Power Management for Energy Harvesting over LEACH Protocol

Moner Alsader, *Member, IEEE* , and Al Savvaris, *Member, IEEE*

Abstract—Wireless Sensor Network devices are characterized by resource constraints such as computational power, memory and energy. Since these devices are powered by batteries, it may not be possible to replace batteries for recharging and therefore, energy harvesting techniques such as Piezoelectric and Thermoelectric can be used if necessary so that the lifetime of these devices can be extended. This paper presents power management for energy harvesting over LEACH protocol. Experimental results based on the NS-3 simulation platform has shown that Low Energy Adaptive Clustering Hierarchy (LEACH) routing protocol improves the energy efficiency for Piezoelectric energy harvesting in aircraft compared to that of direct simulation.

Keywords—Piezoelectric, LEACH, Energy, Power Management, NS-3, WSN

I. Introduction

Power management in aircraft for structural health monitoring (SHM) is a critical constrain that affects successful Wireless Sensor Network (WSN) operations. WSN in aircraft is crucial for SHM because it is made up of permanently monitoring key parameters for aging effects prediction. The major goal is reduce cost and improve mechanical safety by deploying scheduled maintenance by predictive maintenance. For efficient SHM, WSN nodes are required to have enough energy for transmitting key monitored parameters. In order to ensure that enough energy is available at critical moments during transmission, energy harvesting from ambient sources such as vibration and thermal are used to power WSN nodes.

A WSN node can harvest energy from several ambient sources, vibration energy harvesting using Piezoelectric Generation (PEG) and Thermoelectric Generation (TEG) can be a reliable way to harvest energy in the aircraft environment. PEG can harvest higher energies as the airplane wings vibrate because of air turbulence, engine vibrations, weight and stiffness of the wings. TEG can also be exploited around the engine.

A number of researchers have focused on proposing energy harvesting techniques for PEG with low resonant frequency and high average strain [1],[2] and [3]. These techniques are suitable to power low energy WSN nodes in the aircraft wings. The vibration amplitude and frequency determine the amount of the energy that can be harvested by the PEG devices. TEG energy harvesting have recently been proposed in aircraft [4]. In TEG energy harvesting, a thermal gradient is needed for energy extraction [5]. The greater the temperature difference, the more energy will be harvested.

Moner Alsader is with the in the Centre for Autonomous and Cyber-Physical Systems, Cranfield University, UK, e-mail: m.s.alsader@cranfield.ac.uk.

Al Savvaris is with the in the Centre for Autonomous and Cyber-Physical Systems, Cranfield University, UK, e-mail: a.savvaris@cranfield.ac.uk

In order to efficiently harvest and use enough energy in the WSN nodes, this paper proposes the use of LEACH routing protocol. This approach is important due to uncertainty of reliable and enough energy for data transmission. This uncertainty can lead to intolerable latency and even data loss.

The LEACH routing protocol combined with efficient scheduling scheme in order to mitigate data loss and minimize power consumption due to communication channel is required. Therefore, this paper proposes a power management for energy harvesting over LEACH protocol. Experimental results based on the NS-3 simulation platform has shown that LEACH routing protocol improves the energy efficiency for Piezoelectric energy harvesting in aircraft compared to that of direct simulation. The scheme will be implemented, evaluated and validated by simulation based on the NS-3 simulator. NS-3 simulator has been used in many research areas in communications such as in cellular networks [6] and multimedia communication [7].

The rest of this paper is organised as follows, Section II presents the related work that is relevant to the proposed technique. Section III outlines the NS-3 simulation setup. Results and evaluation are presented in Section IV and conclusion and future work are discussed in Section V.

II. Related work

A. Energy Harvesting

The most mature source of energy harvesting is the use of solar cells which can harvest energy from light source. Energy that is harvested is generally used to power outdoor applications. Although the solar energy is very useful and widely used, this source of energy harvesting has severe limitation and it cannot be used for applications and locations where access to light source cannot be guaranteed. For example this type of energy harvesting may not be very useful for applications inside an aircraft. For this case, other sources of energy that can be harvested may be more useful. One of the sources of energy from an aircraft that can be harvested is vibration energy. The vibration and thermal energy are in abundance in the environment of an aircraft [8]. This energy can be harvested to power on-board systems in the aircraft, and applications that harvest power from these energy sources will be outlined in later sections.

It is important that the power consumption requirement of WSNs be fully understood before any attempt is made to determine the source of the power to be harvested and what technology should be used for the harvesting. The power requirement of a WSN system varies from a few micro watts when in the sleep mode to tens of milli watts when the node is in transmission mode. This therefore sets the benchmark in terms of power requirements and any power to be harvested should satisfy this power requirement threshold. Table I shows the amount of power that can be harvested from ambient sources of energy such as light, vibration, thermal and radio frequency (RF) sources. It is evident from the table that power harvested from ambient sources is sufficient to power WSNs because enough power can be harvested from the ambient sources to satisfy the WSNs power requirements.

