Power Consumption for Autonomous Wireless Sensor Network Nodes

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***Abstract*—Environmental parameter using a large number of spatially distributed wireless sensor network (WSN) nodes is an extensive illustration of advanced modern technologies, but high power requirement for WSN nodes limits the widespread deployment of these technologies. Currently, WSN nodes are extensively powered up using batteries, but the battery has limitation of lifetime, power density, and environmental concerns. Recently, Wireless Sensor Networks (WSNs) have been widespread utilized in automation. The power supply of WSNs has significant influences on their performance. This paper presents a novel power management circuit for WSNs. The proposed node needs to be able to send notifications to the utility, demanding the use of backup energy strategies. The authors of the research offered an approach that can help to use solar-based energy harvester EH as the most viable source of energy to be harvested for autonomous WSN nodes. Based on the test results, an integrated power control module parameters are developed. The novelty of the research is an approach that includes different power supply solutions in order to ensure defined signal transition quality parameters for maximum effectiveness of WSN nodes power feeding.**

***Keywords*—wireless sensor networks, WSN, solar energy, energy harvesting**

I. Introduction

One of the most efficient and most widespread condition monitoring methods is Wireless Sensor Network (WSN) monitoring. Wireless Sensor Networks (WSNs) play a key role, given to the fact that they constitute inherent distributed systems, in which different platforms allow the inclusion of multiple analogue/digital input/output ports. A WSN is a distributed network containing a large number of sensors and a control center unit which is able to monitor and control various behaviors of a structure or machinery. Multiple challenges must also be handled, such as compact form factors, reduced energy consumption, interference handling and variable node density allocation. Adequate network operation and design require wireless channel analysis and optimization in order to minimize interference, energy consumption and enhance overall quality of service. WSN monitoring has many advantages over non-networked systems, such as real-time and autonomous data acquisition, enhanced data accessibility and intelligent data analysis through intelligent algorithms [1]. This is of particular interest in the case of wireless sensor networks, given inherent restrictions in their operating conditions, as well as in the potentially large number of nodes present in the network. Utilizing WSN for factory line production monitoring in [2] has leaded to lower operating costs and errors. Utilizing WSNs for performance monitoring in new energy generators as wind turbines and distributed solar panels, brings several advantages such as longer lifetime and lowering failures by reducing human involvement [3] and [4],[5]. Renewable energy sources, such as solar radiation, vibration, human power, and air flow, can be used to solve a problem with long lifetime, as a recharger means to provide power for a long period of time without requiring the replacement of batteries.In modern days, the increasing demand of smart autonomous sensor nodes in the Internet of Things applications (like temperature monitoring of an industrial plant over the internet, smart home automation, and smart cities) requires a detailed literature survey of state of the art in solar energy harvesting WSN (SEH-WSN) for researchers and design engineers.

II. WSN components

Conventional Wireless Sensor Networks (WSNs) have the design limitation of high power consumption during their operation, which has been tackled by mainly duty cycle based approaches until now.

Developing of power supply solution, its working principles, and the system architecture is constructed in order to maximized efficiency. Technology concept and/or application formulated (TRL2 complete) show, that prototype of system is ready to be analytically and experimentally tested in laboratory environment critical function and characteristic proof-of-concept. For example, an area of strip is shown in Figure 1(a) which is equivalent to the drawn power by WSN nodes which transmit data to the adjacent Router. It is to be noted that WSN node consumes significantly high current, while it remains in active mode. But inside active mode, WSN node draws maximum current (e.g., 26 mA) during transmission, while the node consumes significantly different amount of current for the rest of the active mode operation period as shown in Figure 1(a). From Figure 1(a), it is clear that, by plotting the value of consumed current over a period of time and summation of the values, an area of strip equivalent to the amount of power/energy consumed by the WSN node can be determined. Now to measure the value under the strip, the methodology used. According to this methodology, to measure the area, an arbitrary continuous function f(x) is used, which resides in a close interval of a to b The function graph is shown in Figure 1(b).

