Comparative study of energy harvesting wireless sensor node platforms.

V.C. Lokhande* and Y.M. Patil.

Abstract The present wireless sensor nodes work mostly on battery. There are a few platforms available which perform energy harvesting and use the harvested energy for their operation. While doing so they directly store the energy in the only available power source i.e. battery or super-capacitor. There are many such platforms and nodes created. Some of them have energy harvesting capabilities and store the harvested energy directly in the battery or super-capacitors. A comparative study of such nodes is made.

Keywords: Battery, charging-discharging, Energy harvesting, Lifetime, Wireless sensor network, Super-capacitor, Solar panels.

1 INTRODUCTION

The wireless sensor network is a network of nodes which work in cooperation to acquire data and send it to the gateway or the sink node. Sensor networks are formed from a collection of sensing nodes which communicate with one another, typically through wireless channels, in order to collect spatially distributed data about their environment. Such networks have the potential to provide better quality data than single or small numbers of individual sensors in applications such as natural and built environmental monitoring, process monitoring, security and surveillance. Wireless sensor networks (wsn) may be considered as the third wave of a revolution in wireless technology. They promise to have a significant beneficial impact on many aspects of our human existence. These benefits include more efficient utilization of resources, better understanding of the behavior of humans, natural and engineering systems, and increased safety and security. In order to be cost effective in many applications,

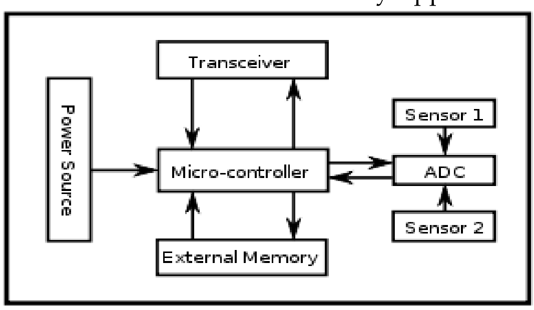

Fig 1 Functional Diagram of wireless sensor node (mote).

The functional diagram in figure 1.1 shows the basic blocks. The node has a power source,

the sensor nodes must be low cost and low maintenance. This presents challenges in terms of sensor calibration, packaging for survival in harsh environments and, particularly, the efficient supply and utilization of power.

The basis of the wsn is the nodes or motes. A mote/node is a unit component of the wsn. Typical mote consists of a sensor, processor and radio interface.

The basic components of a mote/node are:

1. Sensor
2. Power supply
3. Processor and memory
4. Radio interface.

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The basic functional diagram of a mote is shown below.

microcontroller, transceiver, sensor and external memory. However, the memory block is optional and is used as per the application's requirement. The main function of the node is sensing and sending the data to the base station. The sensor is a device which senses a physical parameter and generates or gives out an electrical signal/output. There can be many sensors on the node depending on the physical parameters being monitored. The function of the microcontroller is to control the functioning of the node. It can run the operating system like TinyOS, and control the functioning of the node. Also, in addition to that the micro controller plays an integral part in the working of the network. The micro controller is the main decision making and processing unit on the node. It controls the wakeup and sleep cycle of the node and manages the power of the node. The data from the sensor is processed by the controller and sent to the transceiver. The micro controller also logs the data onto the external memory. The transceiver block provides the communication capabilities to the node. It is the wireless interface using which the node communicates. There are many wireless interfaces available which can be used for communication between the nodes. The transceiver transmits as well as receives the data from other nodes. The data is forwarded to base station with the help of other nodes.

The basic functional diagram of a wsn is shown below.

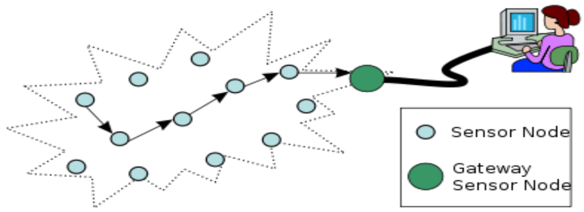

Fig 2 Functional diagram of Wireless Sensor Network.

The wireless sensor network in figure 1.2 is a network of sensor nodes which cooperatively work to transmit data through the network. The nodes transmit data through the network based on the routing protocol used. This protocol determines the path and the way in which communication will take place. The nodes relay the data to the sink node. The sink node aggregates the data from the nodes and then transmits it to the base station. The base station logs the data onto the memory and makes it available to the end users. The base station acts as a gateway- giving an interface between wireless sensor network and other networks. In some cases the sink node and base station may the same and in some large networks there may be multiple sink nodes. The network has substantial influence over the node's energy.

2. Applications of WSN:

The concept of wsn has gained interest due to various sensors it can support. The sensors and sense many physical parameters such as temperature, humidity, seismic vibrations, speed, light, sound etc. The sensors available can be utilized in different applications and ambient conditions. This spectrum of applications includes security, monitoring of space assets for potential and human-made threats in space, ground based monitoring of both land and water, intelligence gathering for defense, environmental monitoring, urban warfare, weather and climate analysis and prediction, battlefield monitoring and surveillance, exploration of the Solar System and beyond, monitoring of seismic acceleration, strain, temperature, wind speed and GPS data.

