OPEN ACCESS

2nd International Electronic Conference on Sensors and Applications
15–30 November 2015

www.mdpi.com/journal/sensors

*Conference Proceedings Paper – Sensors and Applications*

# Power Efficiency Analysis in Internet of Things Sensor Nodes

**Vladimir Vujovic [1,*], Srdjan Jokic [1] and Mirjana Maksimovic [1]**

[1] Faculty of Electrical Engineering, University of East Sarajevo, Vuka Karadzica 30, 71123 East Sarajevo, Bosnia and Herzegovina; E-Mails: srdjan.jokic@gmail.com (S.J.); mirjana@etf.unssa.rs.ba (M.M.)

* Author to whom correspondence should be addressed; E-Mail: vladimir_vujovich@yahoo.com; Tel.: +387-57-342-788; Fax: +387-57-342-788.

*Published: 10 November 2015*

---

**Abstract:** Development of new technologies, particularly the Internet and Sensor Networks, creates a completely new paradigm of the Internet utilization, commonly known as "The Internet of Things (IoT)". The IoT can be defined as a worldwide network of "smart things" enabled to interact and communicate to each other, as well as with the environment, empowering better understanding of the "real/physical world" and discovering and extracting information about objects and actions that drive that world. Sensor nodes today can be looked as smart objects and therefore they can produce significant computational power which can be used for manipulating and processing collected information. Energy and power efficiency are essential factors in the design and operation of sensor nodes and there are a number of initiatives and tendencies to improve the power efficiency in variety of areas. Relying on the fact that the choice of control algorithm and location of the computational logic may strongly influence power efficiency, in this paper a prototype sensor node, empowered by using fuzzy logic in decision making process, is built and tested in real case environment scenario. Used fuzzy logic processing algorithm is based on predefined rules and can detect a temperature changes in order to ensure accurate and timely response in the case of fire presence. Comparative analysis of power efficiency has been done, and was carried out for best, worst and average case of timely depended temperature changes. The aim of the experiment is to show which solution is the optimal in the sense of energy consumption – implementation of computational logic on sensor node or on a remote host.

**Keywords:** power efficiency; Internet of Things; sensor node

---

## 1. Introduction

The Internet of Things (IoT) is an emerging paradigm and a cutting edge technology which goal is to enable things/objects to be connected anytime, anyplace, with anything and anyone ideally using any path/network. Interconnected sensor-based systems are a key enabler in the realization of an IoT vision. Therefore, by populating the environment with real-world sensor-based devices, the IoT is opening the door to exciting possibilities for a variety of novel applications.

Energy is one of the most crucial aspects in real deployments of sensor networks. A sensor node integrates sensing, processing and communication subsystems and the optimization of energy consumption is generally a hard task in sensor networks since it involves not only reducing the energy consumption of a single sensor node but also maximizing the lifetime of an entire network.

The minimizing of sensor networks' power consumption is becoming increasingly significant, especially in a situation where many countries are independently developing programs of improving efficiency of power network and power supplies. The energy efficiency and power consumption for various devices are defined in several different conditions of work. In case of load applications, it would imply also efficiency at different levels in relative to the rated power of the device. The energy consumption of the sensor nodes largely depends on protocols the sensors use for communications [1–3]. On the other side, energy consumption is increased by execution of complex algorithms, and in the process of design and building a smart information system, it is crucial to choose the optimal location (sensor nodes or remote processing unit) for implementation and execution of the computational logic. In general, energy efficient applications are taken into account two aspects: hardware and software, to reduce power consumption [4–7]. Fundamentally, there are also various approaches to gather the information from the observed device. The first one, hardware based approach, which consists of a series of measurements of voltage, current and electric power from the system and the second approach based on the energy consumption models.

In order to give some recommendations to developers and optimize the energy spent of sensor nodes, it is also very significant to analyze computational power which increases cost per unit, and what is more important raises energy consumption which is still a primary limiting factor. Therefore, the remainder of the paper is structured as follows. Section II introduces a problem definition (energy consumption in the logical part of the sensor node and execution of the complex algorithms) as well as adequate measurement and acquisition system. The results of measurements and analysis are performed in Section III. Finally, Section IV concludes the paper.

## 2. Experiment Setup and Data Acquisition

Existing researches have shown that integration of soft computing technologies like fuzzy logic in sensor nodes seems to be a good idea because it can significantly lead to network performances improvements, above all to reduce the energy consumption and enhance the lifetime of the network [8,9]. Therefore, in this paper are used predefined fuzzy rules for detecting a temperature changes in order to ensure accurate and timely response in the case of fire presence. For determining the confidence of fire: previous temperature, current temperature and linguistic variable that serve as a temporal guard are used and the maximum number of rules is 50 [10]. Previous researches have shown that fuzzy logic allows detection algorithm to maintain a high accuracy level despite fluctuations in the sensor values. This feature provides fast and accurate event detection and decreases the number of false alarms and induces cheaper sensor node implementation [8,10].

