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Energy Renewal Approach in Wireless Sensor Networks

G.Lilly Evangeline
Department of ECE
Karunya University

G.Josemin Bala
Department of ECE
Karunya University

Abstract- Wireless sensor networks (WSN) monitor the environmental conditions that can be used for various applications. They are often encumbered with limited battery energy. Thus, the network lifetime is widely regarded as the performance constriction. Wireless power transfer offers the possibility to remove this performance constriction thus allowing the sensor to remain operational forever. In this paper, we discuss the operation of sensor network using this energy transfer technology. We consider a mobile charging node (MCN) which can travel inside the network and charge each node wirelessly. The concept of renewable energy cycle is discussed and offer both necessary and sufficient conditions. The objective is to increase the life time of the sensor network by charging each node wirelessly through this wireless power transfer technology.

Keywords- Wireless sensor network, lifetime, mobile charging node, wireless power transfer.

I. INTRODUCTION

Wireless sensor networks of today are mainly charged by batteries. Due to limitations in the energy storage capability, the wireless sensor network can be operational only for limited period of time. To sustain its life time, several methods have been researched in the recent past. Despite all the research efforts, the lifetime of the wireless sensor network still remains a performance constriction and therefore it impedes its wide scale deployment. Energy harvesting also known as power harvesting or energy scavenging ([2],[3],[10],[12],[17]) is a process by which energy is extracted from the external sources such as solar power, thermal energy, and wind energy which can be used for sensor networks. But these techniques are not very successful; because the proper operation of any energy harvesting technique is highly dependent on the environment. The deployment of these techniques also becomes difficult because of the size of the device. The recent breakthrough in the area of wireless power transfer developed by kurs et al [13] has been a radical epitome for prolonging the sensor network life time. Kurl et al's work showed that by working on a new technique called magnetic resonant coupling wireless power transfer from one device to another becomes possible. In addition to this wireless power transfer, it is also proved that the energy storage device need not be in contact with the receiving device always for the efficient transfer of energy. Wireless power transfer is resistant to the neighboring environment and it is not necessary to have a line of sight between the power transferring and the received nodes. Recent advances in this technique shows it can be adopted for various applications.

The impact of wireless power transfer on wireless sensor networks and on other energy encumbered wireless networks is huge. Instead of generating energy locally at a node, we can bring energy that is generated elsewhere to a sensor node and charge its battery without any restraints of wires and plugs. The applications of wireless power transfer are numerous; it has been applied to replenish battery energy in medical sensors in the health care industry [20].

Enlivened, by this new discovery in wireless power transfer technology, this paper re-examines the network life time paradigm for the wireless sensor network. We visualize a mobile charging node (MCN) which carry power and visit each node to charge them wirelessly. This mobile charging node can be manned by human or it can be entirely autonomous. In this paper, we study the fundamental question of whether such a technology can be applied to remove the lifetime performance bottleneck of a WSN.Through wireless recharge we show that sensor node will always have an energy level above the minimum threshold so that the wireless sensor network can remain operational forever. We bring in the concept of renewable energy cycle where the remaining energy level in each sensor nodes battery exhibits some periodicity over a time cycle. We inquire an optimization problem with the objective of maximizing the ratio of MCN's vacation time (time spent at the home station) over the cycle time. In order to achieve the maximum ratio of MCN's vacation time over cycle time, we show that optimal traveling path for MCN is the shortest Hamiltonian cycle. We deduce several interesting properties associated with the optimal solution such as the optimal travelling path is independent of the traveling direction on the shortest Hamiltonian cycle.

This paper differs fundamentally from so called Delay tolerant network (DTN) [11], which employs various delivery mechanisms such as MULES [21] and message ferry [20], among others. It was presumed that DTN would experience frequent disconnectivity and could tolerant long delays. Both data mules and message ferry employ mobile nodes to collect data when in close range. In effect, the goal of DTN is to execute intermediate nodes to perform "routing" over time and to achieve "eventual delivery". Although the MCN in this paper has some similarity to data MULES and message ferry, there are some fundamental differences between them. First, the mobile charging node is used for wireless energy charging not for data collection. Second, the network life time is not a major concern in the case of DTN, but it is of primary concern in this paper. Thirdly, DTN is assumed to tolerate long delays, while real-time data flow from sensor nodes to base station with negligible delays.

