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A Survey on Harnessing Renewable Energy Sources to Power Wireless Sensor Networks for Agriculture

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ABSTRACT: With the Wireless Sensor Networks distributed over a large area, the management of their energy resources has become a topic of interest in research. Wireless sensors mostly use batteries as their power supply but in some applications battery replacement can be cumbersome and require considerable amount of time which can affect the process being monitored. It is possible to harvest energy from the renewable sources of energy in nature for wireless sensors. In this article, a survey of current alternative energy sources has been demonstrated in order to address the feasibility of their integration with wireless sensor networks.

KEYWORDS: Wireless Sensor Networks; cumbersome; harvest energy; renewable sources

I. INTRODUCTION

Apart from the Service sector and the Industry sector, Agriculture is the other dominant sector of Indian economy, which determines the growth and sustainability. Agriculture forms a means of employment and livelihood for about 65 percent of the population. India is the first in the world in the production of milk, pulses, jute and jute-like fibres; second in rice, wheat, sugarcane, groundnut, vegetables, fruits and cotton production. Agriculture needs fresh water as a continuous supply and fresh water resources are slowly receding and it is very important for us to use efficiently this scarce resource. To save water during irrigation, the amount of water that a plant needs must be known with sufficient precision. So a continuous monitoring of the water content in the soil will lead to better use of water resources. There have been several studies on the implementation of the WSN for agriculture. Wireless sensor networks are a promising technology which can adapt to the system, and have the ease of maintenance and low-cost. Wireless sensors are recent in their applications to agriculture and since they are to be used by farmers, who may not be specialized technically. So suitable training is also required in using these networks. WSNs are also advantageous since they do not need extensive wiring; Wireless sensor networks are a technology suitable for low-power wireless measurement and control applications. Wireless nodes eliminate connecting wires and reduce the cost and create improved reliability for many long term monitoring applications. Sensors communicating wirelessly can exchange data between themselves that is the nodes and the access point. Agriculture needs the continuous monitoring of physical phenomena. This is possible with the development of Wireless Sensor Networks.WSN consists of a radio, which is used for continuous transmission and reception of data, sensors to sense the parameter of interest, processors to process the data generated and batteries to power the network. The COMMON-Sense Net system has designed and developed an integrated network of sensors for agricultural management in the rural semi-arid areas of developing countries. In the project, operational in Karnataka, the WSN nodes are used to monitor the environment and collect information on environmental parameters like soil moisture, rain fall and ambient temperature. Each node will be connected to several sensors and each sensor is programmed to transmit data to a field aggregation node. The field aggregation node collects these data and transmits

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to the Central server in Centre for Electronics Design and Testing (CEDT), Indian Institute of Science (IISc) now known as Department of Electronic Systems and Engineering (DESE) via Data mule. However, a number of limitations and challenges exist in the deployment of sensor networks for agriculture. This includes the limited battery power and the reliability of data transfer from the nodes and within the network. Sensor networks (WSN) use portable energy sources, namely batteries to power the sensors. All components of the WSN depend on power and a primary limitation of a WSN is the constraints on the power source. Battery lifetime is one of the primary challenges, which needs to be addressed. Battery energy is saved if there is no transmission. If a node in a WSN goes to sleep mode, the energy conserved is a maximum. The different rechargeable batteries normally used in WSNs are Lithium Ion and Nickel Metal Hydride batteries. However sensors are to be powered at all times since it provides information to the main control unit. Energy harvesting is a means to provide the sensors with power from alternative sources such as solar, wind, vibrations, and temperature variations. Several types of solar panels are used in sensor nodes. However since the amount of sunlight varies, it is required to store this energy. So a secondary battery may be needed depending on the application. Wind energy can be harvested and used as a suitable alternative energy source. The recent interest in using wind energy is due to the fact that there have been newer technologies to harness this energy. Two important features, which need emphasis in sustainable WSNs, are energy harvesting and energy management in the sensor networks. Energy harvesting is the use of renewable sources to power the nodes in a WSN, and energy management includes power management in the network. Energy management requires the knowledge of different protocols which can be implemented in a sensor network. Presently the gross cost of the wireless sensor networks employed in agriculture is very high. They are either energy-aware or cost-effective, not both. The WSN was implemented for precision agriculture in a vineyard at village Pindhurli, Tahesil Sinnar, District Nasik, Maharashtra, India, but the cost and power constraints were not considered.

