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Abstract - Wireless Sensor Network (WSN) has become an important technology that enhances our normal daily life. This research focuses on one of the most important concepts in WSN technologies; the power conservation methods. The main objective of this research is improving the power conservation of a sensor node by dynamically adjusting recharging cycle of the solar-fed batteries based on the geographical areas and radiation levels of the areas and consequently prolonging the battery lifetime. The simulation results show that the proposed scheme improves the battery lifetime within the same geographical area from 0.69 year to 1.39 year; as well as across different areas from 0.69 year to 2.78 year.

Keywords: Wireless Sensor Node, Power Conservation, Solar radiation

INTRODUCTION

Today many industries are using Wireless Sensor Networks (WSNs). WSN is a new technology that consists of many distributed sensors in a large area. These sensors are used to provide information about the status of a specific system. The information could be measurements of physical or environmental parameters such as temperature, pressure, vibration, etc. The information will then be sent wirelessly and received by a central location for further analysis and usage.

WSNs are being used in various areas such as health, automotive, mechanical, veterinarian and agriculture, just to name a few [1]. In medical application, WSN is used in hospitals to monitor different parameters for patients such as body temperature, heart rate and blood pressure and send the information wirelessly to a control station [2]. WSN helps medical personnel to save human lives by sending patients information to nurses when they are necessary. WSN technology is fast growing and numerous new applications are emerging in the near future.

Researchers around the world are working on improving the performance of WSN such as improvement in power consumption, sensor unit, microcontroller, transmitting and receiving range and the type of connection topologies. In this research we will investigate power management in WSN and design an algorithm to improve the power conservation methods.

The rest of this paper is organized in the following order. In section 2 we present a general background on WSN concepts related to power management and power conservation. Section 3 describes the proposed scheme for the power conservation strategy. In section 4 we present the simulation and calculation methods and the results. Finally section 5 will include conclusion and future work.

BACKGROUND

WSN consists of many sensor nodes working as relay agents to pass information hop by hop to a central station. Sensor node is a part of wireless sensor network that can gather and sense the information from the environment and send it to another node or to the gate node. It consists of one or more sensor, controller, transceiver, external memory and power source. Each component of a sensor node is performing different parts of the work, and requires a power source to perform its function [3].

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Components of WSN depend on the power source while constraints and limitations of the power source is one of the main shortcomings for WSNs. As long as the power is provided to operate the nodes, less maintenance will be required to replace the battery frequently and that will lead to cost reduction associated with replacing the batteries.

There are different types of rechargeable batteries used in WSN. Lead-Acid and Ni-Cad batteries become unattractive because they contain Lead and Cadmium. Over time, the environmental factors such as the temperature and humidity have an effect on the battery and could destroy them. Nickel-Metal Hydride (NiMH) and Lithium-ion (Li-Io) are mostly used to power the sensor nodes [4].

Battery lifetime is one of challenges in WSN. Non-efficient duration of the time a battery can power the node and the lack of enough power to operate the node could potentially disable the operation of a WSN application. Among the components of a sensor node, the transceiver (the transmitter or the receiver) consumes the largest portion of the power inside the node [4]. If there is no data transmission between nodes, most of the battery energy is saved. This leads to a saving of more than 60% of the capacity of the battery. If the node goes into sleep mode, more than 99% of the energy will be conserved. At this point the transceiver is completely disconnected from the microcontroller (PIC) and the power source [5].

Sensor couldn’t be isolated from the power source and should be operating at all times because sensor is the main component responsible for providing information to the MCU in a short time. Sensor does not need a large amount of energy to operate. The sensor could operate with as little as 200uW to 1mW.

Power conservation

Energy harvesting is one of the important strategies to improve the power consumption of WSN. Energy harvesting is a challenging topic for researchers and engineers to improve the performance of the power consumption in any electrical or electronic device. Energy harvesting (EH) is a method used to provide power from environmental resources such as temperature variations, human power, solar energy and vibrations. Different techniques could be used to convert the environment energy to electricity such as conversion of vibrations to electricity found in certain building environments, trains or aircrafts using Piezoelectric or Electrostatic technologies.

The authors in [6] show that about 200 µW/cm³ could be generated from vibrations. Piezoelectric could provide most vibration conversation comparing with Electrostatic and Electromagnetic methods. Theoretical proofs show that 335 mJ/cm³ [6] is the Maximum possible energy that Piezoelectric technology could provide, but practically only 17.7 mJ/cm³ of energy has been observed.