III. Autonomous WSN

Solar energy source and chemical energy source are combined in a hybrid energy harvester, the components become

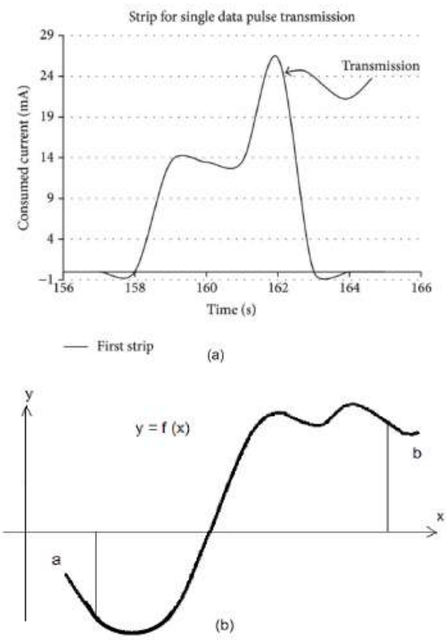

Figure 1. (a) Example of current consumption of a WSN node for transmitting a single data pulse to the adjacent WSN Router. (b) Arbitrary continuous functions for a close interval of a to b. [6]

solar and chemical energy sources, dual input harvesting circuitry, rechargeable storage, step-down output circuitry, and WSN components such as node or router as shown in Figure 2.

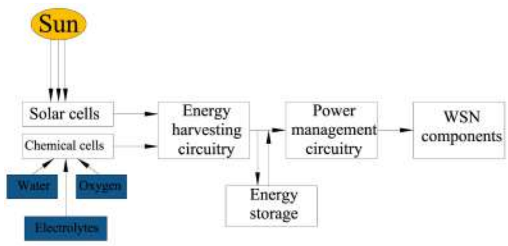

Figure 2. Model of a hybrid energy harvester-based complete WSN system

The intermediate energy storage is required, which can store leftover harvested energy and provide continuous power supply to the WSN node/router even when there is no ambient energy available. Now, to support WSN node/router from the storage, the storage should have capabilities to supply higher voltage than the adjacent node/router requirement. Output circuitry comes into action in this scenario by converting the DC/DC downstream conversion of output power from the storage, according to the requirement of adjacent node/ router. The overall behavior of the hybrid powered energy harvester depends on the design of each component of the system.Solar energy harvesting that provides an alternative power source for an energyconstrained wireless sensor network (WSN) node. The small size solar panels suitably connected to low-power energy harvester circuits and rechargeable batteries provide a loom to make the WSN nodes completely self-powered with an infinite network lifetime. Voltage change steps determine the number of microcontroller bits and solar cell maximum voltage:

$$h = \frac{U_{maxPV}}{2^n}, \tag{1}$$

where h – voltage change step, V; $UmaxPV$ – Maximum voltage of solar cell, V; n – the number of microcontroller bits.

Battery charge monitoring is monitored at the same time with the maximum point detection a level. If the voltage in the load is higher than the maximum allowed (defined by the user), it will charge the process is stopped. If the battery voltage falls to the minimum value, it will charge the process is restored again. This technology, in comparison with analogous solutions, has a clearly defined advantage for use in both sectors of the economy and can be objectively and quantifiably assessed.

The solar energy harvesting simulators use the energy model of a solar-powered WSN node which is composed of three submodels: (1) Energy harvesting model, (2) energy consuming model, and (3) the remaining battery energy model. The energy harvesting system of a sensor node gathers solar energy using a solar panel that stores the harvested energy in the rechargeable battery and operates the sensor system using the stored energy.

Solar photovoltaic (PV) energy harvesting refers to converting solar light energy into electrical energy to operate an electrical or electronic device. As applied to WSNs, solar light energy is converted into electrical energy and is utilized to recharge the battery of a WSN node at the operation site itself. The electrical energy harvested from solar energy (sunlight) can also be used directly to power a WSN node.

The maximum distance of a Zigbee wireless sensor network is 100 m, and it can be extended up to 1.5 km. The maximum data rate of information in the ZigBee protocol is 250 kbps only. In figure 3, the basic version of the WSN setup is shown, which can be extended to SEH-WSN by connecting small size solar panels.

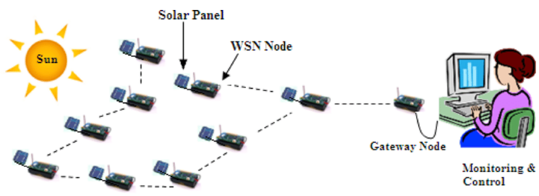

Figure 3. An SEH-WSN scenario for temperature monitoring application

IV. Alternative power source for WSN nodes in particular irradiation conditions

To measure the quality of the solar cell the Fill Factor (FF) is essential. It is calculated by comparing the maximum power (PMAX) to the theoretical power (PT) that would be output at both the open circuit voltage and short circuit current together [7].

$$h = \frac{P_{MAX}}{P_T} = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}}, \tag{2}$$

where VMP – the maximum power point voltage; IMP – the maximum power point current; VOC – the cell open-circuit voltage; ISC – the cell short-circuits current.