TABLE I
COMPARISON OF POWER OUTPUTS FROM ENERGY HARVESTING TECHNOLOGIES

Harvesting method	**Power density**
Solar energy-outdoors	15mW/cm^3 bright sunny day 0.15mW/cm^3 cloudy day [9]
Solar energy-indoors	10-100 μW/cm^3 [9]
Vibrations (Shoe inserts)	330 μW/cm^3 [10]
Vibrations (electrostatic conversions)	0.021 μW/mm^3 105Hz 184 μW/cm^3 10 Hz [11]
Vibrations (electromagnetic conversion)	306 μW/cm^3 52 Hz [11]
Thermoelectric 5 C gradient	40 μW/cm^3 [12]
Wind flow	16.2 μW/cm^3 5m/s [13], [14]
Acoustic noise	3 nW/cm^3 75 dB 960 nW/cm^3 100 dB [15], [16]
Magnetic field energy	130 μW/cm^3 200 μT, 60Hz [17], [18]

B. LEACH Protocol

LEACH is a hierarchical cluster based routing protocol [19] used in WSN applications. It divides the WSN nodes into clusters. After clustering, the nodes will then organize themselves into a hierarchical structure. For each cluster, a Cluster Head (CH) node is picked that will perform the responsibility of Time Division Multiple Access (TDMA) scheduling [20] for its members and transmits the aggregated data to the cluster Base Station (BS). In LEACH, it is assumed that each WSN node has sufficient Radio Frequency (RF) transmission power, the sufficient power enable the CH node to reach the BS or the closest CH node and therefore transmits the data directly to either the BS or to its neighboring CH node. The nodes in LEACH protocol elect their own CH node after deploying and forwarding data to the CH node as shown in Figure 1. Each node is able to conserve its scarce energy with this approach. The additional responsibility as the result of being the CH node will further drain energy in the nodes acting as CH nodes. LEACH protocol mitigates this problem by using random rotation technique in electing CH node among the cluster nodes. LEACH deploys TDMA or Code Division Multiple Access (CDMA) techniques in order to prevent collisions in a cluster.

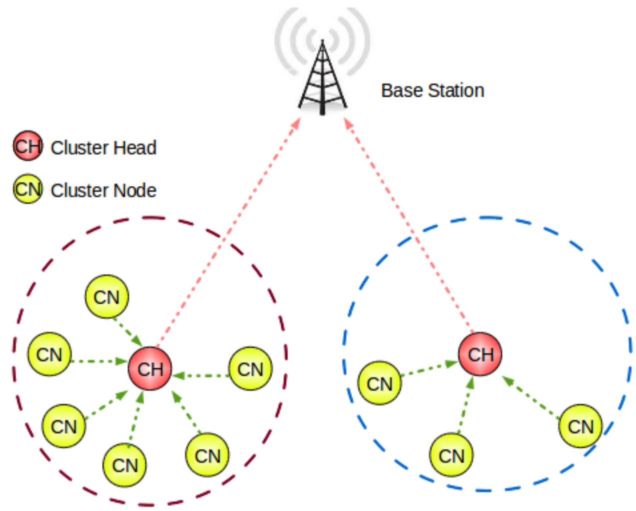

Fig. 1. Clustering model

The operation of the LEACH routing protocol is made up of many rounds. Each of these LEACH protocol rounds is made up of of Set up and Steady state phases,

1) Set up phase: The CH's are chosen randomly among the nodes during the set up phase and several clusters[21] are formed dynamically. Initially, each node generates a random number in the range from 0 to 1. If it is less than a threshold, T(n), that node is elected as a CH for the current round. This decision also involves the past history of the node being CH [22].
2) Steady state phase: After the clusters of nodes are created, the CH node starts allocating its TDMA schedule algorithm to its cluster nodes. Each member node of the formed cluster will then transmit the sensed data to its CH node. After the CH node has collected all the data from its member nodes, it will then send the aggregated data [23] together with its own data to the cluster BS. The steady state phase duration is known to be longer than the set up phase. After a given period of time, the WSN will enter into another set up phase ready for another round. After the completion of each round the CH nodes will be re-elected to form new clusters. Thefere, the WSN lifetime can be approximated based on the number of completed rounds.

C. Power Management System

Power management is a critical constrain of any effective and successful Wireless Sensor Network operations because power management determines how efficiently the electrical power is used in WSN. It becomes more important in aircrafts for structural health monitoring (SHM) such as aircraft wings due to their exposure to unpredictable and harsh environment.

