A Comparative Survey of Energy Harvesting Techniques for Wireless Sensor Networks

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Abstract. In wireless sensor networks (WSNs), one of the major hurdles is the limited battery power that is unable to meet long-term energy requirement. Energy harvesting, conversion of ambient energy into electrical energy, has therefore emerged as an effective alternative to powering WSNs. This paper surveys the most preferred ambient sources available for energy harvesting and the scavenging techniques commonly used in WSNs to deal with energy issues. Furthermore, the energy harvesting techniques are qualitatively compared, and challenges and open issues are discussed.

Keywords: Wireless sensor network, energy consumption, energy harvesting, energy conversion, network lifetime.

1 Introduction

A wireless sensor networks (WSN) consists of spatially distributed, inexpensive miniaturized devices called sensors which are deployed over a geographical area for the close monitoring of physical conditions [1]. However, it is not possible for WSNs with limited power capabilities to afford long-term operation without any external or supplementary energy source [2]. The lifetime of sensor nodes can also be prolonged by compromising with the performance parameters [3]. For example, the use of a low-power processor or low-power transmitter can slow down the depletion of battery energy but it has to deal with lower processing speed and smaller transmission ranges, adding up net delay.

The sources of energy in our natural environment exist in many forms, are distributed widely, and have endless supply which could be exploited indisputably [4]. More importantly, they are readily available in abundance without requiring any extra effort to produce them. Energy harvesting from ambient resources stands as reliable and effective means for empowering the small autonomous sensor nodes. The implementation of energy harvesting technologies is not simple. A large number of things need to be taken into account for effective energy conversion and efficient use.

The rest of the paper is organized as follows: The components of an energy harvesting system integrated to sensor nodes are overviewed in the following section.

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The commonly used energy harvesting techniques and the ambient energy sources are presented in Section 3. In Section 4, the energy harvesting techniques are qualitatively compared and technically discussed. In Section 5, important challenges and open issues are summarized. The paper is concluded in Section 6.

2 Energy Harvesting System

Energy harvesting is the technique of converting the unused ambient energy source into electrical energy. The energy obtained is called harvested energy. The energy harvesting basically consists of three major components: namely, energy source, energy harvesting architecture and energy consuming entity [5]. An energy harvesting system captures and scavenges the ambient energy and then supplies the harvested and converted electrical energy to sensor nodes. The design of the energy harvesting system may differ from one application to another depending on the type of load requirements and the conditions of deployment area [6]. The design and implementation of an efficient energy harvesting system not only requires proper selection of devices with appropriate ratings but also the proper integration of those electronics to the sensor node [7, 8]. Fig.1 shows a usual energy harvesting system integrated with a sensor node.

![Fig. 1. Sensor node with energy harvesting system](image)

3 Energy Harvesting Techniques

Environmental energy sources have been used to generate electricity for a long time. In the this section, we discuss the energy harvesting techniques used in WSNs.
3.1 Photovoltaic Energy Harvesting

Photovoltaic energy harvesting is the technique of converting solar energy into electrical energy. The significance of the system lies in solar cell, maximum power point tracker (MPPT), and voltage converter. MPPT makes sure that the maximum power is extracted from the solar cell by matching the impedance of the solar cell and the voltage regulator or converter [9]. The output characteristics of the photovoltaic system vary nonlinearly with the changing irradiance and time of the day. Under such scenario, MPPT automatically tracks the value of current and voltage at which maximum output power is delivered. A combination of a set of ultracapacitors in parallel connection with a series of alkaline batteries is used in [10] as energy storage module.

3.2 Wind Energy Harvesting

Wind is a commonly available ambient energy resource with a tendency of making WSN completely self-autonomous with sustainable energy. In [11], a wind turbine generator (WTG) is used as the energy harvesting device, consisting of a wind turbine coupled to an electrical generator. This combination allows the conversion of kinetic energy of air flow into mechanical energy by the turbine, followed by conversion of mechanical energy of turbine into electrical energy with the electrical generator. In [12], a DC generator has been used, and it simply requires DC-DC converter instead of the rectifier. The use of MPPT ensures extraction of maximum power from WTG. A low-power microcontroller (MCU) implements the algorithm for MPPT. For the purpose of energy storage, battery or supercapacitor or both can be used.

3.3 Piezoelectric Energy Harvesting

Piezoelectric devices convert mechanical force, stress or vibration into electrical energy. The low-power vibrations are amplified to enhance output power. In fact, a higher output power is possible only when the system is in resonance with the external exciting vibration [13]. The piezoelectric energy harvesting system consists of a piezoelectric material bonded to a cantilever beam [14]. When the beam gets excited by some ambient vibration, a significant strain develops in the piezoelectric patch which is transformed into electrical energy. In [15], a trapezoidal piezoelectric harvester has been used for harnessing electrical energy from ambient vibrations. The device has an excitation frequency of 100 Hz and the resonance is achieved with a software operated trapezoidal cantilever.