Temperature variation is another energy harvesting technology. The amount of solar energy received by any region varies with time of the day or the seasons. These differences in solar energy create temperature variations. Strodeur and Stark demonstrated a thermoelectric micro-device capable of achieving 15 µW/cm³ of power from 10 C° of temperature variation [6]. This method is not used in WSN because the output power of temperature variation is not enough to power the node.

Starner in 1996 [7] and Shenck and Paradiso in 2001[8] studied energy harvesting using Human Power. They found that the most energy can be produced on human at the foot during heel strike and in the bending of the ball of the foot. Their research led to design piezoelectric shoe but the challenge is how to get the energy from a person’s foot to other places on the body.

Solar Energy

Several types of cells are used in solar panels to convert solar energy to electricity such as: Single Crystal Silicon (SCS), Thin film polycrystalline Cadmium Telluride (CdTe), Gallium Arsenide (GaAS), Titanium dioxide (TiO2), and so on. They all use the same way of converting solar energy to electricity with different efficiencies and applications. In WSN the common cells are Single Crystal Silicon (SCS) and Thin film polycrystalline silicon because they could provide the required energy to power the node in WSN. SCS has an efficiency of 11% to 25 % which is the highest among all cells, while thin film polycrystalline has an efficiency of 10% to 13% [9]. SCS is suitable for indoor and outdoor, but it is more useful outdoor since the cell electrons are more sensitive to sun radiation. On the other hand, thin film polycrystalline could only be used indoor. The SCS has a size of 150 mm × 150 mm and a thickness of 650 µm.
Among various ways to improve the power consumption, the most efficient way is to use solar system photovoltaic (PV) cells. The main components of PV are: the external environment, energy storage, the solar collector, secondary battery and load. Usually PV is designed by connecting light-controlled current source (solar collector) in parallel with diode. In addition, PV is designed according to parameters such as battery life, cost, simplicity, etc. By programming the microcontroller, PV could be controlled and managed.

### Energy storage

Since the sunlight is not available all the time, the harvesting circuit should have some types of energy storage. Battery is usually used in PV to keep the energy and feed the load once there is a need for its energy. In sunlight-poor areas, PV system might need a secondary battery or Supercap to feed the load when the main battery is empty.

There are many types of batteries and the batteries are picked according to the application and design of WSN. Some of the batteries have good features such as long life and high capacity. All batteries are adjustable to a set of specific parameters, and the solar radiation is a changeable energy source; the weather changes from one day to another and there could be too much or too little energy collected from the sun radiation. When the power is too high for charging the battery, a charging circuit should control the amount of power that fits with the battery characteristics. The charging circuit used to provide the necessary constant current and voltage to charge the battery and protect the battery from over charging which yields to more lifetime. Therefore the design should be able to convert the changeable energy to a fixed energy.

### The Load Distribution for each Node

Each component in a sensor node needs power to do its job. WSN nodes need a controller to control and distribute the power to different components. Hence, the microcontroller will be responsible for managing, controlling, and distributing the power.

The power that the microcontroller will extract from the energy storage depends on the mode of operation of microcontroller. Normal mode consumes too much power because all the components of the node work in active state. In the normal mode, all parts of the microcontroller will be fully powered. So, the power consumption will be up to 400 mW. In the idle mode, the microcontroller clocks are stopped while the peripheral clocks are active. We will return to normal mode at any interrupt. In this mode, the power consumption is up to 100 mW. In the last mode, only the real-time clock is active [5].

### Clustering used for Energy Conservation

When the number of nodes and their distribution increases and the estimation of population of existing nodes is not calculated easily, cluster-based technique can be suggested as an approach to improve the network lifetime and energy efficiency. In this article we studied a survey of different clustering protocols and methods used in WSN to improve energy conservation. Low Energy Adaptive Clustering Hierarchy(LEACH) is the traditional method in clustering and was improved by a protocol called LEACH centralized(LEACH-C). The idea is reduction of transmission distance by choosing some of the nodes as the head nodes. These head nodes are in contact with BS directly and the rest of nodes are connected to them, therefore not all the nodes need transmit their information to the BS by traversing a long distance, hence the energy consumption is reduced. The non-head nodes are just detectors to monitor the event and transmit data to head nodes. Different recently proposed protocols and algorithms in WSN clustering will be also compared and evaluated for their efficiency as a future work for this study. Many other protocols have been suggested recently to cover the disadvantages of the traditional algorithms. MECA[14], Energy-Effective clustering Algorithm based on adjacent nodes[15], Cluster Allocation and Routing Algorithm based on Node Density[16], GRASP[17], Energy-based Cluster Partition Method[18], and improved LEACH method[19] are all proposed algorithms to improve the current methods.
PROPOSED POWER CONSERVATION METHOD

The proposed power conservation method has three main components; the solar system, the power extracting system and the power usage optimization components; each explained in this section.