There are several researchers who proposed Markov chain models for power management in energy harvesting. Authors in [24] proposed an energy harvesting in WSN with linear topology where they derived the packet loss probability due to channel errors and lack of energy in WSN. The energy harvesting process was modelled as a Markov chain where states represented average harvesting power levels. Although the paper claims to gain near optimal performance of the proposed model, but packet loss probability based on channel errors and lack of energy did not reflect the realistic scenario. Packet loss due to queuing overflow should also be considered.

Authors in [25] found that generalized Markovian (GM) model was effective in representing PEG harvesting because it is bursty in nature. Authors in [26] proposed the Markov based model that has an ability to predict future power consumption and residual availability of energy in WSN. The proposed model captured the energy states of WSN nodes and predicted the probability of a WSN node to fail to detect an event due to lack of energy. The disadvantage of this model is on the scalability because the states are based on the total number of WSN nodes.

The paper in [27] proposed a two dimensional Markov chain model for scheduling between harvested energy and grid. However, the proposed model is not suitable for energy harvesting in aircraft because there is not grid source of power. Markov based schemes are prediction based. The amount of energy a WSN can harvest demonstrates fluctuations and is hard to predict. As a result, EH predictors are prone to errors, either over-use or under-use of the harvested energy occurs. Therefore, prediction model free schemes are preferred for power management strategies. Hence, this study proposes an expert system based on Fuzzy control logics for power management system.

Authors in [28] proposed the integration between LTspice and NS-3 for power management for energy harvesting scenario. Based on the integration between LTSpice and NS-3 simulation with the use of fuzzy control system, the Downtime Ratio and Energy Efficiency Utilization evaluation metrics were used in the simulation and the results were preferable compared to the scenario where fuzzy control was not implemented.

All these proposed power management systems use direct communications and did not implement LEACH routing protocols. This paper goes beyond these systems and implement LEACH protocol in order to save more energy and extend WSN nodes lifetime. The proposed systems is compared to direct communications to demonstrate its efficiency and suitability.

III. SIMULATION SETUP

NS-3 has been used for energy harvesting under LEACH protocol simulation. NS-3 is a discrete-event network simulator, targeted primarily for research and educational use. NS-3 is free software, licensed under the GNU GPLv2 license, and is publicly available for research and development use. In this paper, the nodes are randomly deployed in the area and the BS location is assumed to be outside the WSN node deployment area. The parameters used for the purpose of simulation are given below,

- Routing protocol = LEACH
- Deployment area = $100x100m^2$
- Nodes deployment = random
- Total number of packets = 100000
- Packet size = 32 bytes
- Traffic type = Constant bit rate
- Inter packet Interval = 20ms
- Number of WSN nodes = 10000
- Time slot = 20ms
- Start Time = 0.0s
- Simulation time = 900s
- Threshold battery level for recharging = 0.11J
- Maximum battery level capacity = 0.15 J
- Wireless protocol used is 802.15.4 with TX = 0.0174J and RX = 0.0197J
- PEG recharges the storage in a random and uniformly distributed in [0.0022 0.0044] and is updated every 1ms.

IV. SIMULATION RESULTS

A. PEG Harvested Energy

The current harvested energy values based on PEG are given in Figure 2. It shows that throughout the simulation time, the maximum harvested energy can reach 0.00438774J and the minimum can go down to 0.00014 (almost no vibrations at all). Note during the simulation time, the harvested energy that has less than 0.0022J, indicates that there were no enough vibrations to recharge the energy storage.

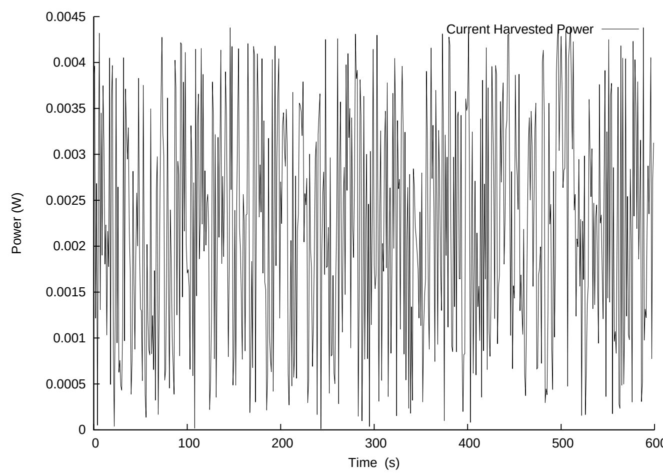

Fig. 2. Current PEG harvested energy

B. Storage Energy

The current energy storage values are given in Figure 3. It shows that once the minimum energy level is reached due to communication, the storage is recharged via PEG. Throughout the simulation time, the maximum energy reached at any given interval was 0.136566J and the minimum energy was 0.107097J.