Military Application:

The main advantage of the wsn is the ability to perform in remote and hostile conditions. The motes can be deployed in region of interest and utilized to reliably monitor the area. Most the military application of wsn is event driven. Motes will communicate data when the event crosses the threshold. These thresholds include sensing of seismic vibrations caused by movement of heavy transportation carriers, sudden change in ambient noise and temperature, detection of human presence (Sniper detection) etc. Some of the military applications of sensor networks are monitoring friendly forces, equipment, and ammunition, battlefield surveillance, battle damage assessment, and nuclear, biological, and chemical attack detection. WSN promises a highly coordinated smart self organizing network which provides vital and reliable data. Such ' intel ' provides a decisive advantage in battlefield.

Environmental monitoring:

In the present day scenario where the global community is facing life threatening problems such as Climate change, biodiversity loss, pollution etc, the wsn can help us in monitoring various environmental parameters as well as animals, birds and crops. Such monitoring may also help us in pinpointing the exact causes and help in mitigating the adverse effects of environmental phenomenon by timely preparedness. The network of motes deployed in an environment can monitor an array of parameters. It can also be used in disaster management by alerting the people and authorities of natural disasters. A similar monitoring for two volcanoes in Chile successfully proved that wsn can perform reliably in harshest conditions to provide with information which can help in disaster management Crops and farming are the most vulnerable to climate change. The wsn can provide a constant monitoring platform wherein most of the parameters required for plant growth can be monitored.

Health care Application: The developments in implanted biomedical devices and smart integrated sensors make the usage of sensor networks for biomedical applications possible. Some of the health applications for sensor networks are the provision of interfaces for the disabled, integrated patient monitoring, diagnostics, drug administration in hospital, tele-monitoring of human physiological data, and tracking and monitoring doctors and patients inside a hospital**.**

While studying the wsn it is necessary to understand the detail working of the node and its components. The applications for which, it is being utilized. The application may require constant monitoring and data transmission or it may be event driven. Depending upon the application optimized choices is to be made regarding the components of the node and other factors such as routing protocol. It is apparent that the most important problem for a wsn is the power. Power on the mote is limited. Mostly the motes are being battery powered and can last upto 2-3 years. However, with use of passive techniques to save power, can extend the lifetime by some margin if not much. These techniques include task scheduling, routing protocol etc. The energy usage is optimized and all the functions of the mote are scheduled so as to conserve the energy available. These methods are only a way to optimize and conserve energy. With a limited power source such as battery which has its own internal losses, such techniques do not contribute much. The answer lies in the energy harvesting from the environment to keep the power source replenished. This not only ensures uninterrupted supply but also a reliable network.

3. Energy harvesting:

Energy harvesting is a technique that captures, harvest or scavenge unused ambient energy (such as vibrational, thermal, wind, solar, etc.) and convert the harvested energy into usable electrical energy which is stored and used for performing sensing or actuation. The harvested energy is generally very small. Energy harvested from the ambient are used to power small autonomous sensors that are deployed in remote locations for sensing or even to endure long-term exposure to hostile environments. The operations of these small autonomous sensors are often restricted by the reliance on battery energy. Hence the driving force behind the search for energy harvesting technique is the desire to power wireless sensor networks and mobile devices for extended operation with the supplement of the energy storage elements if not completely eliminating the storage elements such as batteries.
The most widely used energy harvesting devices rely on solar, thermal, RF, and piezoelectric sources of energy.
Photovoltaic (PV) or solar cells convert light energy into electricity. Photovoltaic cells have the highest power density and highest power output of the various energy harvesting devices.
Thermoelectric energy harvesters convert heat into electricity. They consist of arrays of thermo-couplers that generate voltage in response to a temperature differential across their bimetal junctions (the Seebeck effect). The reverse is also true: impressing voltage on a thermocouple junction heats one junction while cooling the other which is the basis for heat pumps (the Peltier effect).
RF energy harvesters capture ambient RF radiation, rectify it, boost it, and use it to power ultra-low-power embedded devices. RFID works on that principle, though by reacting to a strong RF field that is directed at the sensor and not by harvesting ambient RF.
Piezoelectric transducers convert pressure or stress into electricity. The vibration from motors, airfoils, or roadbeds commonly power piezoelectric energy harvesters that, in turn, power a processor.

Energy Source	Performance (Power Density)
Solar (direct sunlight)	100 mW/cm3
Vibrational Micro-Generators	4 µW/cm3
Piezoelectric Push Buttons	50 µJ/N
RF and Inductive	Wide range
Thermal	0.5-10mW (20 degree gradient.)

Table-1. Comparison between power densities of various energy sources

The table 1 compares different energy sources used for harvesting energy. Out of all the sources, solar energy produces highest output. The RF and thermal sources also produce considerable output but are still too low to be harvested for wireless sensor network.

