Sensor Nodes for Energy Harvesting: A Review Paper

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ABSTRACT: To detect and collect data for application-specific analysis, a sensor network, a network of collaborating embedded devices (sensor nodes) having sensing, processing, and communication capabilities, is employed. Sensing modality, sensor node computation, communication, and storage capabilities, cost and size of each node, type of power source, deployment architecture, data dissemination and communication protocols, applications, and management tools are just a few of the design dimensions of a sensor network application. Sensor networks with battery-powered nodes rarely achieve the design goals of longevity, cost, sensing reliability, and sensing and transmission coverage at the same time. The conversion of ambient energy to electrical energy, known as energy harvesting, has emerged as a viable alternative to power sensor nodes. Energy collecting sensor nodes have the potential to solve the competing design goals of lifetime and performance by utilizing recharge chances and modifying performance parameters depending on current and predicted energy levels. This study examines the architecture, energy sources, and storage technologies of energy harvesting sensor systems, as well as examples of harvesting-based nodes and applications.

KEYWORDS: Energy-Aware Systems, Energy Harvesting, Sensor Networks, Implications, Solar Energy.

1. INTRODUCTION:

The utilization of battery-powered sensor nodes is a common and frequently used application category. Habitat monitoring, for example, is one example of such an application. A major limitation of undeterred nodes is finite battery capacity, nodes will operate for a finite duration, only as long as the battery lasts. Finite node lifetime implies finite lifetime of the applications or additional cost and complexity to regularly change batteries. Large batteries might be used in nodes for longer lifetimes; however this would result in greater size, weight, and expense. Nodes may also choose to make advantage of low-power hardware, such as a processor and a radio, the expense of reduced computing power and transport capacity ranges. An alternative technique that has been applied to address the problem of finite node lifetime is the use of energy harvesting[1]. Energy harvesting refers to harnessing energy from the environment or other energy sources (body heat, foot strike, finger strokes) and converting it to electrical energy.

The harnessed electrical energy powers the sensor nodes. If the harvested energy source is large and periodically/continuously available, a sensor node can be powered perpetually. Further, based on the periodicity and magnitude of harvestable energy, system parameters of a node can be tuned to increase node and network performance. Since a node is energy-limited only till the next harvesting opportunity (recharge cycle), it can optimize its energy usage to maximize performance during that interval. For example, a node can increase its sampling frequency or its duty-cycle to increase sensing reliability, or increase transmission power to decrease length of routing pa.ths. Figure 1 shows harvest use and Figure 2 shows harvest store use.

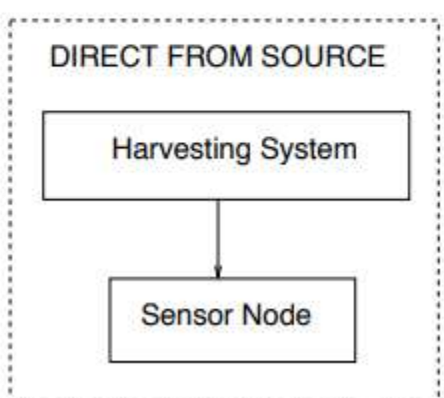

Figure 1: Harvest Use.

