Energy Issues and Solutions using Renewable Energy Resources for Wireless Sensor Networks: A Survey

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Abstract— Energy consumption is the most important parameter to estimate the life of a sensor network because usually sensor nodes are driven by battery and have very low energy resources. This makes energy optimization more complicated in sensor networks because it involved not only deficiency of energy utilization but also extending the life of the network as much as possible. This can be done by having energy awareness in every aspect of design and operation. This can also be achieved by using both predominant and renewable energy resources. Here is a survey on potential renewable energy resources along with their characteristics and applications in WSN.

Key words: WSN, Nodes, Actuators, Energy Harvesting

I. INTRODUCTION

In recent years there have been several technological advances in Wireless Sensor Networks, but energy still remains a paramount resource. The amount of available energy has a direct effect on the performance, functionality and lifetime of WSN. Being bound by cost and size, sensor nodes are usually equipped with limited amount of energy and therefore require a replacement of batteries occasionally. But replacement might not always be feasible option and in some scenarios might even be prohibitive. This indicates the need for more viable solutions, these involve generating energy at the sensor nodes or have it delivered to them i.e., energy harvesting or wireless energy transfer.

A critical constraint on sensors networks is that sensor nodes employ batteries. A second constraint is that sensors will be deployed unattended and in large numbers, so that it will be difficult to change or recharge batteries in the sensors. Therefore, all systems, processes and communication protocols for sensors and sensor networks must minimize power consumption. The existing research on energy consumption of sensors is usually based on either theoretical models or computer simulations. One widely cited model of energy consumption has been used extensively as a guide for simulations and the design of low power consumption communication protocols [15].

Energy consumption is one of the most important concerns to the wireless sensor network, which determines the network lifetime. The non-uniform property of energy consumption is studied. Theoretical analysis indicates that the average energy consumption of the sensor is heavily non-uniform, which decreases with the hop number to the sink node. In a wireless sensor network, the rate of energy utilization is very low while the co-efficient of energy waste is very high, which are monotone decreasing and increasing with the hop number to the sink node respectively [16]. Energy efficiency is a Major consideration no matter what the problem is. This is because sensor nodes only have a small and finite source of energy.

A Wireless Sensor Network consists of small, low cost, low power sensor nodes deployed in a region for monitoring different aspects of environment. Generally, as sensor node is made of four basic components with additional units being added depending on application requirements. The basic components of sensor node consists of a sensing unit used for acquiring data from the environment and converting it to digital data, a processing unit for processing raw data to store the results, and a transceiver unit for sharing data with other nodes for the end-user. Finally, there is a power unit that consists of a energy sink battery, capacitor o and power management that monitors and routes power to the entire node. Lifetime of a sensor node depends on the capacity of the power resources it is equipped with. One way of prolonging lifetime of sensor network would be to periodically replace the batteries of all or some of the deployed sensor nodes. Since WSNs can be deployed in scenarios where nodes are left unchecked for weeks, months and may be years so frequently replacing batteries will be a tiresome task and might even not be possible like in critical environment , where it is needed to recharge in order to get as much autonomy as possible[17,18].

II. LITERATURE SURVEY

A number propose solutions to one or more of the above problems. This survey focuses on the suggested solutions in the following areas

A. Energy Efficiency

Energy efficiency is a dominant consideration no matter what the problem is. This is because sensor nodes only have a small and finite source of energy. Many solutions, both hardware and software related, have been proposed to optimize energy usage.

B. Lifetime of Wireless Sensor Networks

Critical to any wireless sensor network deployment is the expected lifetime. The goal of both the environmental monitoring and security application scenarios is to have nodes placed out in the field, unattended, for months or years. The primary limiting factor for the lifetime of a sensor Network is the energy supply. Each node must be designed to manage its local supply of energy in order to maximize total network lifetime. In many deployments it is not the average node lifetime that is important, but rather the minimum node lifetime. In the case of wireless security systems, every node must last for multiple years. A single node failure would create vulnerability in the security systems. In some situations it may be possible to exploit external power, perhaps by tapping into building power with some or all nodes. However, one of the major benefits to wireless systems is the ease of installation. Requiring power to be supplied externally to all nodes largely negates this advantage. A compromise is to have a handful of special nodes that are wired into the building's power infrastructure. In most application scenarios, a majority of the nodes will have to be self-powered. They will either have to contain enough stored energy to last for years, or they will have to be able to scavenge energy from the environment through devices, such as solar cells or piezoelectric generators. Both of these options demand that that the average energy consumption of the nodes be as low as possible [1].