II. RELATED WORK

Numerous research efforts have been reported on renewable energy harvesting. Of one such is Radiated far-field, Radiated far-field power can propagate to a longer distance compared to near-field inductively coupled power due to a different attenuation rate. Far-field energy attenuates at 20dB/decade, which is a much smaller rate compared to that of near-field energy. Many reported efforts have used complementary metal–oxide–semiconductor (CMOS) technology to harvest power at UHF radio-frequency identification (RFID) band utilizing conventional RFID standards. The RF energy harvesters based on CMOS technology are much more compact than board level designs, but they are challenging to optimize at various frequency bands and various input power levels once a design is fixed. In this section, recently reported board-level designs for far-field ambient RF energy harvesting are discussed. Board-level harvesting systems utilizing the conventional RFID standards have been reported, and have been optimized for collecting a single tone within the RFID frequency band of 862–928 MHz. They utilize an RFID reader as the source, which it has 2–4 W of equivalent isotropic radiated power (EIRP) and operates in midrange (4–5 m). The sensitivity of the RFID-based RF energy-harvesting system has been improved to power values below 14 dBm by introducing a charge pump circuit; nevertheless, this sensitivity is not sufficient to harvest practical ambient wireless power from long-distance sources in TV, radio, or cellular bands. Wireless energy-harvesting devices for ambient signals far away from the RF sources have been reported in various papers. A rectifier with a dc–dc converter topology for the cellular frequency band at 1.96 GHz was proposed. The reported RF–dc conversion efficiency was more than 60% when the input power level was higher than 15 dBm (30W) and the RF source was 50 m away from the energy harvester, a shorter distance compared to other similar harvesters. A lithium battery was charged by the harvested RF power. The high density of RF energy in an urban area has been considered an energy source as well. The wireless signals, such as TV, cellular, global system for mobile (GSM), and radio signals, are spread over multiple frequencies in urban areas although the power level of each signal could be as low as 40 dBm. Multiband antennas, optimized rectennas, and power management modules for each frequency band were designed and integrated to collect efficiently the ambient RF energy. A magnetic material loaded antenna was utilized to harvest energy in these reported efforts. The reported works in demonstrated the feasibility of powering low-power electronics from prebuilt wireless infrastructure systems, such as a communication system or a broadcasting system, without a battery. Recently, an ambient digital TV signal at the UHF band has been harvested and autonomous operation of a sensor platform has been demonstrated in. In this research effort, a high-gain broadband antenna was utilized to harvest a sufficient amount of power to turn on an embedded microcontroller or a sensor and implement a truly autonomous operability. Digital TV signals within 512–566-MHz frequency bands were captured, rectified, and stored in a capacitor to drive the embedded systems from 6.3km away from the digital TV broadcasting station. A charge pump circuit was optimized to rectify and create 1.8–3.3 V from ambient RF power (below 25 dBm) at the UHF band.

III. TOPOLOGY OF THE SENSOR NETWORK

A.SENSOR NETWORKS

Wireless sensor networks (WSN) consist of a large number of densely populated small sensor nodes which sense, acquire data, compute and have wireless communication capabilities. Sensor nodes do not incorporate an infrastructure. Sensor networks have the capability to build a network, without any external guidance or supervision. Precision agriculture is one of the most common applications of WSNs where wireless sensor networks may deliver a feasible or optimal solution. Wireless sensor networks are composed of battery-driven communication entities performing multiple, usually different tasks. Batteries are portable sources of energy and can be drained due to current leakages. This can occur even when they are not used. Also, any defect in packaging due to long term wear and tear can lead to environmental problems. A wireless sensor network that is not dependent on a limited power source such as a battery can last very long, ideally infinite lifetime. All sensor nodes exchange and forward measured and acquired data. This collaboration can take place in an ad hoc manner to complete an assigned task.

B. NETWORK TOPOLOGY

The WSN consists of nodes. Each node contains a power supply, sensor and a processing unit. The power supply is from a battery, which has to be charged frequently. It may have an energy harvesting system such as a solar panel, Piezoelectricity, Thermal Energy, Radio or a wind energy harvester associated with it. A node can have one or more sensors attached to it. The processing unit listens to the sensors and then transmits the received data to other nodes. The nodes typically relay the information to the central processor. The protocols for a particular application in a sensor network are specifically designed. WSNs typically have low volumes of data, hence need low bit rate. Communication in a sensor should be reliable and should consume minimum power. This leads to a trade-off between reliability and energy efficiency. We assume in our project the presence of six nodes being monitored by a central processing unit. Two important features which need emphasis in sustainable WSNs are energy harvesting and energy management in the sensor networks. Energy harvesting is the use of renewable sources to power the nodes in a WSN, and energy management includes power management in the network. Power management of nodes in sensor networks can be handled with suitable metrics. However residual battery levels are not always the best measure. This is because such data does not provide any definite information on the future energy available from the battery and hence is not well suited in power management. Instead, information about future energy available from the battery is a better measure to make optimal routing decisions where throughput is the main consideration since energy can be replenished. However, the amount of power provided by the environment is limited. Therefore a routing algorithm that takes into consideration actual environmental conditions is required. Using energy harvesting to supplement batteries does not eliminate the problem of having to replace the batteries when they run out. It only delays the replacement.

C. SLEEP SCHEDULING

A node need not necessarily be listening to the network all the time. The wastage in power due to idling is a serious concern. So periodic listen, sleep and transmit operations have to be performed to mitigate power wastage. Basic idea is that a node listens to the network for a certain fixed time and then goes to sleep, during which the power consumption of the transceiver is negligible. A node needs to listen only to its immediate neighbours, which is an added advantage with respect to power savings. The duty cycle of a node depends directly on the number of neighbours as given in the equation. Meanwhile, the received data is stored and processed. The abstract data to be transmitted are stored and forwarded to the best neighbour (in energy-aware sense) by the node, during its turn to transmit. The i^{th} pulse is dedicated for the i^{th} node for transmitting the packets assembled during sleep as indicated in the Fig. 1. As a result there is inherent latency added due to scheduling.Fig.1 Periodic listen, sleep and transmit. Even though all the nodes in the network are synchronized there will be a phase difference due to the latency experienced the broadcast packet (synchronization packet) from coordinator to the farthest node (in terms of number of hops).This delay is called “To” overlap is given by the relation.