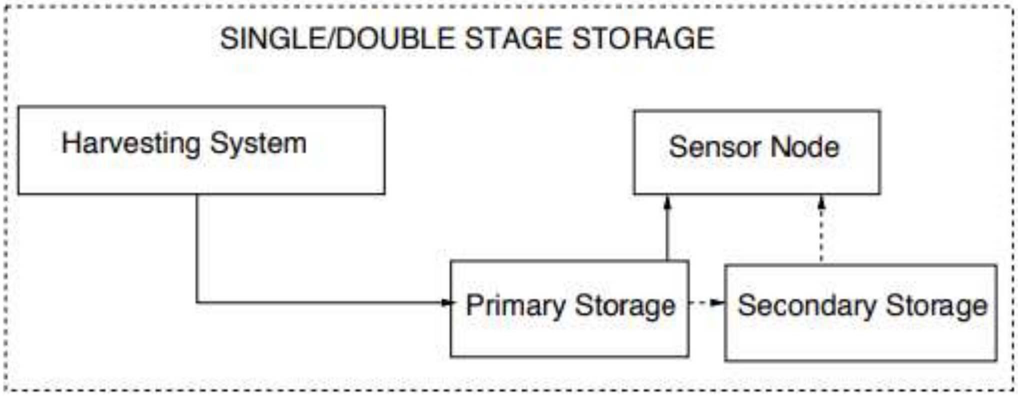

Figure 2: Harvest-Store-Use

Energy harvesting refers to scavenging energy or converting energy from one form to the other. Applied to sensor nodes, energy from external sources can be harvested to power the nodes and in turn, increase their lifetime and capability. Given the energy-usage profile of a node, energy harvesting techniques could meet partial or all of its energy needs. A widespread and popular technique of energy harvesting is converting solar energy to electrical energy. Solar energy is uncontrollable—the intensity of direct sunlight cannot be controlled, but it is a predictable energy source with daily and seasonal patterns. Other techniques of energy harvesting convert mechanical energy or wind energy to electrical energy[2]. For example, mechanical stress applied to piezo-electric materials, or to a rotating arm connected to a generator, can produce electrical energy. Since the amount of energy used for conversion can be varied, such techniques can be viewed as controllable energy sources. A typical energy harvesting system has three components, the Energy source, the Harvesting architecture and the Load. Energy source refers to the ambient source of energy to be harvested. Harvesting architecture consists of mechanisms to harness and convert the input ambient energy to electrical energy. Load refers to the activity that consumes energy and acts as a sink for the harvested energy.

2. LITERATURE REVIEW

Bryant, Matthew et al. in their case study suggested that in the developing field of wireless sensing, energy harvesting has enabled new operating approaches. A unique energy harvesting device powered by aeroelastic flutter vibrations has been invented, and it could be employed in wireless sensing applications to supplement conventional environmental energy harvesters like solar cells. The authors develop and present an analytical model of mechanical, electromechanical, and aerodynamic systems that may be used to construct aeroelastic energy harvesters for a variety of flow applications[3].

Ruan, Tingwen et al. in their case study suggested that the necessity to reduce the power consumption of WSNs while increasing the power provided by energy harvesters has prompted extensive study on energy harvesting powered wireless sensor nodes (WSNs). Because the ambient environmental energy is limited and varies over time, the mismatch between the energy generated by the harvesters and the energy demanded by the WSNs is constantly a bottleneck. To deal with the mismatch, this work offers a combined energy-aware interface and an energy-aware programmers that manages the energy flow from the energy storage capacitor to the WSNs[4].

Toh, Wang Yun et al. in their case study suggested that Wireless body sensor networks use distributed wearable wireless sensors for a variety of physiological monitoring applications, such as health and performance monitoring. The actual difficulties in using these wearable wireless sensors on humans are: 1) a large and stiff system design that makes it impossible to fit to human body contours, and 2) a limited battery operational lifespan with finite energy supply. An autonomous body-worn wireless sensor node for biometric monitoring is suggested in this study, using a flexible energy harvesting (FEH) mechanism that can conform to body contour[5].

3. DISCUSSION

3.1. Energy harvesting sensor nodes:

Energy harvesting refers to scavenging energy or converting energy from one form to the other. Applied to sensor nodes, energy from external sources can be harvested to power the nodes and in turn, increase their lifetime and capability. Given the energy-usage profile of a node, energy harvesting techniques could meet partial or all of its energy needs. A widespread and popular technique of energy harvesting is converting solar energy to electrical energy. Solar energy is uncontrollable the intensity of direct sunlight cannot be controlled, but it is a predictable energy source with daily and seasonal patterns. Other techniques of energy harvesting convert mechanical energy or wind energy to electrical energy. For example, mechanical stress applied to piezo-electric materials, or to a rotating arm connected to a generator, can produce electrical energy. Since the amount of energy used for conversion can be varied, such techniques can be viewed as controllable energy sources.

A typical energy harvesting system has three components, the Energy source, the Harvesting architecture and the Load. Energy source refers to the ambient source of energy to be harvested. Harvesting architecture consists of mechanisms to harness and convert the input ambient energy to electrical energy. Load refers to the activity that consumes energy and acts as a sink for the harvested energy. Radio Frequency Energy Harvesting: When a timevarying electromagnetic radio frequency (RF) field passes through an antenna coil, an AC voltage is generated across the coil. A magnetic coupling due to mutual inductance generates voltage[1]. In RF energy harvesting, a passive RF tag uses RF energy transmitted to it, in order to power itself a form of energy harvesting. This is not applicable to active RF tags, which have their own battery supply and do not depend on external RF energy for their power requirements. In RFID systems, an RFID reader queries an RFID tag, which in turn, responds with its own identification.