The rest of the paper is organized as follows in Section II, describes about recent advances in wireless transfer technology. In section III, we depict the scope of our problem for a renewable sensor network. In Section 1V, shows the optimal traveling path, In Section V, we present the simulation results. Section VI, gives the conclusion of this paper.

II. WIRELESS POWER TRANSFER

The attempts of wireless power transfer can be dated back to early 1900's when Nikola Tesla experimented with large scale wireless power distribution[23].Telsa's pattern was never put into practical use because of its large electric field. Since then, there was hardly any progress in the case of wireless power transfer for many years. In the early 1990's the need for wireless power transfer came forth when portable electronic devices become widely spread. The well known example is electric tooth brush. However due to strict requirements such as close contact, accurate alignment in changing direction, and uninterrupted line of sight most of the wireless power transfer technologies found only limited applications.

Recently, wireless power transfer based on radio frequency (RF) between 850MHz – 950 MHz has been researched. Under such radiative power transfer technology, an RF transmitter broadcasts radio waves in the 915 MHz ISM band and an RF receiver tunes to same frequency band. Many similar experimental findings were also accounted in [24].The technology is also sensitive to hindrances between source and devices, requires complicated tracking mechanisms if position change and poses more rigorous safety concerns.

The foundation of this paper was due to recent breakthrough in wireless power transfer technology by kurs et al[13].It experimentally demonstrated that efficient non-radiative energy transfer was not only possible, but was also practical. They used two magnetic resonant objects having the same resonant frequency to exchange energy efficiently, while frittering little energy in extraneous off-resonant objects.

There has been a rapid advancement on the wireless power transfer technology after the first demo by kurs et al [13], particularly to make it portable. They used this technology for many portable devices such as cell phones. The source coil remains sizeable, but the device coil always portable. With the recent advancement in wireless power transfer technology it is expected that wireless power transfer will overturn, how energy is replenished in the near future.

III. PROBLEM DESCRIPTION

We consider a set of sensor nodes N, distributed over a two dimensional area, and each sensor node has a battery capacity of $E_{\max}$ and initially it is fully charged. $E_{\min}$ is represented as the minimum energy sensor node battery. The network life time can be defined as the time until the energy level of any sensor node falls below $E_{\min}$. Within each sensor network, there is a fixed base station B, which is the sink node. Each sensor node i generates data at the rate of R_i , $i \in N$ .Multihop data routing is employed here. Each sensor node depletes energy for data transmission and reception. To recharge the battery of each sensor node, the Mobile charging node (MCN) is utilized in each network. The mobile charging node(MCN) starts at the home station(S) and it travels with the speed of V in(m/s).When it arrives at each sensor node say I, it will spend some amount of time say τ_i to charge the sensor node's battery using the wireless power transfer technology. After the MCN visits all the sensor nodes in the network, it will come back to the home station to get its battery recharged and it will get ready for its next turn. We can denote τ_{vac} as the resting period or the vacation time. After this vacation time, the MCN will get ready for its next trip. We can refer τ as the trip time for the mobile charging node (MCN). In this paper, we would like to maximize the percentage of time in a cycle that MCN spends on the vacation time i.e $\frac{\tau_{vac}}{\tau}$ as given in[1]or equivalently minimize the percentage of time that the MCN spends outside on its field.