Comparison of FF of the panels does not give us clear indication which type of the tested panels is better for operating in low irradiation conditions, therefore the Efficiency indicator n is evaluated. Efficiency is the ratio of the electrical power output Pout, compared to the solar power input, Pin, into the

PV cell. Pout can be taken to be PMAX since the solar cell can be operated up to its maximum power output to get the maximum efficiency.

$$\eta = \frac{P_{out}}{P_{in}} = \eta_{max} \frac{P_{MAX}}{P_{in}} \tag{3}$$

Pin is taken as the product of the irradiance of the incident light, measured in W/m2 or in suns (1000 W/m2), with the surface area of the solar cell [m2]. The maximum efficiency (nMAX) found from a light test is not only an indication of the performance of the device under test, but can also be affected by ambient conditions such as temperature and the intensity and spectrum of the incident light [7].

Due to the test ensured similar lighting and temperature conditions for PV, the cells can be used for evaluation of the panel efficiency. Because Pin is the same for all panels, Pout indicates which panels are most efficient for operating in low irradiation conditions. Actually, A and E panels appeared as more efficient for the conditions set in the test.

A. Maximum Power Point Tracker for WSN nodes

Maximum Power Point Tracker (MPPT), a power electronic module that significantly increases the system efficiency use a microcontroller based charge controller connected to a battery and the load is developed in this research. It ensures the charging of a battery and providing power to the connected equipment by optimizing the solar panel maximum possible power rate at varying lightning conditions [8].

Solar Energy harvesting (SEH) is a technique that scavenges unused ambient solar energy and converts the collected light energy into electrical energy. This electrical energy can be stored for future use by the sensor node. The following are the Design Challenges at the Solar energy harvesting level:

- All the light energy coming from sunlight rays should be fully utilized. The SEH-WSN node should use solar energy as the primary source and rechargeable battery energy as the secondary source.
- To expand the battery charging-discharging life cycle.
- Designing of a simple and inventive solar charger.
- To shrink the overall power use.
- To enhance the stability of the overall SEH-WSN system.
- Energy harvester circuits should be compatible existing WSN industry communication standards like IEEE 802.15.4 (ZigBee) and IEEE 1451.5 standards.
- To achieve the highest power from the sun.
- To ensure small power consumption for DC-DC Boost converter operation.
- To convey maximum power to the SEH-WSN node using the harvested energy.
- To start-up (or bootstrap) the SEH-WSN node.

- Variations at the solar radiation level, Solar Cell efficiency (n), DC-DC converter design, and MPPT design and Energy Prediction Algorithms.
- Cost Effective energy harvesting solutions (cheaper than the battery replacement cost).

Pertaining to the use of solar energy to power WSNs, a lot of researchers have done a lot of research work. But still, there are many design challenges in SEH-WSNs, which need to be explored for further optimization. The design challenges in SEH-WSN are shown in Fig. 4.

The internal block diagram of an WSN node is displayed in figure 5. An WSN node consists of the following two main units [11]:

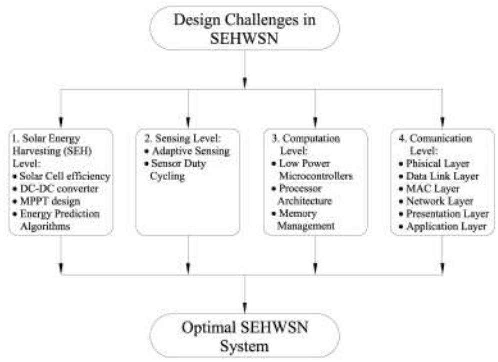

Figure 4. Design challenges in SEH-WSN

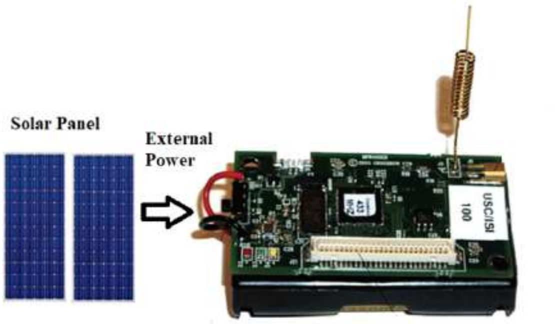

Figure 5. WSN node connected to solar panels

B. Microcontroller

The ATTINY13A [9] task is to combine the solar panel voltage measurements with ADC, to drive the digital potentiometer by ensuring the optimal charging current selection and to control the load disconnection and connection. The interface of the digital potentiometer is SPI where the pin number 8 of the microcontroller is used.

