Energy Harvesting Techniques For Wireless Sensor Nodes Connected In IoT

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Abstract - As the Internet evolves, communication is no longer predominantly between users. Machines have begun generating and consuming content and this trend is accelerating massively. The Internet of Humans is increasingly being complemented by an Internet of Things (IoT) providing a wealth of new information and enabling new forms of automation. But the communication in the IoT has specific requirements. Energy harvesting wireless sensor nodes can meet these demands.

INTRODUCTION

The necessary networks built of sensors, actuators and processors can be composed and flexibly modified according to the actual demand. In the process, data storage and processing can be done locally or within a cloud-based infrastructure (Infrastructure as a Service – IaaS). Hence, a user instructs the heating system over the Internet to raise the temperature to comfort level ahead of returning home. Here, the content or the command respectively is generated by the human being, whereas the heating system processes the data and turns up the heating in a specific period of time.

Additionally, wireless sensors measure outdoor and room temperature which, together with the current weather forecast, can be used by the home automation system to calculate the required heating. Machines (sensors, actuators, control units) now communicate directly with users or other machines on a broad. With the Internet of things (IoT) and IPv6 users will be able to directly access data related to the current situation, followed by calculations in real time and the intelligent control of actuators.

BENEFITS OF INTERNET OF THINGS

Having a large network of sensors, actuators and control units all interacting with each other and the user can bring several distinct benefits. More input (sensor) data usually yields a better insight into the system status. This additional information allows a better decision-making process considering a broad range of criteria. Examples, where this is true, include industrial process control and automation, structural monitoring and agriculture. Unlike the standard approach of one or more sensors being connected to one central control unit, an Internet of Things allows the sharing and reuse of available information between different partners. Thus, the system collects data only once but uses the information for several applications.

Current control systems are usually local; for example sensors, control unit and actuators are often in close proximity and directly connected with each other (wired or wireless). An Internet of Things no longer requires such proximity. It allows centralized, or even outsourced computing resources (cloud-based computing), thus driving down infrastructure cost. The IoT also allows a dynamic creation of control networks. The networks can be formed or dissolved dynamically based on time, location or other parameters. For instance, cars could automatically query temperature sensors in the street to determine if there is a danger of ice on the roads and warn the driver accordingly. These examples illustrate the enormous potential that can be unleashed by Internet of Things. All the required base technologies for forming such network already exist today – sensors, actuators, local or cloud-based control units and IPv6 to connect all of them together.

REQUIREMENTS FOR A CONNECTED WORLD

Computing power is readily available both locally or cloud-based. The main challenge is how to deploy large numbers of sensor and actuator nodes and connect them in a suitable way. A large numbers of new sensor and actuator nodes need to be deployed (often in an existing infrastructure) where scaling up in the number of deployed units due to expansion etc. Service and maintenance required by individual nodes have to be minimal when creating large scale networks. The vast majority of nodes in such networks needs to be maintenance-free. Communication between all parties involved has to be rolled out. A true Internet of Things can only be formed if all of its nodes can be accessed via Internet Protocol (IP). It is not required that the nodes themselves physically communicate via IPv6 as long as the translation between the node's protocol and IPv6 is transparent. At the same time, secure data exchange is a key consideration when sensor information and actuator commands are exchanged over the Internet. Finally, the cost is almost always a limiting factor, so the total cost of ownership must be low.

These requirements can all be met by wireless systems giving ease of installation and scalability. Maintenance-free, zero cost of operation sensor and actuator nodes can only be achieved via energy harvesting wireless sensor nodes.

ENERGY SOURCES

There are three main categories of energy that are typically used for self-powered energy harvesting devices. Additional, less widely used ambient energy sources include electromagnetic waves as well as chemical and bioelectric systems. The key challenge with all these energy sources is that they provide very small amounts of energy. Energy release can occur either in short bursts or as a continuous trickle. In both cases, it typically needs to be accumulated and often converted (to higher voltage levels) to be usable. This places significant challenges on the design of energy harvesting wireless sensor nodes. Specifically, such devices need to have a very energy efficient system design using a very low duty cycle (devices are sleeping most of the time) and requiring only extremely low standby currents while sleeping. The communication protocol used by such devices needs to be optimized for energy efficiency to minimize their active time.

A. Main Power

Devices in IoT, may be connected to a wired power supply. This is more suitable for IoT applications with fixed-location devices, where a constant power supply can be connected to the device through wires or cables. This however makes the devices immobile, which limits its application in massive IoT. Moreover, it is impractical to connect every device to the power supply through wires when the number of devices is very large. This option is only feasible when the number of devices is very small, and due to specific requirements of the devices is the only way to power the devices.

