the air. Cell towers are continuously transmitting signals for mobile communication and TV-broadcasts. From measurements at University of Agder, it shows that harvested RF power is in range of 4-5nW indoors with a microstrip patch antenna designed for GSM frequencies. This is quite small compared to harvested solar energy, and is therefore not included in the prototype. It may however prove useful in other scenarios.

D. Power management

A 120mAh, 3.6V lithium ion coin cell battery is used for energy storage. BQ25570 is used for photovoltaic harvesting with MPPT, battery management and voltage conditioning [4]. It has a cold start voltage of 100mV, which is highly suitable for a solar panel in an indoor environment. During indoor testing the BQ25570, along with battery and the 1W panel, measurements showed an average current of 1.02mA, and an average power of 4.05mW, as shown in Fig. 3.

IV. Prototype Testing, Results and Discussion

Two sensors are included in the prototype. The HDC1010 which measures temperature and Relative Humidity (RH), and TSL2561 which measures light levels [5][6].

A full-scale test of the WSN setup was conducted for 7 days in the WISENET Lab at University of Agder. The setup consists of the sensor node, the gateway and the IoT server. The functionality of the WSN was successfully verified throughout the test, with no major errors except for a few missed transmissions at 20 meter range through one drywall. The sensor node, with a transmission interval of 30 seconds, consumed 135.3μW on average, while the harvested energy through the 1W solar panel was 4.05mW average. The transmission included sensor readings of light levels, relative humidity and temperature, as well as node ID.

V. Conclusion

A prototype IoT device has been developed based on modular approach and tested successfully. The EH levels using low cost solar panels with relatively small sizes proved sufficient. The power consumption of the wireless sensor node was found to be many times lower than the amount of harvested energy on average with 30 seconds transmission intervals when using the nRF24l01 transceiver. The IoT device can potentially last for more than 5 months (transmission interval of 30 seconds) on the coin cell battery without any energy harvesting, sufficiently long for the dark seasons of the year.

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