4.Comparison of various platforms.

Everlast: F Simjee and P. Chou [2] built a node which completely cut out the battery factor coming in to play. The node is powered by a super-capacitor which has high capacity. The super-capacitor is connected to the solar panels through MPPT circuitry. Since the node is powered by only a super-capacitor, any available solar panel output should be used efficiently. This is one of the reasons to introduce MPPT in the node. The node uses V_{oc} lookup table type MPPT. It requires a dedicated microcontroller and hardware to perform MPPT. The novelty of this system lies in the feed-forward, PFM (pulse frequency modulated) converter and open-circuit solar voltage method for maximum power point tracking, enabling the solar cell to efficiently charge the super-capacitor and power the node. The system is designed for three primary tasks: charging the capacitor using a pulse-frequency modulated (PFM) regulator, feeding the PFM controller the optimal operating point for the solar cell, and all the typical WSN functions including reading sensor data and communication with nodes and base stations through the wireless transceiver.
The Everlast sensor node had put for a radical concept of battery less wireless sensor node. This naturally reduces the cost and increases the lifetime. With the the replacement of the battery with the super-capacitor, sensor nodes can operate for 20 years while maintaining high data rates. Using a feed-forward PFM regulator with open-circuit voltage MPPT, the Everlast system charges the capacitor efficiently by enabling the solar cell to generate maximum power. More accurate MPPT and higher efficiency can be achieved with some fine-tuning of the present design.

AmbiMax[3]: AmbiMax is an energy harvesting circuit and a super-capacitor based energy storage system for wireless sensor nodes (WSN). Previous WSNs attempt to harvest energy from various sources, and some also use super-capacitors instead of batteries to address the battery aging problem. However, they either waste much available energy due to impedance mismatch, or they require active digital control that incurs overhead, or they work with only one specific type of source. AmbiMax addresses these problems by first performing maximum power point tracking (MPPT) autonomously, and then charges super-capacitors at maximum efficiency. Furthermore, AmbiMax is modular and enables composition of multiple energy harvesting sources including solar, wind, thermal, and vibration, each with a

different optimal size. Experimental results on a real V platform, Eco, show that AmbiMax successfully man multiple power sources simultaneously and autonomousl several times the efficiency of the current state-of-the-art WSNs. hardware architecture of the AmbiMax platform consists of three subsystems: Energy Harvesting (I Reservoir Capacitor Array (RCA), and Control/Charger (C Each energy harvesting subsystem harvests energy charges its own reservoir capacitors (RCs) at the source's maximum power point. The RCs of different sources comp the Reservoir Capacitor Array. The system can be powered the ambient sources or battery. It draws power from battery when the RCA's terminal voltage drops below threshold. When the ambient power sources produce m energy than needed to drive the system, then they also ch the battery. All the functions are mostly controlled by analog circuitry. Hardware used in implementation, solar module (4-40-100) whose maximum output voltage current are
4.0V and 100mA, respectively, The energy harvesting consists of a switching regulator (LTC 3401) and an M tracker. Super-capacitor used are two 22F and two 10F Panasonic super-capacitors. AmbiMax can harvest three times more energy 12.5 times faster under good supply (solar, wind) condition, and can continue harvesting even at lower supply levels.

Prometheus[4]: Xiaofan Jiang, Joseph Polastre, and David Culler in their paper "Perpetual Environmentally Powered Sensor Networks" introduced a node capable of harvesting energy and storing it in super-capacitors. The solar panel output is directly connected to the super-capacitors. These capacitors when fully charged will charge the battery. And with sufficient voltage on the solar panels the super-capacitor will power the node. The node normally works on the super-capacitor's energy seldom drawing current from the battery. Since the battery is used less, it needs to be charged less number of time. This increases the overall life of the node. Hardware used is Sunceram's 37x82mm solar panel producing output of 5 V, super-capacitors of 22F capacity and a lithium ion battery of 500mA has been used.

Comparative table:

Name	Energy harvesting	Source	MPPT Used.	Hardware
Everlast	Solar energy.	Super-capacitor	Look up Table.	Solar panel and super-capacitor
Ambimax	Temperature, vibration, solar energy.	Dual	Open circuit voltage.	Solar panel, super-capacitor and battery
Prometheus	Solar energy.	Dual	Constant voltage.	Solar panel, super-capacitor and battery

Table 1 Comparison between three platforms and nodes.

5. Conclusion:

The three nodes have been comparatively studied. The Everlast system uses only super-capacitor to avoid the battery aging problem. It uses capacitor of higher capacity and therefore it is essential to charge using MPPT. It can maximize the life of node upto 20 years. AmbiMax is a platform which can harvest energy from various sources. The node uses dual source and can also charge on board battery. Prometheus also, uses solar panels to charge super capacitor and the battery. The lifetime of the node with 1% duty cycle is 43 years. However, the life of the node is limited by the component lifetime.

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