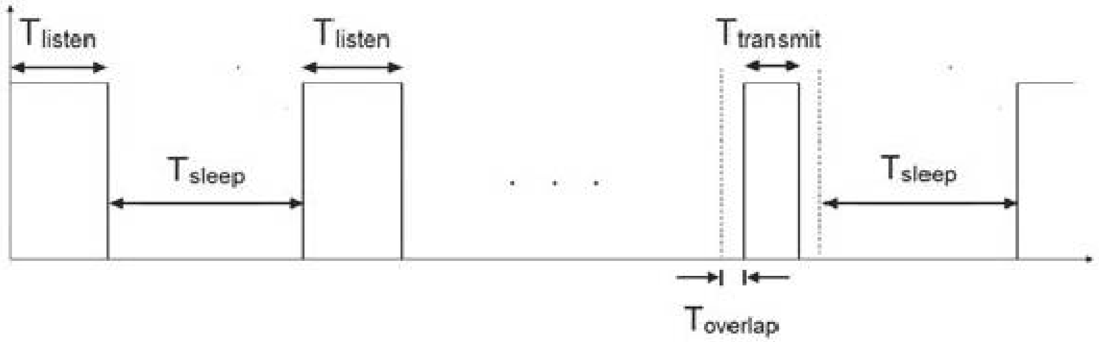

Fig.1 Periodic listen, sleep and transmit

D. POWER MEASUREMENT OF WSN NODE

Generally lifetime of wireless sensor node is correlated with the battery current usage profile. By being able to estimate the power consumption of the sensor nodes, applications and routing protocols are able to make informed decisions that increase the lifetime of the sensor network. As most WSN nodes are battery powered, their lifetime is highly dependent on their power consumption.

To capture the power consumption, a digital oscilloscope Tektronics was set up to measure the voltage v(t) over a series resistor R. A small resistance value was chosen in order to minimize additional voltage drop. The setting is shown in Figure 2.

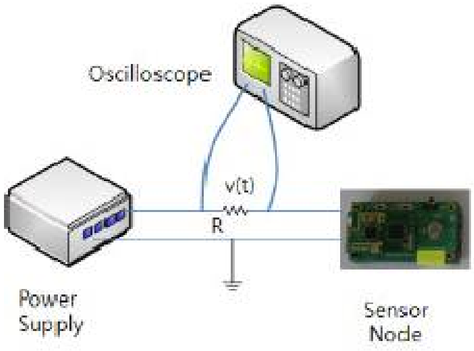

Fig 2: Set up to measure the voltage v(t) over a series resistor R

During measurement the oscilloscope has been setup to use as much as possible of the available resolution. There is CF card interface for exporting screenshots and measured data. The resistor was chosen to 10 Ohm to get a reasonably large signal to measure while keeping the voltage fluctuation.

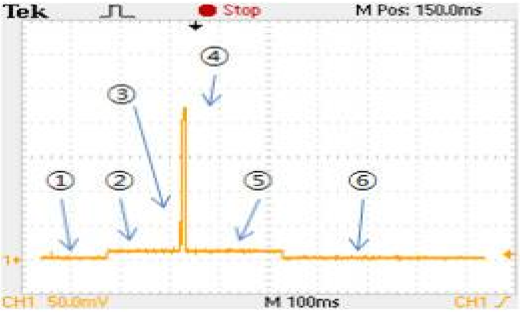

Fig 3. Measured voltage profile

Table 1 gives approximate values for power consumption. EPIR_LED is power consumption of LED while humidity sensing, ETX_PIR is power consumption while data transmission, ESleep is power consumption while sleeping, and ETX_PIR is power consumption while time stamp data transmission. ISleep is current consumption while sleeping.

Table 1. Power consumption parameters

Interval		Power Consumption
	E_{PIR_LED}	0.80568
②	E_{PIR_LED}	0.29760
⑤	E_{TX_PIR}	0.73877
③, ④	E_{Sleep}	0.60418
①⑥ -	E_{TX_Time}	0.61572
	I_{Sleep}	0.401 [mA]

The power consumption W was measured in six representative operating modes, based on these measurement the model was formulated. The expression is given in Equation 1 with a description of the variables given in Table 1.

$$W = \left(N \cdot (E_{TX\_PIR} + E_{PIR\_LED} + E_{Sleep}) + E_{TX\_Time} + 3V \cdot I_{Sleep} \cdot (3600 - (N+1)\sec)\right) / (3600\sec/h)$$

Where N is a number of movements per one hour.