C. Energy Efficient Estimation in Wireless Sensor Networks

Wireless sensor networks are fundamentally different from other wireless networks due to energy constraints and spatial correlation among sensor measurements. Mechanisms that efficiently compress and transport sensor data in the network are needed. We consider the problem of maximizing lifetime of wireless sensor networks that are entitled with the task of estimating an unknown parameter or process and thus need to adhere to estimation error specifications. We investigate optimal endogenous sensor measurement rate control, in-network data aggregation and routing for achieving the goal above. Sensors take measurements and aggregate incoming data from neighbors in a single outgoing flow by applying appropriate aggregation weights. By doing so, they control the variance of outgoing flow. Each sensor controls its measurement rate and aggregation weights, and aggregated measurement data are routed.. The challenge is to find an optimal compromise between eliminating data redundancy and maintaining data representation accuracy so as to adhere to estimation quality constraints and reduce the volume of transported data, thus improving network lifetime. Sensor spatial correlation, measurement accuracies, link qualities and energy reserves affect sensor measurement rates, data aggregation and routes. On the other hand, measurement rates, aggregation, and sensor characteristics impact the estimation error. We show that the problem can be decomposed into separate optimization problems where each sensor autonomously takes its measurement rate, aggregation and routing decisions. We design an iterative primal-dual algorithm that relies on low overhead feedback from the FC to the nearest sensors .

D. The Power Management Subsystem in Wireless Sensor Networks

One of the key design objectives of the system is to increase the system lifetime to three to six months in a realistic deployment. Due to the small form factor and low-cost requirements, sensor devices are equipped with limited power sources e.g., two AA batteries. The normal lifetime for such a sensor node is about 4 days if it remains active all the time. To bridge such a gap, is equipped with a power management subsystem. Among all the middleware services, the tripwire service, sentry selection, duty cycle scheduling, and wakeup service form the basis for the power management subsystem. These services are organized into a multi-dimensional architecture. At the top level, the tripwire service is used to divide the sensor field into multiple sections, called tripwire sections. A tripwire section can be scheduled either into an active or a dormant state at a given point of time. When a tripwire section is dormant, all nodes within this section are in a deep-sleep state to conserve energy [2]. When a tripwire section is active, a second-level sentry service is applied within this section. The basic idea of the sentry service is to select only a subset of nodes, defined as sentries, to be in charge of surveillance. Other nodes, defined as non-sentries, can be put into a deep-sleep state to conserve energy. Rotation is periodically done among all nodes, selecting the nodes with more remaining energy as sentries. The sleep/awake schedule of a sentry node can be either independent of other nodes or coordinated with that of others in order to further reduce the detection delay and increase the detection probability. More information on power management can be found [3].

Being a low cost and a small device, sensor nodes can only be equipped with limited energy source which can only provide limited functioning time. In other words, power is a critical asset and must be utilized efficiently. Power efficient techniques have been proposed from all aspects starting from conserving power in WSN such as a trade-off off functionality with battery life by gradually reducing the use of additional functions with respect to battery life [4]. This is achieved by reducing the run time of additional functions in which a mote can switch-off and conserve energy during idle periods, life time of a node by exploiting battery recovery effect a phenomena by which a battery self-recharges while left idle [5].

Different sources of energy exist in different forms e.g. light, vibration, air, and electromagnetic waves. These sources can be harvested and used to extend battery life of a sensor node. Harvested energy can also be used for battery extensive tasks. Battery life can also be extended by recharging a battery either physically or wirelessly. Reducing or eliminating the problem of limited lifetime will enable node designers to enhance the functionality of a node by adding extra features and components.. More specifically, we focus on energy harvesting from renewable as well as traditional energy resources in sustainable Wireless Sensor Networks. It is to be discussing sources available, techniques used for scavenging, storage methods and deployment architecture [6].