3.4 RF Energy Harvesting

A radio frequency (RF) energy harvesting system allows the energy-constrained WSNs to harvest energy from the radio signals for performing their operations. It is a combination of impedance matching, rectifier, and DC-DC converter, and it is devised to collect radio signals and convert them to corresponding electrical equivalent with maximum efficiency. The use of Schottky diode in the rectifier can improve the efficiency of power conversion significantly [16]. In [17], far-field RF energy harvesting has been implemented to energize a low-power and low-duty-cycle WSN with radio
signals in gigahertz band. Data transmission, which is the most energy consuming operation, is not performed continuously. Hence, harnessed energy is stored during the periods of no data transmission.

3.5 Thermal Energy Harvesting

The inevitable component of thermal energy harvesting is a thermoelectric generator (TEG). TEG basically consists of a pair of p-type and n-type semiconductor connected in series electrically but in parallel thermally between two ceramic layers [18]. A thermal powered WSN is presented in [19], with a simplified power manager (PM). The PM balances the performance of the system by changing the duty cycle of the node such that the energy is in proportion the harvested energy. Supercapacitor is used as a main storage element, the voltage level of which determines the active or sleep period of the sensor node.

4 Comparison of Energy Harvesting Techniques

The most common form of energy harvesting techniques have been reviewed and compared qualitatively and presented in Table.1.

The major advantage with solar energy lies in the fact that it is green energy with limitless availability. However, the point to be noted that solar based system are functional only when get exposure to the sunlight. Wind being uncontrollable and unpredictable needs special caring and techniques to get the best out of it. Usually, wind based energy scavenging system consist of mechanical parts which may produce unnecessary noise. Piezoelectric energy harvesting is the most appropriate form of energy harnessing mechanism for fabricated environment. It is more or less dependent on the environment or apparatus set for excitation or generating vibration. The development and implementation of RF based system needs to consider the characteristics of propagation channel, distance from the RF transmitter, design of the rectenna, antenna size and transmit power. Since the thermal energy systems are more prone to charge, leakage care must be taken to prevent the energy loss.

Table 1. Comparison of different energy harvesting techniques for WSNs.

<table>
<thead>
<tr>
<th>Harvesting Technique</th>
<th>Energy Source</th>
<th>Energy type</th>
<th>Harvesting device</th>
<th>Merit</th>
<th>Demerit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar energy harvesting [9]</td>
<td>Sun</td>
<td>Radiant energy</td>
<td>Solar cell</td>
<td>• Limitless availability</td>
<td>• Needs exposure to light</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Poor indoor efficiency</td>
</tr>
<tr>
<td>Wind energy harvesting [11]</td>
<td>Wind</td>
<td>Kinetic energy</td>
<td>Wind turbine</td>
<td>• High power density</td>
<td>• Noisy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Unpredictable</td>
</tr>
<tr>
<td>Piezoelectric energy harvesting [13]</td>
<td>Stress or vibration</td>
<td>Mechanical energy</td>
<td>Piezoelectric film or ceramic</td>
<td>• Equally efficient indoor and outdoor</td>
<td>• Piezoelectric devices are brittle</td>
</tr>
</tbody>
</table>
RF energy harvesting [16] | Radio signals | Electromagnetic energy | Rectenna
---|---|---|---
Thermal energy harvesting [18] | Heat | Heat energy | Thermoelectric generator

**5 Challenges and Open Issues**

Integrating energy harvesting systems to WSNs requires a lot of processes that involves capturing, storing, conditioning, regulating, and managing. The miniaturization of the energy harvesting system to fit the requirements of WSNs is always a challenging job. Followed are the challenges and open issues in this regard.

- The power conversion efficiency of an energy harvester and the overall system is always an issue of interest. For most of the harvesting techniques, the overall conversion efficiency turns out to be low.
- In addition to harvesting power from the ambient sources, it is also important that the harnessed power is efficiently stabilized, stored and delivered to the targeted destinations.
- The excess energy obtained from the harvesting system need to be stored efficiently. Because the energy supplied by harvesters is discontinuous, the task of generating a continuous and constant supply goes to energy storing devices.
- The control over the transmit power and regulation of convenient wake-up and sleep schedules for sensor nodes can help in efficient conservation of hard-earned energy.
- Energy harvesting in itself is a great effort to address the energy constraint in WSNs. Implementing the harvesting technique is just not enough to reap all the benefits of energy-harvested WSNs.

**6 Conclusion**

In this paper, the most widely used and efficient techniques for energy harvesting in WSNs have been extensively surveyed and qualitatively compared. Undoubtedly, the recent advancement of the energy harvesting systems is offering a huge supplement to the conventional battery-dependent systems. The challenges and important issues on the way to more efficient harvesting have been discussed as well. The need for smart grid technologies to deal with variability would be an effective solution for extracting energy in a more efficient way. To sum up, energy harvesting with the ambient energy resources is reliable, safe and clean, and it has the potential to power WSNs endlessly.

**References**