C. Microcontroller software – control algorithm

The control software is modular: ADC, digital potentiometer driver, disconnection module and algorithm logical machine. ADC measured input voltage of the solar panel, for the selected panel it is in the range up to 20V. The divisor reduces the voltage to a reference voltage and the software finds the current voltage value. This voltage is the starting point for the determination of the optimal power point for the selected solar panel. This point must be observed by monitoring the nominal voltage drops and adapting of the charging current [10]. Here is a simple application of the research results. The average current of a gateway developed at Beagle Bone board is 350mA. Imagine that for particular WSN it is sufficient, if a gateway operates at least 8 hours per one twenty-four hours. Therefore, 350 mA x 5V x 8 hours = 14000 mAh. The best solar plate, tested in the paper, theoretically has Pout about 9000 mW/m2 that is 9000 mW/m2 x 0.25 m2 = 2250 mW – the Pout of the one panel. So 14000 mWh: 2250 mW = 6.2 hours. It means that for our case one solar panel is able to ensure feeding of the device in the summer during 8 hours, but in the winter, when the day light is much shorter and is less solar days, one solar panel is not enough. To ensure the operation of a particular WSN, the decision can be made to use a lower power rating solution like a repeater node to compensate for the lower solar irradiation levels, in any case the evaluation of each individually deployed PV panel is vital to ensure critical data transmission. However, for reliable result for real WSN it is necessary to make also field research on solar irradiation in different time of the day and time of the year.

CONCLUSIONS

This paper makes the following contributions in the field of autonomous WSN. The fundamental concepts of an autonomous WSN system have been explained to understand the state of the art and operation of an autonomous WSN. We survey the autonomous WSNs at four basic levels, i.e., energy harvesting, sensing, computation, and communication levels with various design challenges.

In this paper, a thorough investigation has been carried out to design and implement a hybrid energy harvester that is capable of harvesting energy from ambient sources to powerup the WSN nodes. The authors of the research offered an approach that can help to use PV panels as alternative power source for WSN nodes in particular irradiation conditions. Survey and testing of the main types of PV panels offered in the market in conditions closed to real ones, in which WSN nodes are maintained, was implemented. Based on test results, a maximum power control module parameter can be calculated in order to achieve the best effectiveness of the power control system. The conclusions were made that conditions one solar panel is able to ensure feeding of the device in the summer during particular hours, but in the winter, when the day light is much shorter and is less solar days, one solar panel is not enough. The novelty of the research is PV testing method and selection of design and MPP control module parameters, which ensure maximum effectiveness of WSN nodes power feeding.

The future scope of autonomous WSN is very promising in the field of smart homes using sensors (Home Automation), smart buildings, smart cities, environment monitoring, industrial process control, security, and the Internet of Things (IoT) applications.

We draw attention to the fact that one of the possible use of this research may be the recognition and control of speech on the basis of various kinds of sensors.

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ПОТРЕБЛЕНИЕ ЭНЕРГИИ АВТОНОМНЫМИ УЗЛАМИ В БЕСПРОВОДНЫХ СЕНСОРНЫХ СЕТЯХ

Чайко Е. В., Витулёва Е. С., Солощенко А. В.

Параметр внешней среды, использующий большое количество пространственно-распределенных узлов беспроводной сенсорной сети (WSN), является обширной иллюстрацией передовых современных технологий, но высокие требования к мощности для узлов WSN ограничивают широкое распространение этих технологий. В настоящее время узлы WSN активно питаются от батарей, но у батареи есть ограничения по сроку службы, плотности мощности и экологическим проблемам. В последнее время беспроводные сенсорные сети (WSN) широко используются в автоматизации. Источник питания WSN оказывает значительное влияние на их производительность. В этом документе представлена новая схема управления питанием для WSN.

Предлагаемый узел должен иметь возможность отправлять уведомления в программу, требуя использования резервных энергетических стратегий.

Авторы исследования предложили подход, который может помочь использовать накопитель ЕН на основе солнечной энергии в качестве наиболее жизнеспособного источника энергии для автономных узлов WSN. По результатам испытаний разработаны параметры встроенного модуля управления мощностью. Новизна исследования — это подход, который включает в себя различные решения в области источников питания, чтобы обеспечить определенные параметры качества перехода сигнала для максимальной эффективности подачи энергии узлами WSN.

Авторы обращают Ваше внимание на тот факт, что одним из возможных применений этого исследования может быть распознавание и контроль речи на основе различных видов датчиков.

Ключевые слова: беспроводные сенсорные сети, WSN, солнечная энергия, сбор энергии.

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