Solar system

Designing solar energy system is affected by the geographical area and the application of WSN. Various geographical areas experience different level of solar radiation, as well as different types of applications, such as those of indoor versus outdoor also require variations in the design due to the amount of solar energy they could absorb. Such variations in the design could significantly change parameters such as: low cost, low power consumption, automated systems, battery life, and high performance. In this study we focus on two different designs for efficient power consumption.

The battery lifetime

The lifetime of a rechargeable battery refers to the number of charging/discharging cycles that the battery could have before fading [5]. Battery lifetimes of 500-1000 are common in the industrial manufacturing of the rechargeable batteries used for wireless sensor nodes [12]. The proposed energy conservation method extends the battery lifetime by designing a rechargeable method that dynamically changes the recharging cycle based on the geographical area and the corresponding solar radiation level achieved.

The battery does not die suddenly after reaching to its lifetime limits, it often continues working as a lower than normal rate, where the capacity of the cell will fall, however, it allows the battery to continue working to more cycles with lower capacity. With lower capacities, the battery needs to be recharged more frequently, which requires more energy, to a point that the recharging will not be economically justified, and the battery loses the efficiency of battery’s capacity that will result in the cell being unable to store the energy required by the specification. In other words it reaches the end of its useful life and since the capacity loss is brought on by high current operation, we can expect that battery cycle life will be shortened. While the battery has small number of charging/discharging, its lifetime will increase. For instance, if the battery charges twice every day, its lifetime will be shorter compared with charging the same battery once every day.

Photovoltaic cell (PV cell)

Single Crystal Silicon (SCS) is one of the best materials used for Photovoltaic (PV) cells in solar system due to its efficiency. In the proposed research we simulate a rechargeable system that works based on SCS solar cell and calculate achievable energy according to its efficiency of between 11% – 25% [6]. Efficiency of cells is defined as how much power can be converted from sources either sun’s radiation or office lights. At the minimum efficiency (11%), SCS can produce an electrical power of close to 2.48 W [6]. While the efficiency of the cell increases, more power is produce. At the maximum efficiency of 25% is the maximum power will be converted from the sources (Sun radiation or office lights).

Extracting solar energy

Solar radiation emitted by the sun produces electromagnetic source of energy which could be converted to electrical energy using solar power systems. Different regions on earth have different values of solar radiation, therefore the solar power systems are designed accordingly, to efficiently collect, store and use the solar energy.

The National Renewable Energy Laboratory (NREL) has collected information regarding the solar radiation across the country, and calculated the electrical energy that could be generated by conversion of solar energy for each area [10]. NREL has designed a map that shows the amount of solar radiation that could be collected in different regions (available in [10]). The values presented on the map are divided into various regions, starting from lows of close to 0-2 KWh/m2/day up to highs of 10-14 KWh/m2/day of solar energy from radiations. The unit KWh/m2/day is the amount of energy that can be extracted by the cells size (m2) per day. The amount of electrical energy converted from the solar energy could then be calculated from Equation (1).

\[ E_e = E_s \times A_{eff} \times PV_{eff} \]  

Where:

\[ E_e = \text{Electrical Energy} \]
\[ A_{eff} = \text{Effective area} \]
\[ E_s = \text{Solar radiation energy} \]
\[ PV_{eff} = \text{PV efficiency} \]
System design
The proposed system designs a method that checks the radiation level, where it is implemented, and dynamically adjusts the recharging cycle of the sensor node battery based on the level of radiation. The rechargeable batteries have a maximum \( (C_{\text{max}}) \) and a minimum \( (C_{\text{min}}) \) capacity threshold for their recharging patterns. \( C_{\text{max}} \) is the maximum capacity of the battery that it should be recharged to, and \( C_{\text{min}} \) is the minimum capacity level that triggers a recharging cycle. These values potentially affect the battery lifetime, as they could greatly alter the total amount of energy extracted during the battery lifetime by changing the number of times the battery is recharged. The upper bound threshold \( (C_{\text{max}}) \) is usually constant and the same in most areas. In this study, we assume the \( C_{\text{max}} \) to be 90% to protect the battery from overcharging. The minimum threshold \( (C_{\text{min}}) \) could assume a range of values according to the geographical area and the radiation level in each area. The rationale for the variation in \( C_{\text{min}} \) design is that in areas with lower radiation levels, the system should be prepared for unexpected lack of sunshine or lower than standard levels of radiation. The idea is that in areas with higher rate of radiations, there is also lower rate of unexpected outcomes with respect to the amount of cumulative solar energy.