B. Battery and Super Capacitors

Battery is the most common energy source which has been widely used in our everyday devices. The stored energy in batteries however is limited; therefore the battery-driven systems have a finite lifetime. It is also difficult and costly to regularly maintain and replace batteries especially when the nodes are remotely located or the number of nodes is very large. These are the main problems of battery-driven systems, which limit the use of batteries in some massive IoT applications. Non-rechargeable batteries cannot be solely used for many IoT applications due to ecological implications and the fact that they have only limited storage.

Battery storage is a mature technology when compared with energy harvesting technologies, and the fact that batteries are available in different sizes and shapes, make them strong candidate for many massive IoT applications, which are expected to operate with ultra-low power and have limited life time, up to 1o years. Therefore, the battery technology still plays an important role in the IoT ecosystem for many years. The unique requirements of many IoT applications open new challenges for battery providers.

C. RF Energy

In RF energy harvesting, the electricity is generated as a result of magnetic inductive coupling effect [10]. It is basically based on the induction of an open circuit voltage around the receive loop from a loop which carries a time varying current. The flux and the open-circuit voltage are mainly determined by the distance between the turns of the loops, the amplitude of the transmit loop current, and the dimension and distance between the loops [10]. The induced voltage at the recieve loop can be used to power a passive RFID tag or stored in a rechargeable battery. The voltage induced in the receive loop is approximately o.5 V [11].

Wireless energy harvesting (WEH) has been considered for powering IoT devices in [12] and improvements in terms of being wireless, availability of the RF energy, low cost and relatively easy implementation were shown. Sensor nodes which are powered by WEH usually consist of a transceiver and antenna element, a WEH unit which is responsible for scavenging RF energy and delivering a stable output power, a power management unit, and possibly an onboard battery. Recently, Freevolt proposed an innovative technology, called Low Energy Internet of Things (LE-IoT) devices, which can harvest RF energy from both short-range and cellular wireless networks, such 4G, WiFi and Digital TV [13].

D. Solar and Photovoltaic Cell

Photovoltaic (PV) is considered as one of the most effective EH techniques to power IoT devices due to its power density, efficiency, and the flexibility in terms of different output voltage and current [17], [18]. When sunlight is directed to certain semiconductor materials, solar energy will be converted into DC power. This is called the photovoltaic (PV) effect. A solar cell is usually composed of silicon and when it is stroke by sunlight with enough energy, the electron and holes are separated and using an input an output regulator, electrons start to move towards the load [19]. To control the charging current to a battery or super-capacitor a maximum power point tracking (MPPT) unit is necessary, which also maximize the efficiency of the PV cells.

E.Thermal energy

A thermal energy generator (TEG) converts temperature differences into electrical energy. A TEG usually suffers from low efficiency (5-1o%) which limits its widespread adoption [14], [15]. However it has a long life cycle and stationary parts. To extract the energy from a thermal source, a thermal difference is required; e.g, 3o degree difference in the temperature of hot and cold surfaces of the device in the room temperature, results in only up to 1o% conversion efficiency [16].

F. Mechanical Energy

Electrical energy can be harvested from vibrations, pressure and stress-strain. Electromagnetic, electrostatic, and piezoelectric are three main mechanisms to generate electricity from mechanical sources [19]. In electromagnetic energy harvesting, the electric current is generated when a magnet moves across a coil. In piezoelectric materials, an electric potential is induced at the terminals of a piezoelectric material due to the polarization of ions in the crystal as a result of the strain. In electrostatic converters, the plates of a charged capacitor are pulled using the vibration, which then results in electrical energy due to the change in the capacitance. Piezoelectric energy harvesters has the highest energy density, that is higher energy can be produced for a given surface area, which is very important in micro scales, where most IoT devices are supposed to operate. Electrostatic mechanism requires separates voltage source and electromagnetic usually generate low voltages.

G. Human Body

Human body is considered as a rich environment to scavenge energy to power wearable electronics [20], [21]. Wearable devices are very important in health monitoring applications, where sensor nodes are deployed on or implanted inside the human body, which form a network called wireless body are network (WBAN). As the battery replacement for wearable devices are inconvenient for people and sometimes impossible in cases when the devices are deployed inside the human body, the sensor nodes in WBAN must have very long lifetime. Therefore, energy harvesting from human body is favorable in these applications [19].