This is used to identify, locate and track people, assets and animals. The RF signal is sent by the RFID reader and the RFID tag is energized by the voltage obtained from the mutual inductance of their loop antennas The response of the tag involves amplitude modulating the received carrier signal according to its own identification data that is stored in non-volatile memory. This is called backscatter modulation. The RFID reader keeps sending out RF signals and monitoring the reflections for change in amplitude. Any amplitude change denotes presence of an RFID tag. Thus, unlike normal sensing applications where the sensor itself harvests energy, here the sensor (RFID reader) senses the presence of the energy harvester (RFID tag)Applications on similar lines, with nodes doing more than just sending back their identifications would be an interesting direction to pursue. An example scenario would be a mobile data sink moving in an area of interest and source nodes harvesting RF energy from the sink and feeding data of interest back to it.

3.2. Application:

Is the energy source; it determines the amount and rate of energy that can be used. Along the axes of controllability, predictability, and magnitude, different energy sources have different characteristics. Energy availability does not need to be forecasted before harvesting because a variable energy source can deliver harvestable energy anytime it is needed[6]. When dealing with non-controllable energy sources, energy must be captured whenever it becomes available. If the energy source is predictable, a prediction model that forecasts its availability can be used to determine when the next recharge cycle will occur. Furthermore, energy sources can be divided into two categories: renewable and non renewable. Super-capacitors, instead of or in addition to rechargeable batteries, can be employed as storage components. Super-capacitors, like batteries, store charge; however they self-discharge at a considerably faster rate than batteries, up to 5.9% every day. Furthermore, the weight-to-energy density of a super-capacitor is relatively low, only 5Wh/kg when compared to a battery. NiMH batteries have a power density of 100Wh/kg. Super-capacitors, on the other hand, having a high charge-discharge efficiency (97-98%) and can also[7].

There is no memory effect. Super-capacitors are another option Like NiMH batteries, they are trickle-charged and hence do not require charging circuits for charging complexes Super-capacitors are a type of capacitor that, in theory, can store a large amount of energy have a limitless number of recharging cycles.) Wireless, Self-Powered Push-Button Controller: The self-powered push-button controller described in is able to wirelessly transmit a digital code to a distance of 50 feet on a single button push. It does not need batteries since it generates energy from the energy expended in the button push. A piezo-electric conversion mechanism is employed to harness energy from the push motion. The push energy impacts the PZT element and it self-oscillates at its resonant frequency. A step-transformer couples the high voltage/low current from the piezoelectric to a low voltage/high current of standard electronic circuitry. After rectification, the electrical energy is stored in a capacitor. It is regulated down to the required 3V of the RF transmitter circuitry. The RF circuitry can transmit the 12-bit digital code up to 50 feet. The systems described above are instantiations of using piezoelectric materials for harvesting mechanical energy. Harvesting significant amounts of human power needs sustained effort for long durations due to the very small amount of energy harvestable. Up till now, these energy sources have not been used in wireless sensor network deployment. An open direction is engineering and research to develop piezo-based harvesting sensor nodes which intelligently combine human activities and energy harvesting.

3.3. Advantage:

Two network deployments, one in an urban setting and the other in a forest watershed, were used to evaluate Hydro watch. In the city, at least half of all nodes received power. Every day, one hour of sunlight (>130mWh) is required. It was, interestingly, it was also discovered that solar panels that were ordinarily obstructed got on cloudy days, and there is more solar energy than on sunny days. The cloud's dispersion of light was blamed for the phenomenon. Layers. However, the majority of the nodes in the forest watershed are received no more than 50mWh of energy every day, which was insufficient.79.2 mWh/day is less than the aim. This energy scarcity was not due to a lack of sunlight, but rather to a lack of the spotting light. Because all rechargeable battery technologies have a certain number of deep recharge cycles, it’s best if the battery can be recharged quickly. Modest recharge cycles rather than deep recharge cycles.

This is achieved by the use of a first-stage of super-capacitors. Which may theoretically go through an endless number of deep recharge cycles the use of super-capacitors as the principal energy source can reduce battery access. As a result, the battery does not discharge. There is a complete and shallow recharging. Furthermore, Prometheus employs Second-stage storage with a lithium polymer battery. The option Instead of NiMH batteries, Lithium-based batteries is used. Avoid the state-of-memory impact caused by insufficient recharging cycles. We described various node-level and network-level implications of energy harvesting on sensor network design. Potential node and network-level parameters to tune and affect network design and performance were presented. As discussed above, system design and node-level adaptations are inter-dependent. Tuning of node-level parameters affects network solutions and communication protocols, e.g., change in transmit power changes neighborhood and affects routing metrics, variations in duty-cycle affect MAC parameters, change in node sensing rates affect network data collection. This reasserts the point that design considerations of sensor network applications and node-level power management mechanisms are tightly coupled[8]. The description of node-level and network-level implications presented examples and potential directions of solutions to exploit harvesting opportunities in order to simultaneously improve performance parameters and network lifetime[9].