The proposed solar rechargeable system is designed based on an algorithm to dynamically change the value of \( C_{\text{min}} \) based on the radiation level. We first perform a heuristic method, and try various values for \( C_{\text{min}} \) to establish a set of standard threshold values and to verify the assumptions, then develop the dynamic model to adjust \( C_{\text{min}} \) automatically based on an optimization algorithm. We first try the two areas used in the previous section, and assume values for \( C_{\text{min}} \) to be 50% for NEW Haven and 30% for Arizona. In both cases \( C_{\text{max}} \) should not exceed 90% of the capacity of the battery to protect it from overcharging.

Power usage Optimization
Power usage optimization methods are critical for electronic design circuits to reduce the power consumption. In WSN, saving the power has direct effects on the efficiency of the node. WSN consists of 100’s, sometimes 1000’s of nodes and if the efficiency of the nodes improves the performance of entire WSN system will improve. WSN performance is affected by longevity, maintenance, battery replacement, cost, and so on.

There are various types of sensors used in WSN. In this project we selected temperature sensor to measure the temperature for human’s body [11]. The sensor is responsible for providing information to microcontroller; hence it needs to be connected to the power source at all times. It is important to read the temperature for patients and to send it to the microcontroller constantly. If the sensor is not active and there is abnormal patients’ temperature, unwanted results might happen. Therefore the sensor should be ready to send the temperature all the time and to ensure patient’s safety. Therefore in such critical situations, the sensor node should always be ready with proper power source.

Therefore the optimized point is between the number of recharged cycles and the readiness of the sensor node at all times. If the battery is recharged too many times, the performance is reduced, on the other hand if the battery is not sufficiently ready at all time, there is a risk of inadequacy in readiness. We prose a power conservation method that is optimized and presents a balanced model between efficiency and readiness.

SIMULATION AND RESULTS
The proposed solar system and the node are implemented in MultiSim software simulation environment [13]. In this section we discuss the components of the proposed solar system and how they work. Then, we compare the results between two areas to show how to improve and increase the battery lifetime by dynamically adjusting the rechargeable threshold level. The design will contain the components of the node including temperature sensor, Analog to Digital Convertor (ADC), Micro Controller Unit (MCU) and the transceiver. The results of the simulations and the power optimization will be discussed in details at the end of this section.

Solar system simulation
The main components of our solar system are the PIC (Peripheral Interface Controller) microcontroller and the battery system. The PIC is used to control charging and discharging of the battery. We use PIC Microcontroller
8051 to simulate solar system. PIC 8051-MC is a microcontroller that separates code and data spaces for devices. PIC-8051 has 40 pins performing various functions for several components including CPU, data memory, program memory, and a built-in external memory on a single chip. We use three pins to perform the dynamically adjustable recharging feature; Pin number 1 will stop the solar system from charging the battery when it reaches to 90% of its capacity. We programmed Pin number 2 to control and feed the load once the recharging is ordered. This pin will work only when the load needs power, otherwise it is on hold. The battery is charged till 90% by using pin number 3, and then it will be on hold. The PIC 8051 controls the battery by charging and discharging it to a limited point. We can also control the speed of the current by adding a potentiometer to the system.

Simulation system design

The battery recharging could be in three different states: the first state is when the system reaches the minimum capacity (Cmin) of the battery and how it will start the recharging process at a determined value for Cmin; the second state is when the system reaches the maximum capacity (Cmax) of the battery and how it will stop the recharging process at Cmax; finally the last state, when the battery capacity is between the minimum and the maximum values and how the system checks and operates the recharging if need be.

Figure 1 illustrates the design of proposed solar system in MultiSim simulation environment. The system includes several components such as the sensor, the battery and the controller using the PIC 8501. The three PINs used in this experiment are controlling the dynamic recharge process. When pin 3 will send a signal to the solar system, pin 1 and 2 will be on hold. Then the solar system will start charging the battery until the battery reaches Cmax. Once the battery reaches Cmax capacity, pin 1 will send a signal to stop charging the battery and pin3 will go off. Ccurr fluctuates between Cmin < Ccurr < Cmax. The system determines the current location and dynamically adjusts the recharging process. The process of recharging is implemented based on Algorithm 1 and depicted in Figure 2.
Algorithm 1
1. update battery’s current capacity ($C_{curr}$) periodically
2. if $C_{curr} \leq C_{min}$
3. keep pin1 connected
4. if pin1 connected
5. set pin2 and start charge
6. while $C_{curr} \leq C_{max}$
7. do not interrupt charge process
8. elseif $C_{curr} \geq C_{max}$
9. stop charge process
10. go back to 1
Algorithm 1 is implemented for both Area 1 and Area 2, and three cases are tested for start, stop and ongoing recharging of the battery.