PIEZOELECTRIC ENERGY-HARVESTERS

Piezoelectric energy harvesters provide the consistent source of energy and the potential of generating electricity from piezoelectric energy harvesters is higher than alternative energy harvesting technologies. In this section, we study piezoelectric phenomena to be able to compare existing piezoelectric materials in the market. Piezoelectric materials can be optimized based on the intended application, to deliver the required level of voltage or current, and can be manufactured in any shape or size.

A. Piezoelectric phenomena

Direct piezoelectric effect is being considered as the main approach for harvesting energy from vibrations, where the external vibrations causes electrical charge on the terminal of the piezoelectric material [22]. The monocrystal and polycrystalline structure of same materials can be used to explain the piezoelectricity concept. As shown in Fig. 5-a the polar axes of all carriers are aligned in the same direction in a monocrystal. In polycrystal however, different regions within the material have different polar axes. The piezoelectric effect can be obtained by heating the polycrystal to the Curie point and then applying at a same time a strong electric field.

There are several figure of merit (FoM) for piezoelectric energy harvesting, but we only discuss about the power density which is more relevant to our topic. The power density which is defined as the ratio of generated power over the active material volume or over the active material area. The output power of a piezoelectric generator is proportional to the proof mass, the square of the acceleration magnitude of the driving vibrations, and inversely related to the frequency. As mentioned in [23], piezoelectric devices provide high voltages and low currents. However, using multiple layers of bio-morphs, it is easy to design a system that produces voltages and currents in an appropriate range.

B. Advancement in piezoelectric fabrication for energy harvesting

Various materials have been previously shown to demonstrate piezoelectric effect and used in several applications such as actuators, sensors, nanogenerators, atomic force microscopes (AFM), high voltage application, energy-harvesting devices, and medical applications. All of these technologies mainly rely on the mechanical energy harvesting [24]. A wide range of both natural and synthetic materials exhibit piezoelectricity. More than 2oo piezoelectric materials are available now, where for each energy harvesting application a specific type can be used. Many biological tissues such as bone, intestine and tendon exhibit piezoelectricity. Some naturally occurring crystals, such as quartz, rochelle salt, cane sugar, topaz, sucrose are classified as natural piezoelectric materials. Lead zirconate titanate (PZT), zinc oxide (ZnO), barium tintanate (BaTiO3), gallium orthophosphate(GaPO4), potassium niobate (KNbO3), lead titanate (PbTiO3), Lithiul tantalate LiTaO3), langasite (La3Ga5SiO14), sodium tungstate (Na2WO3) and PVDF are the main synthetic piezoelectric materials, which have been widely used.

C. Design considerations for piezoelectric based EH-enabled devices

We have conducted some research in the area of PVDF based piezoelectric materials. The primary focus has been on the investigation of fabrication methods for composite fibers and powder including nanomaterials. By changing the fabrication techniques, process parameters, starting materials, the piezoelectric, morphological, and mechanical performance of PVDF are completely varied. By tuning the process parameters, tailored PVDF fibres with the desired piezoelectric performance can be developed. To develop more efficient nanogenerator for energy harvesting from piezoelectric materials, we need to optimize the output performance to achieve a higher energy efficiency. In addition to piezoelectric performance, properties such as formability, corrosion/wear/fatigue resistance need to be considered in fabrication of flexible nanogenerators.

CONCLUSION

This paper reviews energy harvesting techniques for Internet of Things (IoT) services and applications. Over 5o billion multi-role devices, capable of sensing and actuating, will be installed by 2o25, which shows a tremendous growth in the number of devices and creates new challenges and opportunities. A major burden is powering these devices, as using the main power and batteries is mostly restricted due to the small sizes of many devices and the fact that these devices are installed in hard-to-reach areas, where regular battery maintenance is impractical and very expensive. A viable solution is to use energy harvesting techniques to harvest energy from environment and provide enough energy to the devices to perform their operations. This will significantly increase the device life time and eliminate the need for the battery as an energy source. Different energy harvesting techniques were presented in this survey and pros and cons of each techniques were discussed. As efficient energy harvesting technique, we focused on piezoelectric energy harvesting and radio frequency energy harvesting due. We briefly introduced the main concepts and design challenges for these technologies.

As short-range wireless technologies are operating at mW power range, the development of battery-less IoT devices may be feasible. However, due to the large transmit power of most LPWAN technologies, which are expected to play key roles to provide massive IoT services, batteries will remain an essential parts of IoT devices operating over LPWANs. Energy harvesting techniques will then play key roles in increasing the device life-time by providing a sustainable way to recharge the batteries.

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