Sensing modules powered two 1.5V (2000mAh) AA batteries. Total lifetime is given Equation 2.

$$Lifetime[h] = \frac{3V \times 2000mAh}{W}$$

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IV. RENEWABLE ENERGY SOURCES

A. SOLAR ENERGY:

Typically, a sensor node which uses energy from nature, consists of several blocks such as energy harvesting module, the storage unit such as a supercapacitor, sensing element, microcontroller and a transmitter as shown in Figure 3

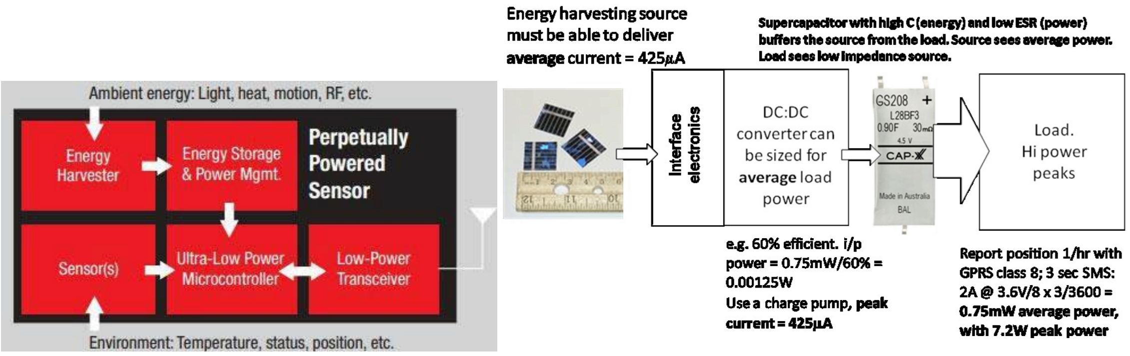

Fig.4 Wireless sensor network with an energy harvesting module

Photovoltaic is the technology that generates direct current from semiconductors when they are illuminated by photons. Most of the solar cells today are made of crystalline silicon (c-Si). Silicon has been the most widely used material in the production of photovoltaic modules. The mono- crystal, multi-crystal, micro-crystal and amorphous are the most widely used forms of silicon in the production of photovoltaic cells.

Solar energy can generate enough amount of power necessary for wireless sensors. A solar panel is used as an energy harvesting source for the wireless sensor. Solar energy harvesting provides direct DC voltage and therefore additional circuit rectifications are not required. This type of energy scavenging is free of emissions since it does not produce contaminants or bypass products that are harmful to the environment. One of the limitations of solar energy is its dependency on solar radiation, which can be degraded in areas where enough sunlight is not available. Solar energy is characterized by having a varying nature. The other issue associated with solar cells and for which some research is ongoing is the cooling of solar cells and recovering heat.

B. PIEZOELECTRICITY:

Piezoelectricity stems from the Greek word “piezo” for pressure and the word “electric” for electricity. The main advantage of piezoelectric materials as shown in Figure 4 is the high amount of voltage they can provide. Some materials which have piezoelectric effect are quartz, soft and hard lead ziconate titane piezoceramics (PZT-5H and PZT5A), barium titanate (BaTiO3) and polyvinylidene flouride (PVDF). In the piezoelectric effect the usable output voltage can be obtained directly from the material and there is no need for applying multistage post processing for generating the desired amount of voltage. Piezoelectric materials require dynamic forces in order to retain the output voltage and a notable drawback of piezoelectric sensors is their inability to respond to static loads.

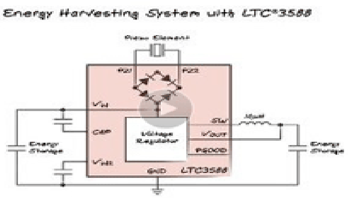

Fig 5: Energy Harvesting with LTC 3588

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C. RADIO ENERGY:

The possibility of harvesting RF energy, from ambient, enables wireless charging of a sensor node. Having a transmitter set, one can harvest energy from radio waves and the advantage of this alternative is the fact that the scavenging mechanism can be flexible and it is possible to control the amount of transferred energy by making it continuous i.e. on regular intervals or the amount of radiated energy can be adjusted according to the requirements of the relevant application. It is necessary to note that, according to the Friis equation, the amount of power collected at the receiver side is not equal to the exact value sent by transmitter.

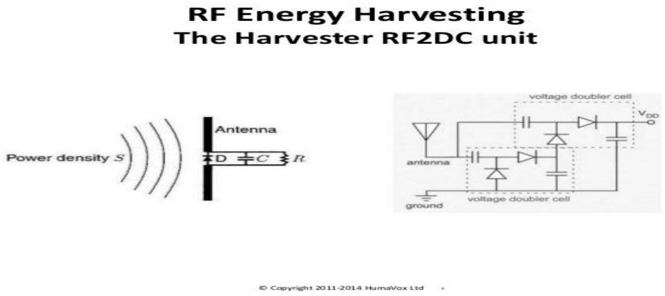

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Fig 6: RF Energy Harvester System

D. THERMAL ENERGY :

Thermal energy produces electricity when there is a temperature difference (Seebeck effect).