3.4. Working:

Prometheus design favors second stage of Lithium batteries because shallow recharge cycles can ensure longer lifetime. With low leakage, high charge-discharge efficiency and no memory effect, Lithium-based batteries are better suited than NiMH batteries to operate with shallow recharge cycles. Prometheus handles the complex charging logic of Lithium batteries through software control[8]. Having software control provides flexibility to re-program/change the harvesting logic and parameters without re-deployment. In summary, if simple charging control is desired and if energy requirement is moderate or if energy availability is high, then a Hydro watch-like design is preferred. On the other hand, if charging efficiency is required or energy available is less or flexibility is desired to change harvesting procedure and parameters (implying a software charging control), then a Lithium battery based system may be better suited. Further, in really long deployments, expected to last several tens of years, use of high-capacity super-capacitors seems to be the most viable option. Figure 3 discloses trio system hardware architecture.

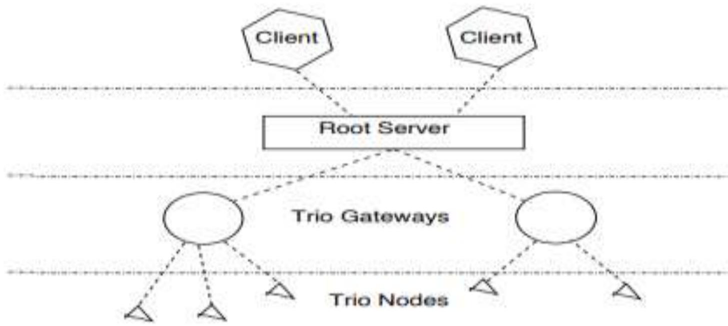

Figure 3: Trio System Hardware Architecture.

With battery-based storage, the battery will eventually age and die. Replacement and maintenance in such cases, particularly for a large number of nodes, will be prohibitively costly, making the use of super-capacitors attractive. Trio is a solar energy harvesting node that is part of an in-situ sensing network of static nodes. The Trio node is based on the Prometheus design and incorporates changes to address some of Prometheus' design flaws. A total of 557 solar-powered Trio motes, seven Trio gateway nodes, and a root server were used to test the Trio. There are three stages in the Trio system: Trio nodes, Trio gateways, and the Root server. Trio's purpose is to test multi-target tracking systems at a large scale. An approach for high throughput data extraction from all nodes in the network while meeting per-node energy neutrality constraints, is presented in [83]. An optimal lexicographical rate is estimated with the aim of maximizing the minimum data rate across all nodes. With a lexicographical rate assignment, it is not possible to further increase the rate of one node without decreasing the rate of another. The rate assignment problem is formulated as a linear optimization problem, and both centralized and distributed solutions are proposed. The centralized approach accounts for effective energy at nodes (i.e., predicted and residual energy) and computes the data rates and routes from each source to a single sink. The distributed solution assumes prior knowledge of routes to the sink and solves the data rate assignment problem[10].

4. CONCLUSION

The capability of a wireless sensor node to harvest energy has the potential to simultaneously address the conflicting design goals of lifetime and performance. In this paper, we discussed various aspects of energy harvesting systems. We presented basic concepts of harvesting systems, architectures, types of harvestable energy sources, and storage technologies. We described details of existing energy harvesting sensor nodes and applications, most notably the ones dependent on solar energy. Further, we presented insights into implications of recharge opportunities on node-level operations and design of sensor network applications and solutions. We believe these insights will motivate further research towards usage of energy harvesting sensor nodes and their applications. A wireless sensor node's ability to capture energy offers the potential to address the contradictory design goals of lifetime and performance at the same time. We examined many features of energy harvesting systems in this research. We covered the fundamentals of harvesting systems, including topologies, types of harvestable energy sources, and storage options. We went over the specifics of existing energy harvesting sensor nodes and applications, with a focus on those that use solar energy. We also discussed how recharging opportunities affect node-level operations and the design of sensor network applications and solutions. We trust that these insights will inspire you.

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