For evaluation, testing and measurement power consumption of sensor nodes, it was necessary to build an experimental Data Acquisition System (DAQ). Based on novel concepts like IoT and cheap microcomputer, a *Smart Sensor Node* which possesses the power to process incoming data and communicate with clients over HTTP protocol is created. Hardware components used for building the system as well as their characteristic, are shown in Table 1.

**Table 1.** Hardware components.

| | Model | Characteristic |
|---|---|---|
| **Microcomputer** | Raspberry Pi Model B | Broadcom BCM2835, 512 MB SDRAM, 750 mA up to 1.2 A @ 5 V |
| **AD/DA converter** | PCF8591 | $I^2C$ bus 8-bit A/D and D/A converter |
| **Sensor (thermistor)** | 10kNTC | 3950 K, −20–105°C, Waterproof |
| **Power Supply** | HNP10L-Micro USB | Input AC: 100–240 V 50/60Hz 0.45 A Output DC: 5.0 V 2000 mA |

The operating system of proposed Raspberry Pi (RPi) sensor node is a Linux based distribution (*Raspbian Jessie*), which provides minimal resource consumption (memory and storage) and maximal customizability. To apply an IoT concept on RPi, a Java language is chosen as implementation language as well as Apache Tomcat 8 server, which is used for running Jersey 2.2 Framework (RESTful services). For greater precision of the DAQ system sampling rate for all measurements is 1 second, but the carrying out of Fuzzy logic rules is restricted on 30 second period.

During the experiment the following measurement equipment was used:

- AC/DC Power Quality Clamp Meter;
- Digital, USB Multimeters;

Therefore, to perform the experiment, hardware based measurement system to collect data from the experimental structure with single temperature sensor was implemented. Two different points of measurement are analyzed. The first is current and electric power consumption of the overall system, fed from the electrical power supply. Considered point was from the DC side of the power supply adapter that was operated below 50% of nominal current value. The second measurement point was the current and power consumption of the used temperature sensor. This measurement point is accompanied with the temperature measurement on acquisition system. Generally regarded, there were two separate measurements: one, on the system with fuzzy computational logic on the sensor node and two, on system with a remote processing unit on external computer. Both of measurements have three cases in term of temperature change. The first case concerns on measurement with stable temperature values. The second case involves minor changes in temperature, not exceeding ±20 °C. The third case analyses the impact of extremely large temperature fluctuations on power consumption. The system is based on the acquisition of one sensor, taking as the fact that the impact of a larger number of a sensors easily can be seen in the total consumption and the consumption change will be visible in both considered measurement, with integrated computational logic or not.

## 3. Results and Discussion

As mentioned above, the experiment was carried out for the best, average and worst case of timely depended temperature changes. Registered temperature from Measurement 1 (with computational logic on sensor node) and Measurement 2 (with computational logic on remote processing unit) are shown in Figure 1.