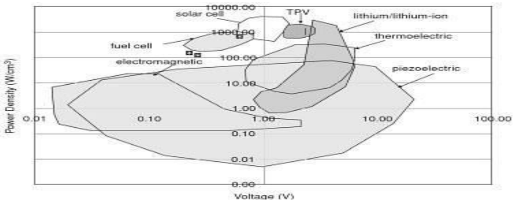


Fig.7 The voltage generated by the piezoelectric material itself is greater than the value produced by some other harvesting sources.

Most thermoelectric generators consist of n type and p type or an array of p- and n- type semiconductors in series. Heat from a hot source reaches the hot shoe and is conducted through to the semiconductors. The hot shoe has a high thermal conductivity and as well as a high electrical conductivity. Electrons are released from n type semiconductor and establish a current through p type semiconductor. Cold shoes transfer the current to the electric load. Commercially available thermoelectric generators require a temperature difference of 10–200°C. This type of energy is able to provide supply DC power continuously but temperature differentials can be difficult to generate in enclosed environments.

E. WIND ENERGY:

Among the various forms of existing renewable energy sources, wind energy is one of the remarkable sources in the macro scale for generating electricity. Countries like Germany, Spain and Denmark have provided a significant amount of their required electricity by using this type of energy. Having evaluated the given possibilities in high power electronics, its application can be also surveyed for miniaturized devices. In the study presented, different wind turbine blade configurations (two, three and six blade propellers) within a wind speed interval of 3.5 to 7 m/s were tested. The propeller with six blades output the maximum power. It is proposed that to add a solar panel to the harvesting system. In case the amount of energy provided by wind energy will not suffice. During the analysis of alternative sources for wireless sensor networks, an experiment to survey the feasibility of using wind energy as a complementary system for wireless sensor systems was performed. In this experiment, two types of blades were tested. The measured wind speed was 3.7 m/s and 4.5 m/s. In the first case, the length of each blade was 4.35 cm and in the second one, it corresponded to 8.85 cm. Figure 6 shows power generated by the wind turbine as a function of load. The peak power for the propeller with smaller blades at the speed of 4.5 m/s is 7.2 mW. At 3.7 m/s, the peak value of power for the first type of blade is 5.5 mW and for the second type of blade, the maximum amount of power at the speed of 4.5 m/s is approximately 5.5 mW (Figure 6). As the rotor of the DC motor starts rotating, the AC current flows in the circuit which consists of motor windings and the load. As a result of this, self-induction takes place. This effect can be seen in Figure 6 for the first type of propeller when the load resistance is less than 500 Ohm and in the meantime the experimental points and the approximation do not converge. The experiment indicates that a microturbine based on a DC motor can be represented as a voltage source and an internal resistance according to the Thevenin's theorem. Two factors which have caused less amount of power in our experiment in comparison with are the wind speed and motor. It can be also observed from Figure 6 that the larger propeller provides maximum output at smaller values of load (~60 ohm) and the smaller one reaches its power peak values at higher loads (~250 ohm), i.e. depending on the load value, the necessary blade can be chosen. This model is valid only in cases when the induced current is greater than the self-induction current. Wind is a free energy that nature provides us and there is no limit in using it. It produces no polluting emissions of any kind. Wind energy in some environments cannot be considered as a primary source for electricity generation due to its intermittent behaviour which causes instability to the power system.

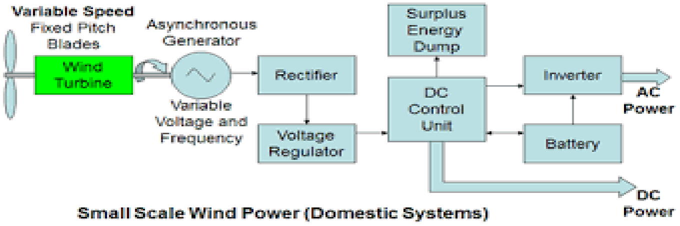


Fig 8: Wind energy harvesting

V. APPLICATION

Alternative sources can be used along with batteries as a complementary system or in case of existence of enough energy from the environment, they can be employed as primary power sources. Pipeline monitoring in industrial complexes is a remarkable example where wireless sensors can be deployed. It is quite plausible to employ energy harvesting techniques as primary or secondary power supplies for the sensors in this scenario. In case of battery replacement, the harvesting technologies increase the possibility of continuous operation of the system and consequently the process will not be stopped. Bridge health monitoring is another example discussed in. In the Jindo Bridge Project, Eight Sensors Out Of 70 Are Equipped with Solar Panels. The Charging Process of The Solar System Is working well except one node which is not receiving enough sunlight due to its location. It is suggested that in the next deployment, either a more sensitive solar panel can be used or another type of energy harvesting may be considered.