III. RENEWABLE ENERGY RESOURCES FOR WSN

Different forms of naturally replenished inexhaustible energy exist in the ambient environment all around us. This type of energy is often referred to as renewable energy and although they are not generated in electrical form but they can be harvested and converted to electricity using appropriate hardware. Using renew- able energy to fulfill power requirements is not a new concept and has been implemented on large scale worldwide. Fortunately, due to advancement and miniaturization of electronics, it is possible to integrate energy harvesting modules in small and compact sensor nodes. Such nodes are often referred to as Energy Harvesting (EH) sensor nodes. These nodes have all the basic components required for performing traditional functions and tasks with the addition of a EH module which can convert the energy from the ambient environment to electrical form.. The conversion technique used in EH module depends upon the type of energy i.e., solar for scavenging light energy, piezoelectric for pressure, and thermoelectric for heat. Scavenging the infinite amount of renewable energy will not only extend the operating lifetime of WSN but also enable Sensor nodes To perform complicated and energy demanding Tasks and functions

A. Light

One of the most matured, common and promising among different types of renewable energy is gained from light; either sunlight or artificial light [8, 9]. It can be scavenged in outdoor as well as indoor environment [7] as enough amount of light is available for optimal functioning of the system. Power in outdoor environments is scavenged from the sunlight which is often referred to as solar. Solar power is highly time and seasonal dependent and is not steadily available throughout the day due to environmental conditions. But if the energy is extracted efficiently, the energy harvested during day can last throughout the night. For indoor environments, artificial lightening can be scavenged for viable functioning of a node.

B. Vibration

Ambient environment is filled with vibrations, generated either by pressure, rotation, kinetic energy, or bio-motion. These vibrations can be scavenged and converted to usable electrical energy by employing specific equipments [10]. Unlike solar energy, the availability of vibrations cannot be predicted but it can be controlled to some extent depending on the application. For instance, the vibrations produced on a bridge are random through-out the day, whereas the duration of vibrations by bio-motion can be controlled.

C. Heat

Heat is ubiquitous in the ambient environment. It can be gained from structures, mechanical or electrical equipment, nature, and organisms. The temperature difference or the heat generated from these sources can be transformed into electric potential providing a long lasting supply. This method is particularly prominent where losses in a system results in generation of heat.

D. RF

Communicating and broadcasting devices such as television broadcasting, cell phones, radio towers, and Wi-Fi router employ the electromagnetic spectrum or more specifically Radio Frequency (RF) radiation. Due to emerging wireless communications and networks, the ambient environment is filled with potential RF radiation sources which can be scavenged for generating usable electric energy. RF radiation is critically dependent on location of RF transmitter. While densely populated or urban areas may have a large amount of harvestable RF power, rural areas may not. RF broadcasting transmitters are random and uncontrollable.

E. Wind

Wind is another naturally available harvestable resource which can be used for generating electricity. Wind can be harvested using a wind turbine which utilizes the linear motion of the air flow for generation of electricity. Availability of wind is dependent on climatic features of a region and can be predicted to some extent [11], but the speed of air flow is unpredictable. The authors in [12] developed an anemometer based wind harvester for low power nodes. The wind causes a motion in anemometer shaft which in turn drives an alternator hence generating power. The system is able to generate a maximum power of 651 µW at a air flow of 8 m/ s. Piezoelectric based turbine for wind harvesting is demonstrated in [13]. An anemometer causes the rotation of a shaft which has bumps on it, so as turbine rotates piezo-electric material vibrates due to bumps, hence producing electricity. A battery-less, electro-mechanical wind harvesting sensor node for transmitting air velocity and temperature measured in a duct is proposed in [14]. The harvester uses a DC motor to generate electric energy from wind; maximum power gained from the motor was 45 mW at a air flow of 9 m/s.

IV. ISSUES, CHALLENGES AND FUTURE RESEARCH DIRECTIONS

A. Energy Storage

For efficient functioning and long operational lifetime, it is crucial that sensor nodes incorporate proper energy storage mechanism. As discussed in previous sections that two main storage technologies can be integrated in sensor nodes super-capacitors and rechargeable batteries. Selecting a appropriate method is just a first step, these technologies have specific issues which limits exploiting the full potential of system and thus require research effort. Super-capacitors compared to rechargeable batteries is relatively a new and immature technology. A major challenge con-corning its use in WSN applications is the selfdischarge rate which is substantially high and halts its use in regular applications. The energy density of these devices is also relatively which is another concerning issue limiting its use [20].