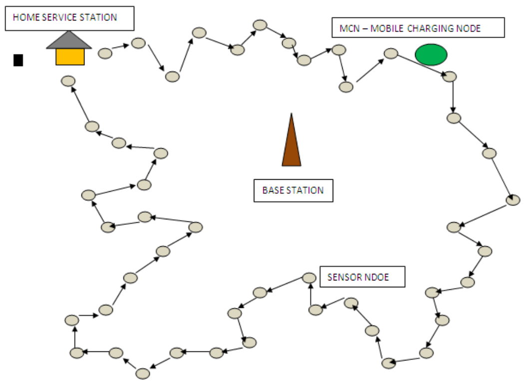

Figure 1. The optimal traveling path for the mobile charging node of a 50node sensor network

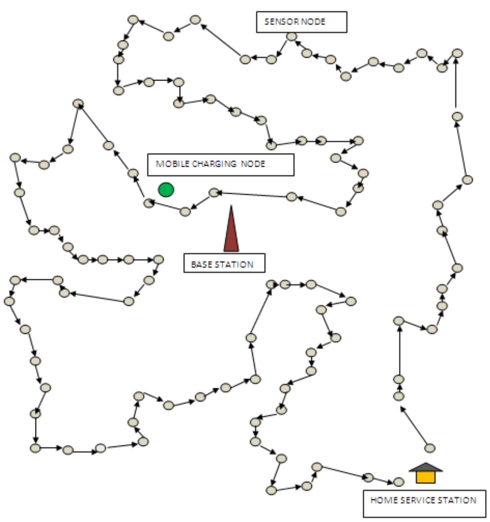

Figure 2.The optimal traveling path for the mobile charging node of a 100 node network

IV. OPTIMAL TRAVELING PATH

In this section, for an optimal solution, we show that the Mobile charging node must move along the shortest Hamiltonian cycle which is stated in the following theorem

Theorem 1: In an optimal solution, the MCN must travel along the shortest Hamiltonian cycle that connects all the sensor nodes in the network and the home station with the objective of maximizing $\frac{\tau_{vac}}{\tau}$.

This can be obtained by solving the well known Traveling Salesman Problem(TSP) in[7],[16]. D_{TSP} is denoted as the traveling distance in the shortest Hamiltonian cycle and let $\tau_{TSP} = \frac{D_{TSP}}{V}$ as given in [1]. Then using the optimal traveling path the equation becomes

$$\tau_{TSP} + \tau_{vac} + \sum i \in N^{\tau_i} = \tau \qquad (1)$$

as given in [1].The shortest Hamiltonian path may not be unique always. The choice of a particular Hamiltonian cycle does not affect the restraint (1), and also yields the same optimal objective since any shortest Hamiltonian cycle has the same total path distance and traveling time τ_{TSP} Figure 1 and 2, shows the optimal traveling path for the mobile charging node of a 50 node and 100 node sensor network.

V. SIMULATION

Simulation were done using the Network Simulator version 2.34.This network has been considered on an area of 1000X 1000m2 with the set of nodes placed randomly with the broadcasting range of 200m.The propagation model which is used here is shadowing. Initially each node is set with the energy of 100J. 11e6 bandwidth and the frequency of 2.4e6 is used. Topology used is flat grid addressing. The simulation was carried out for different number of nodes using Network Simulator (NS2).

Mannasim, a wireless sensor network simulation environment which comprises of mannasim framework and script generator tool was installed. The energy and position of each node was obtained from the trace file. Also the node color tells about the energy levels i.e. Green depicts energy level >80%, Yellow<50%, Red<20% defined in cmutrace.cc in ns2.The mobile charging node (MCN) is a mobile node, the rest are set as static nodes. Data transmission occurs from the source to the sink node. Energy for each node is obtained before and after the transmission. As the mobile charging node periodically moves around the network, each node is recharged, thus the network can remain operational forever.

VI. RESULTS

The experimental results were carried out for the network with the proposed new energy renewable solution with the other existing methods. Simulation results are as follows:

A. Network Throughput

Simulation result for average throughput of the network with the usage of MCN and without the usage of MCN is shown in Figure 3. With the employment of the mobile charging node, the life time of the network is increased and thus the throughput of the network also increases to 25%.

B. Packet delivery ratio

Figure 4. Shows the packet delivery ratio for the network with 50 nodes and 100 nodes, As the source increases, the packet delivery ratio for the network without the use of mobile charging node decrease, and best results are shown for the network which employs the energy renewable method.