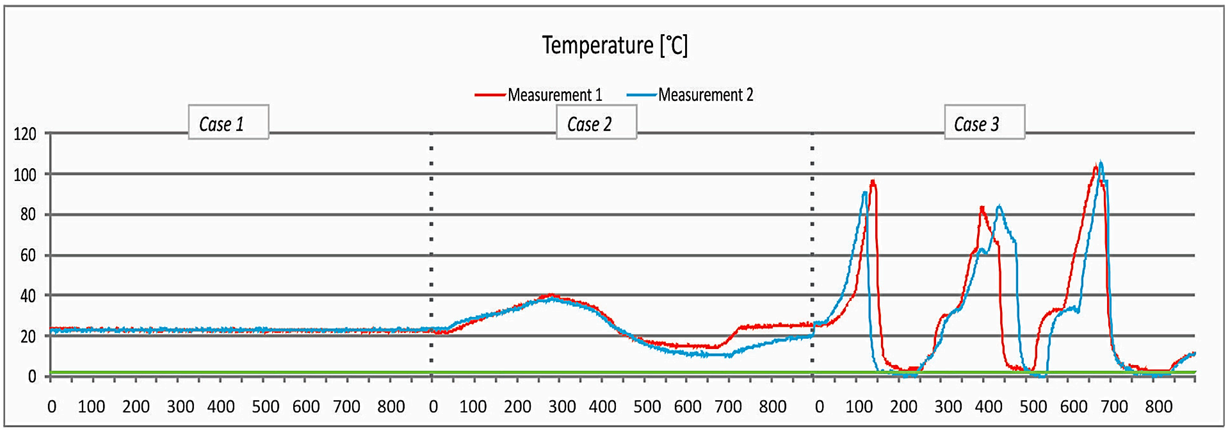


**Figure 1.** Temperature from measurement 1 and measurement 2 for the three acquisition cases.

The temperature changes are systematically carried out during both measurements in order to provide reliable comparative analysis of sensor active energy changes. Considerable deviations between first and second temperature change in the Fig. 1 can be attributed to the different sensor positions in relation to the heating source. The third, extreme case includes the temperature changes caused by taking into account the working range of the sensor.

The sensor active power changes during acquisition are also monitored (Figure 2) and this parameter is negligible compared to the total consumption of the experimental setup shown in Figure 3. The changes of the active power follow the temperature changes and the maximum value of the power in the observed case does not exceed the value of 2.13 mW.

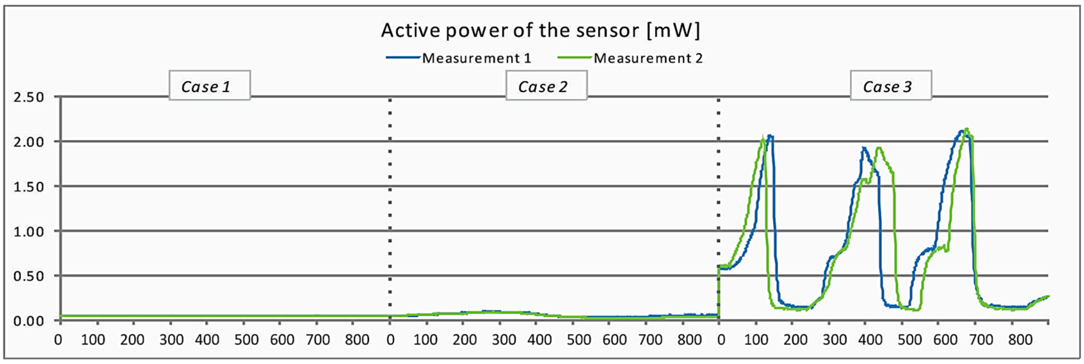


**Figure 2.** The active power of the sensor from measurement 1 and measurement 2 for the three considered cases.

The visible fluctuations in active power for all the three cases in the Figure 3 are not caused by the temperature changes or due to the power supply of the thermistor and can be attributed to the operation of power electronics within the experimental setup and to the existence of the local interference. In addition, it can be noticed that the fluctuations are present in both measurements, when the operation logic is relocated and when it is not. It can be concluded that the changes of the sensor node active power are insignificant during the three cases, for two performed measurements.

The power efficiency for the used power supply adapter in the analysis was not taken into account, but it can be considered that the degree of efficiency remains the same for the different levels of consumption.

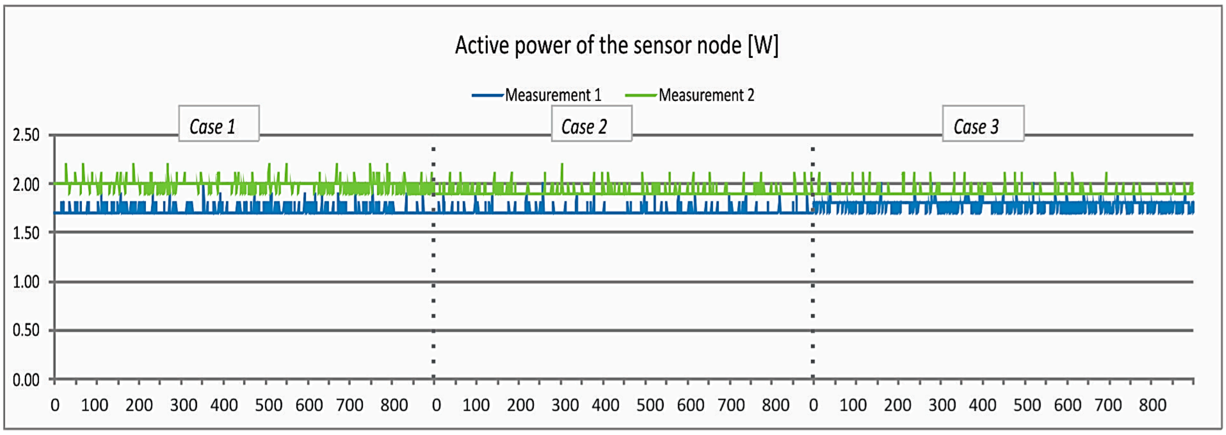


**Figure 3.** The active power of the sensor node from measurement 1 and measurement 2 for the three considered cases.

Experimental results presented above show that in the sense of energy consumption, implementation of computational logic on a sensor node increases active power and generally total power consumption. For the considered system setup, the active power increases of approximately 10% compared to the case when the logic is implemented on external computer.