VI. ENERGY MANAGEMENT PROTOCOLS

At the moment, batteries are still the most common way to provide energy for low electronic devices. The specifications of Li –ion and thin film batteries are shown in Table 2. The majority of wireless sensor networks are powered by batteries. As mentioned at the beginning of the article, the batteries used in wireless sensor networks have a finite lifetime which requires replacement or recharging. Primary cells which cannot be recharged may cause a huge amount of work associated with replacement if used in a large network like in the case of pipeline monitoring. Secondary batteries are rechargeable but they have a lower energy density than primary batteries. The combination of an energy harvesting scheme with a rechargeable battery or with another storage system such as a thin film rechargeable battery or a supercapacitor can be implemented for wireless sensor networks. It is assumed that the volume of energy storage scheme is 1cm^3. If the energy consumption is 100µW then the operation time of the primary battery lasts just for only a few months. The combination of an energy harvester with a rechargeable battery ensures a long term operation of the system. Developing this strategy may be necessary since sometimes the output power from the energy harvesting due to their intermittent nature may not be enough to compensate for the current consumption at receive and transmit periods.

VII. PROPOSED ALGORITHMS

Two important features which need emphasis in sustainable WSNs are energy harvesting and energy management in the sensor networks. Energy harvesting is the use of renewable sources to power the nodes in a WSN, and energy management includes power management in the network.

The following routing algorithms are employed for energy aware battery cost routing:

MTTPR (Minimum Total Transmission Power Routing): The criterion for determining the routing path is the sum total of transmitting and receiving energies of the nodes along the path.

MMBCR (Min-Max Battery Cost Routing): The routing path is decided based on the residual battery capacities of the sensor nodes along the path. The weights of the edges in Dijkstra's (**Dijkstra's algorithm** is an algorithm for finding the shortest paths between nodes in a graph, which may represent, for example: road networks)shortest path algorithm are inversely proportional to the residual battery capacities of the nodes involved in routing.

DEHAR (Distributed Energy Harvesting Aware Routing): The data is broadcasted only to the neighbouring nodes. The states of the neighbouring nodes are periodically estimated based on the latest state for determining the routing path using the MMBCR algorithm.

VIII. IMPLEMENTATION

According to Anuj Nayak, Geetha Prakash, Ashish Rao, the topology of the wireless sensor network is as shown in Fig. 8. Low power Zigbee transceivers (IEEE 802.15.4) are used for wireless communication in the network. The WSN consists of one central unit (coordinator) and six remotely located sensor nodes across the field. Each node consists of a low power microcontroller (MSP430G2253IRHB32), a moisture sensor, a rechargeable Ni-MH 700mAh, 3.6V battery and Zigbee transceiver which is configured to be a router.

The **MSP430** is a signal microcontroller family from Texas Instruments. Built around a 16-bitCPU, the MSP430 is designed for low cost and, specifically, low power consumption embedded applications.
MSP430F2618ATZQWT-EP" consists of the following pieces:

- **MSP430**: Standard prefix.
- **F**: Indicates a memory type or specialized application. "**F**" indicating flash memory is by far the most popular. Other options for memory type include "**C**" for masked ROM, "**FR**" for FRAM, "**G**" for Flash Value Line, and "**L**" as in the MSP430L09x series, which indicates a RAM-only part; it must remain continuously powered to retain its programming. A second letter (except for "FR") indicates a specialized application for the part. For example, "**G**" is an optional specialization letter indicating hardware support for a specialized use. "**E**" indicates special electricity meter functions, "**G**" devices are designed for medical instrumentation, and "**W**" devices include a special "scan interface" designed for flow meters. An exception is the MSP430FG2xx devices, which are considered a separate generation.

- **2**: The generation of device. There can be significant changes to core peripherals (clock generators, UARTs, etc.) in different generations. These are not in chronological order, but rather higher values roughly indicate greater size, complexity and cost. For example, generations **3** and **4** include LCD controllers which the others do not.
- **6**: The model within the generation. This indicates the mixture of on-board peripheral devices and number of pins.
- **18**: One or two digits indicating the amount of memory on the device. The numbering is (mostly) consistent throughout the MSP430 series. Not all suffixes are valid with all models; most models are available in 3–6 memory sizes, chosen to match the other capabilities of the device. Larger numbers indicate increasing amounts of memory, but sometimes one type of memory (RAM or ROM) is sacrificed to fit more of the other.

A. SETTING UP A WIRELESS SENSOR NETWORK

The ZigBee coordinator is interfaced with MATLAB. Initially, coordinator broadcasts ATID API frame across the network to obtain MAC addresses of all the wireless devices present in the network. The user defined node IDs are assigned to each node in the application layer. The node IDs and the corresponding MAC addresses are broadcasted to all the remote nodes, where they are stored. The coordinator then broadcasts a “Start” frame. All the routers present in the network identify their neighbours using RSSI (Received Signal Strength Indicator) feature of the transceivers. The node IDs of the neighbours and the corresponding RSSI values (dBm in hex) are routed to the coordinator. The next hop table (having the best neighbours in energy-aware sense)for each node is computed in MATLAB (at the coordinator) using Dijkstra’s shortest path algorithm using RSSI values to set weights of the edges. Thus, next hop determined is based on MTTPR (Minimum Total Transmission Power Routing) algorithm. The next hop tables are transmitted to the respective nodes. Finally, a “Setup Complete” frame is broadcasted across the network for time synchronization.