Simulation environment using MultiSim software

Figure 1 shows the design of the solar system using MultiSim program [13]. At the beginning of the program, the solar system will charge the battery until $C_{max}$ and will stop charging the battery at that point. If the load needs power, the battery will send the power to the load until the determined point that is specified by the designer. Once the battery reaches the lower bound threshold, the solar system will charge the battery again until $C_{max}$. There are two outputs and one input in the battery box. The first output (controller) sends a signal to the solar system while the second output (load battery) feeds the load with the power. On the other hand, the input of the battery (i.e. solar_charger) allows the solar system to charge the battery.

Battery lifetime calculation: The solar radiation and resulting solar and electrical energy conversions are calculated using Equation 1. The results are presented in Figure 3. The battery lifetime is calculated using Equation 2:

$$T_{batt} = \frac{N_{chrg}}{N_{chrg}}$$  \hspace{1cm} (2)
Where:

\[ T_{\text{bat}} = \text{battery lifetime in years} \]

\[ N_{t,chrg}^f = \text{total number of recharging} \]

\[ N_{d,chrg}^d = \text{daily number of recharging} \]

Three different efficiency levels were tested for two selected areas discussed previously and the following assumptions were made:

- The battery needs at least 7000 joule to be recharged.
- The battery lifetime is 500 charge/discharge cycles.
- The battery is used at a rate of 10% per day.

Assuming the battery is recharged once per day, the battery lifetime (in years) is calculated according to Equation (4):

\[ \text{Battery lifetime (in years)} = \frac{500}{[1*360]} = 1.3889 \text{ years.} \]

The battery lifetime calculation from Equation 1 is used with four Cell efficiency levels for the two areas. Results are presented in Figure 3.

It is observed from Figure 3 that when the efficiency increases, the battery life will also increase. The battery life depends on the efficiency as well as the number of charging/discharging cycles, which in turn depends on the area and corresponding radiation level. In the next set of calculations, we find the battery lifetime for four different areas (Newhaven, Miami, Arizona, and North Mexico). In each case we look at four different solar radiation levels and their corresponding rate of recharging per day. For instance in area 1 the solar energy at the solar radiation level of 2...
KWh/m²/day is 7.2 MJ. This energy generated 1.98 KJ of electrical energy using Equation 1. At this rate, the battery is required to be charged twice per day, which yields a battery lifetime of 0.69 years using Equation 2.

Using the same calculations, and considering an area within New Haven with solar radiation of 2.7 KWh/m²/day, the solar and electrical energy generated would be 9.72 MJ and 2.673 KJ respectively. At this rate, the battery is required to be charged 0.7 times per day, which yields a battery lifetime of 2.08 years using. Similar calculations were performed for four different sub-areas within the four selected areas. The results are presented in Figure 4.

It is observed from Figure 4 that as the solar radiation increases the battery life increases. The solar radiation energy in 4 levels are selected for four areas, with different levels of cell efficiencies. The results indicate that with similar radiation levels and different efficacy levels in the four areas, the battery lifetime could vary significantly. In the range of ~2 KWh/m²/day, by selecting different area and different efficiency level, the battery lifetime is improved from less than a year to almost 7 years. The same trend is repeated with higher radiation levels.

CONCLUSION AND FUTURE WORK

In this study, we focused on one of the critical research areas in wireless sensor networks; the power conservation strategies. We designed two methods to improve the power conservation of sensor nodes by fluctuating the recharging cycles of the rechargeable batteries in a sensor node.

In the first method, we selected a weak solar radiation area and a strong solar radiation area. With 11%, 15%, 20%, and 25% cell efficiencies, we calculated the electrical energy and the battery lifetime. We found that the battery lifetime is longer in area 2 versus area 1.

In the second method, four areas were selected with different PV efficiencies and different radiation levels in each area. The results show that on average the battery lifetime varies diversely by adjusting the PV efficiency and using different radiation levels within the same area as well as selecting different areas.

Based on the solar radiation we designed an algorithm for variation in the recharging cycle of the battery, and consequently prolonged the battery lifetime. In future we plan to expand on this study and try different types of batteries, and adjust different environmental conditions such as temperature and humidity and see their effect on the battery lifetime. Also different newly proposed cluster-based protocols and algorithms will be investigated and compared as other approaches to save the energy in Wireless Sensor Networks.

REFERENCE:


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