It can be observed from the simulation results (see Figure 4) that LEACH routing protocol can attain higher energy efficiency than direct communication. In a large coverage area of the WSN, some of the CH nodes are far away from the BS in direct communication, this results into high transmission power to transmit the data to the BS, as the result associated nodes will die very early as a consequence of energy draining.

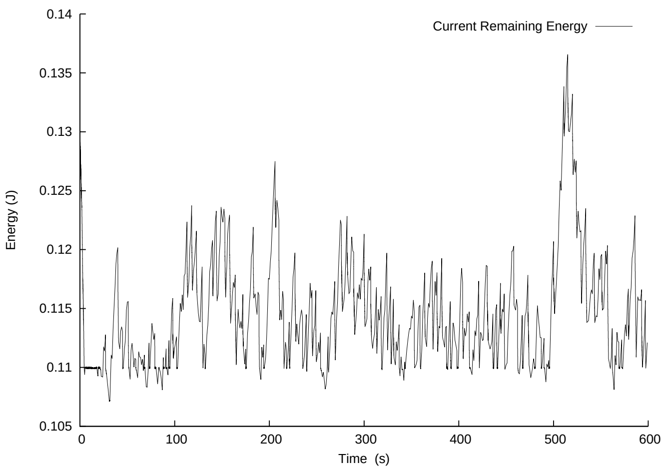

Fig. 3. Current energy storage values

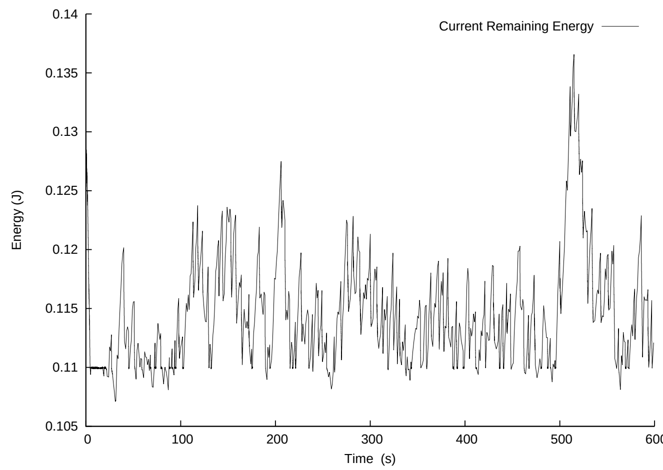

Fig. 5. Number of rounds Vs bits received by the base station

The LEACH routing protocol is capable to last for higher number of rounds than the direct communication, therefore, the lifetime of the WSN increases when using LEACH routing protocol for large coverage areas. The Figure 4 depicts that the number dead nodes in the WSN using under the LEACH protocol is less than the ones in the direct communication. In the direct communication, nodes die sooner and that leads to low number of simulation rounds.

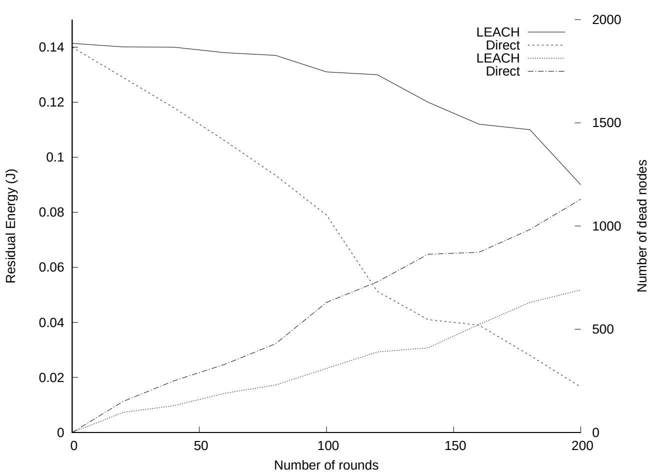

Fig. 4. Total residual energy and number of dead nodes Vs number of rounds

Figure 5 depicts the total number of bits received by the base station over 200 rounds duration. The results show that higher number of bits information is received by the base station over the LEACH routing protocol than the ones with the direct communication.

The total number of nodes and clusters increases as the WSN deployment area is increased. Due to this, the energy consumption also increases because of the increased distances between nodes in the direct communication, this eventually reduces the WSN lifetime. The lifetime of the WSN is relative longer under the LEACH routing protocol because the energy consumption is less.

V. Conclusions and Future Work

In this work a simulation model using NS-3 tool for the power management over LEACH routing protocol has been proposed. From the simulation results, it can be concluded that the LEACH routing protocol is more energy efficient when compared to the direct communication. The lifetime of the WSN also gets extended as the deployment area of the WSN increases. These results have potential use in aircraft energy harvesting for structural health monitoring. Future work will involve Thermoelectric energy harvesting and comparing the proposed approach to the existing ones in the literature.

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