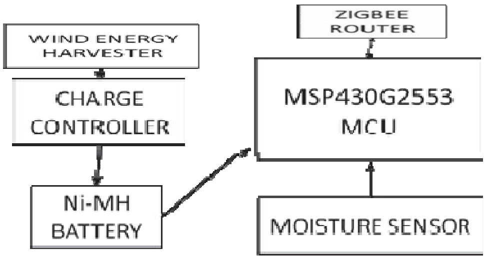


Fig. 9: Basic Setup of our implementation

B. SENSOR NETWORK OPERATION

The battery status of each node is defined by the instantaneous residual battery capacity. Four threshold values are defined for MMBCR (Min-Max Battery Cost Routing) algorithm – thresholdHH > thresholdHL > thresholdLH > thresholdLL. The change in battery capacity is broadcasted to the neighbours in the following scenarios: a) If the battery capacity rises above thresholdHH b) If the battery capacity drops below thresholdHL c) If the battery capacity rises above thresholdLH d) If the battery capacity drops below thresholdLL. Any node with a battery capacity less than thresholdLL goes to sleep (switches its receiver off) and refrains from communicating with the network. A node is prohibited from forwarding any packet to the neighbour with the battery status indicating battery capacity below thresholdLH. The time duration for which the radio listens to the network is determined by the number of neighbours. Each node is allotted a transmit time of 0.25 sec in a round-robin fashion. The total time allotted in the time duration of Tc =30 seconds for listening to the network is equal to (n neighbours x Treceive) second. For the rest of the time, the transceiver is set to sleep (receiver-off) state. When a remote node receives a change in the battery status of its neighbour, it updates the routing table (next-hop table if the broadcast radius is 1 hop).The sampling rate for transmitting the soil moisture level sensed at the remote nodes is assumed to be 30 seconds. When there is a change in the soil moisture at a remote node, the change is routed towards the coordinator based on the current battery status of the next hop in the table. To avoid any looping conditions, each packet carries along with it the node. IDs of all the predecessor nodes. An API packet received by the coordinator is illustrated in Table II.

C. ILLUSTRATION OF AN API FRAME RECEIVED BY THE COORDINATOR

TABLE II

Frame Field		Example	Description
Start Delimiter		0x7E	
Length		0x00	Number of bytes between the length and the checksum.
		0x15	
Frame Specific Data	Frame Type	0x90	Zigbee Receive Packet
	64-bit Source Address	0x0013A200	MAC address of the source node.
		0x408BB02D	
	16-bit Source Network Address	0x39	Network address of the source node.
		0x62	
	Receive Options	0x01	Packet Acknowledged
	Received Data	0x01	User defined frame type
		0x03	User defined source node ID
		0x03	Battery Status
		0x00	Soil Moisture Status
		0x01	Data Indication Flag
		0x02	No. of predecessor nodes Traversed
		0x03	First Predecessor node ID
		0x02	Second Predecessor node ID
Checksum		0x67	

IX. SIMULATION RESULTS

In the Fig. 11, it can be observed that up to 75 hours, performances of inbuilt Ad-hoc On-demand Distance Vector routing algorithm of the ZigBee module and the adaptive energy-aware routing algorithm are identical. After the lowest residual battery capacity in the network drops below threshold$_{HL}$, DEHAR combined with MTTPR and MMBCR performs better. The improvement in the performance of DEHAR algorithm is due to the change in the routing path as shown in Fig. 4 and Fig. 5. Change in soil moisture level is detected by the sensor at node 5. This change has to be routed to the coordinator along the energy-aware path. Fig.4 shows the route taken, till the residual battery capacity of node 2 drops down to threshold$_{HL}$. Node 2 then broadcasts the change to the neighbours (nodes 1, 4, 5 and 3). Node 5 updates its routing table based on the information broadcast by the node 2. Node 5 chooses an alternate path via node 3 after 75 hours as shown in Fig. 9

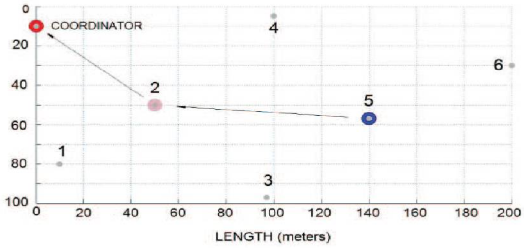
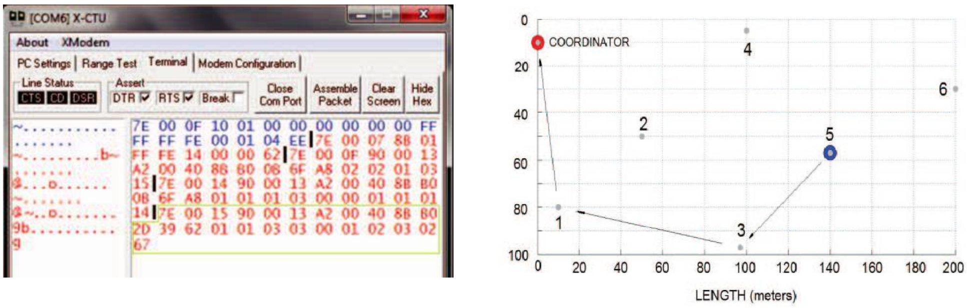