## 4. Conclusions

Typical sensor nodes usually collect data and send them to a central sink node where they are processed, analyzed, and used by the application. Rapid technological development leads to the emergence of a smart sensor – a sensor node that not only holds the power to sense the environment and sent a data, but also has the ability to process incoming data and communicate with clients using a well-known IP protocol. These smart sensors today are usually implemented as IoT solution, and the existence of sink node is not necessarily because they have the possibility to communicate directly with clients over the Internet. Using a smart sensor, two main cases of data processing, which directly dictated power consumption of sensor node energy, were recognized. In this paper, analyzes of the power consumption of IoT sensor node, when the fuzzy computational logic is implemented at the node's end and when it is relocated at a remote external computer, has been done. The experimental results of two performed measurements have shown that:

- Power consumption of sensor element depends on the best, average and worst examples of temperature change;
- The power consumption of sensor is negligible compared to the total consumption of the experimental setup; and
- Implementation of pre-defined computational logic on a sensor node increases total power consumption of approximately 10% compared to external computer logic implementation.

It can be assumed that by using this experiment system and implemented sensor node, the sensor number increase in the both analyzed measurements, will imply the same improved energy efficiency achieved in the measurement 1. *i.e.*, the total power consumption for the relocated computational logic will not be greater.

## Conflicts of Interest

The authors declare no conflict of interest.

## References


1. Sichitiu, M.L. Cross-layer scheduling for power efficiency in wireless sensor networks. *23rd Annual Joint Conference of the IEEE Computer and Communications Societies* INFOCOM, Hong Kong, 2004; Volume 3, pp.1740 – 1750.
2. Dutta R.; Gupta, S.; Mukul, K. Das Power Consumption and Maximizing Network Lifetime During Communication of Sensor Node in WSN. *2nd International Conference on Computer, Communication, Control and Information Technology* (C3IT) Hooghly, West Bengal, India, 2012; Procedia Technology, Volume 4, pp. 589–594.
3. Lindsey, S.; Raghavendra, C.S. PEGASIS: Power-efficient gathering in sensor information systems. *IEEE Aerospace Conference Proceedings,* Big Sky, Montana, 2002; Volume 3, pp. 3-1125 - 3-1130 vol.3.
4. Calandrini, G.; Gardel. A.; Bravo, I.; Revenga, P.; Lázaro, J.L.; Toledo-Moreo, F. J. Power Measurement Methods for Energy Efficient Applications, *Sensors* 2013, *13*(6), pp. 7786-7796;
5. Passos, R.M.; Coelho C.J.N.Jr.; Loureiro, A.A.F.; Mini, R.F. Dynamic Power Management in Wireless Sensor Networks: An Application-Driven Approach. *2nd International Conference on Wireless on Demand Network Systems and Service* (WONS), St. Moritz, Switzerland, 2005.
6. Nazhandali, L.;Zhai, B.; Olson, J.; Reeves, A.; Minuth, M.; Helfand, R.; Pant, S.; Austin, T.M.; Blaauw, D. Energy Optimization of Subthreshold-Voltage Sensor Network Processors. *32nd International Symposium on Computer Architecture* (ISCA), Madison, Wisconsin, USA, 2005.
7. Lent, R. A Sensor Network to Profile the Electrical Power Consumption of Computer Networks. *IEEE Global Telecommunications Conference* GLOBECOM. Miami, Florida, USA. 2010.
8. Kapitanova, K.; Son, S.H.; Kang, K.-D. Using fuzzy logic for robust event detection in wireless sensor networks, *Ad Hoc Networks*, 2012; Volume 10, Issue 4, pp. 709–722.
9. Maksimović, M.; Vujović, V.; Milošević, V. Fuzzy logic and Wireless Sensor Networks – A survey. *Journal of Intelligent & Fuzzy System*s, 2014; Volume 27, no. 2, pp. 877-890.
10. Maksimović, M.; Vujović, V.; Perišić, B.; Milošević, V. Developing a fuzzy logic based system for monitoring and early detection of residential fire based on thermistor sensors. Computer Science and Information Systems 2015; Volume 12, Issue 1, pp. 63-89.