B. Renewable Energy

Renewable energy is not a new concept but employing such a concept in miniature devices like sensor node is still immature and have issues which require considerable research effort. Light scavenging, which is considered a mature energy for harvesting, is directly dependent on the surface area of PV cells which also limit the energy captured especially in area where direct sunlight is not available; also the size of panel must be kept in compact form as increased size contradicts with miniature sensor nodes. The initial voltage required in electrostatic method is a major issue restricting the use of electrostatic energy harvesting system, so it requires considerable research. A research challenge in thermoelectric harvesting system is to use the wasted heat from different sources, and increase efficiency. Research is need in the development of materials that can operate at higher temperature gradients, and efficiently conduct electricity without conducting heat. Research is needed on small scale wind energy harvesters. Apart from source specific issues, other challenges also require critical attention. The scavenged energy requires effective power management among the sensor node this includes efficient utilization of extra energy, making optimal data collection and packet routing decision [21]. A lot of contribution has been made towards wake-up scheduling, as a consequence several effective robust schemes have been proposed, by incorporating energy scavenging schedules with these schemes a magnitude of energy can be conserved resulting in decreased issues related to harvest-ing. A node can also suspend its operation and retire to sleep mode for fast recharging when a node does not have enough power, thus some research effort should be performed for coupling wake-up scheduling schemes with harvesting schemes.

C. Wireless Recharging

Even though inductive coupling technique has been revised many times still the issues related to alignment and almost non-existent power transfer range are considered critical when employing this method. On the other hand, in refined form of this method the resonant coupling also suffer from the inherent problem of decrease in efficiency as the distance increases. If a mobile charging host is employed for these methods it will consume considerable energy by traveling to the sensor node, so to ensure that the host has enough amount of energy remaining to charge a number of nodes either traveling power consumption should be minimized or the mobile host should be equipped with two separate sources, these constraints require research effort. The RF method has only proven to be viable for low powered nodes, it requires considerable research for using this technique in regular nodes. The use of laser for powering sensor nodes is still in its infancy stage. Although it has a considerably high transfer efficiency but the power conversion is dependent on PV cells which can only provide a maximum conversion efficiency of 20%. Moreover, its use in a low cost sensor node is expensive and it can prove to be hazardous to health. The requirement for LoS makes it challenging for powering scattered nodes. Nevertheless, it is a viable method which can further enhance with research in decreasing the cost of hardware used. Like laser acoustic based energy transfer is also immature, the main drawbacks are related to transducer losses, medium losses, spreading losses and misalignment losses between the receiver and the source. These issues can be reduced by efficient transducer designing which is quite challenging and depends on factors like wave reflections, power level and efficiency of material used. Besides biomedical implementations, the use of acoustic as a energy transfer method requires a considerable research effort [19].

D. RF Energy Harvesting By Exploiting CR Technology

An important aspect which needs to be considered during wireless recharging is to exploit Cognitive Radio (CR) technology. Wireless sensor nodes equipped with CR devices can help in overall wireless recharging process[22,23]. Several CR device can simultaneously harvest energy emitted from a cellular base stations. When a primary user (PU) receives/transmits information

V. CONCLUSION

The evolution of Wireless Sensor Network have not only made them miniaturized but ubiquitous as well, enabling a wide range of applications. One of the paramount challenges that limit the performance of node is inadequate battery life. We have presented a brief survey on renewable energy approaches and battery recharging techniques for extending network lifetime. In this paper, we have discussed different aspects of renewable energy including primary concepts, potential source techniques to search these sources and presented WSN applications in which renewable energy is exploited. Furthermore, we have also surveyed battery recharging features, distribution approaches and a comparison between recharging techniques. To summarize, this paper contains a brief and up-to-date survey on energy scavenging and wireless recharging from renewable and traditional energy resources in sustainable Wireless Sensor Networks.

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