C. *Average End To End Delay*

Figure 5. Shows the average end to end delay of the network. The average delay values are comparable because the path taken by the data packets are same for both the network with the proposed energy renewable method and the existing methods. For a transmission range of 200m, the results show that the delay of the network is approximately 2.3seconds. As the transmission range increases, the delay also increases at the same time.

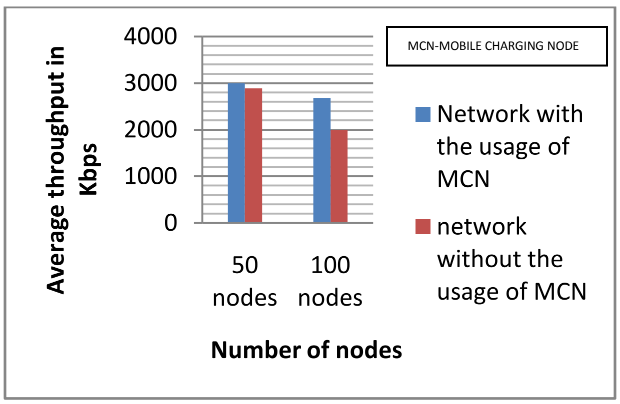

Figure 3. Throughput Vs Number of nodes

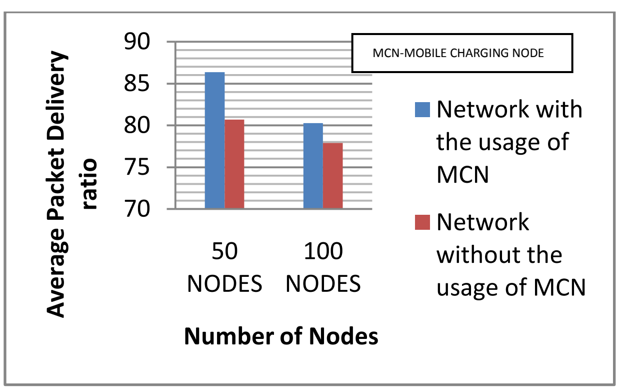

Figure 4. Packet delivery ratio Vs Number of nodes

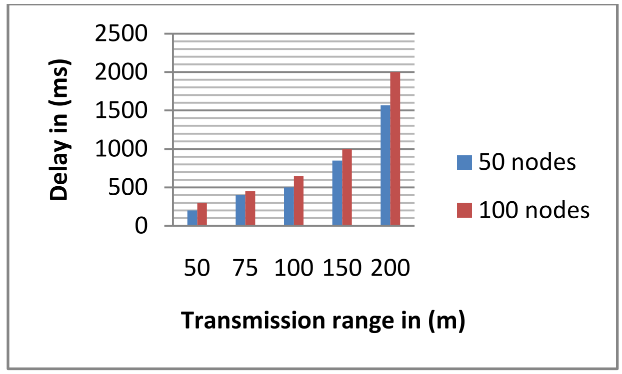

Figure 5. Average End to end delay Vs Transmission range

CONCLUSION

The existing wireless sensor networks have many constraints particularly it has limited battery energy and thus the life time of the sensor network is confined. This paper has exploited the recent development in wireless power transfer technology and it shows that once a network is properly designed and using a mobile charging node the network can remain operational forever. We examined the scenario where a mobile charging node periodically visits each node and charge them wirelessly without the use of any plugs or wires. We examined that wireless power transfer can be performed from one energy source to multiple energy receiving nodes and therefore the mobile charging node can charge multiple nodes at its traveling path and has the potential to work in densely deployed sensor networks.

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G.Lilly Evangeline received her B.tech degree from Karunya University, India in 2011.Currently pursing her master's degree in communication systems. Her area of interest includes digital signal processing, image processing, distributed wireless sensors, multimedia devices. Currently working on towards the progress of increasing the life time of sensor networks, design and analysis of MAC layer techniques for the digital ecosystems.

G.Josemin Bala, with over a decade of academic and research experience inclusive of a Doctorate from Anna University, Chennai. She has earned a name as a Teacher and Researcher in the field of electronics and communication. She is a member of professional bodies like ISTE and IEEE.