Fig.10 Energy-aware routing when residual battery capacity of node 2 is greater than threshold$_{HL}$

This prevents excessive drain of the battery at node 2 and hence, the battery life of the network is extended. The DV routing algorithm does not take the residual battery capacity into account and keeps routing the sensor data via node 2, which results in curtailing the battery life of the network. This is indicated in Fig. 12.



```
~............  7E 00 0F 10 01 00 00 00 00 00 00 FF
.......        FF FF FE 00 01 04 EE 7E 00 07 8B 01
~.........b~   FF FE 14 00 00 62 7E 00 0F 90 00 13
.......        A2 00 40 8B B0 08 6F A8 02 02 01 03
$...o......    15 7E 00 14 90 00 13 A2 00 40 8B B0
~.......       0B 6F A8 01 01 01 03 00 00 01 01 01
$~..o.......   14 7E 00 15 90 00 13 A2 00 40 8B B0
9b..........   2D 39 62 01 01 03 03 00 01 02 03 02
g              67
```

Fig.11 Energy-aware routing when residual battery capacity of node 2 drops below threshold$_{HL}$

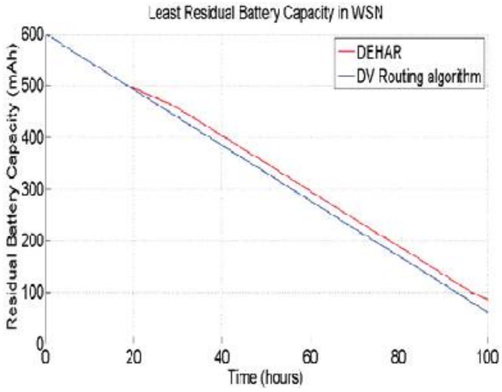


Fig 12: Residual battery capacity without using a wind energy harvester

Figure. 12 indicates the plot of residual battery capacity of the node in the network having the least residual battery capacity among all the nodes without using a wind energy harvester. Evidently there is not much improvement with the use of energy-aware routing algorithm. Figure. 13 shows the plot of least residual battery capacity in the network versus time. It can be observed that there is considerable improvement in the performance of DEHAR over Ad Hoc On-Demand DV routing algorithm of ZigBee transceivers. This is due to the increased threshold crossing rate of the least residual battery capacity in the network leading to frequent switching of the routing path which in turn results in the distribution of energy consumption among all the sensor nodes. The circles in Fig. 14 indicate the switching in routing path when a battery capacity crosses one of the four threshold values. Figure. 8 shows the variation of residual battery capacities for various cross sectional areas of wind belts for an efficiency of 10 percent.

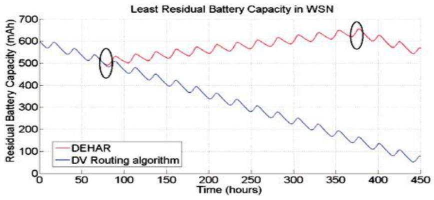


Fig. 13: Least residual battery capacity in the network using wind belt

The threshold cross sectional area of the wind belt is 0.0028m^2, above which the battery life of the network virtually infinity, which means that the energy-aware WSN switches the route taken suitably and dynamically resulting in the extension of the battery life of the network. In this paper, we have discussed the implementation of a WSN with renewable energy harvesting. We have also derived an expression for the percentage of energy saved at a node. With our implementation using the data corresponding to a renewable energy harvester we have proved the utility of using a solar, thermal, radio energy, piezoelectric, wind belt as an alternative energy source to extend the battery life. In addition, we obtain the optimal dimension of the wind belt desired

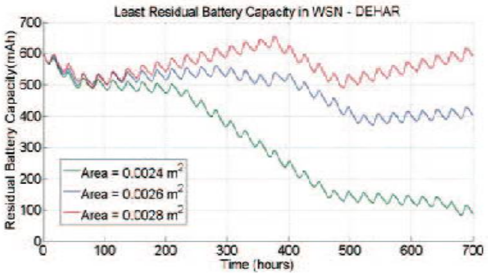


Fig. 14: Least residual battery capacity in the network with various cross sectional areas of wind

X. CONCLUSION AND FUTURE WORK

With the depletion of fossil fuel, and cumbersome of battery replacement the world is looking at greener solutions, the use of renewable sources wherever possible will benefit both the environment and the economy. With this intent, in this paper it is suggest that the use of renewable energy to power the sensor nodes used in agriculture. While the suggested system needs to obtain power from solar photovoltaic cells, wind belts, geothermal energy, RF etc. By using suitable transducers, its discuss in detail how this power can be used with energy efficient algorithms to route the data. With 12% of the global greenhouse gases coming from agriculture, we suggest that our system can save and extend battery life of the sensor nodes. Such a system can be put to use by forming a conglomerate of farmers with financial assistance, since this system would be cost effective in large farms or a set of closely located farms. In Future Kinetic Energy, can be used as Human or Animal Motion, Vibrations, Air or Water Flows, Human or Animal Motion.

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