Green Communication in Wireless Sensor Networks

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***Abstract*— One of the visions of wireless sensor networks (WSNs) is autonomous long-term monitoring of the environment, and a key limiting factor is the ratio of energy consumption and delay. Most sensor net applications in outdoor environments run on battery, since it is easily accessible in off-the-grid environments and is relatively inexpensive. However, a battery-powered application is not suitable for a long-term deployment due to the finite capacity of the energy storage and the battery capacity to powerconsumptionratio. In order to address the nodes are put in to sleeping mode and limited-lifetime problem, delaying of data's, many solutions have been proposed at the application level and networking level. These solutions lengthen the lifetime of a sensor network by using various techniquesto reduce power consumption and delay, such as aggregation, data compression, and radio duty cycling, though the improvement is only a constant factor and does not solve the limitedlifetimeproblem. We analyze the comparison among renewable energy sources, in this paper we discuss solar energy is the most promising for an outdoor wireless sensor net application. It has higher power density than other renewable energy sources, and this allows a sensor node to collect sufficient energy and it stores energy through super capacitor with a small form factor and minimum delay when all the time nodes are awakening.**

Index Terms - Quality of service, solar energy, energy storage, delay, super capacitor

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are a certain type of un-attended ad hoc network consisting of numerous small independent sensor nodes that are either deployed in the activity region or nearer to it. The sensor nodes in the network are self-contained units containing advanced sensing functionalities, limited battery (energy), radio, and a minimal amount of on-board computing power. These sensor nodes exchange information in order to build a global view of the sensed region and the information is made accessible to the external user through one or more gateway node(s) [1]. Such networks are increasingly attractive means to enable a variety of applications and services. Some of the application domains include environment monitoring, health, military and home [2]. However these applications are delimited to a great extent due to the limited energy at the sensor nodes as it directly corresponds to network operational lifetime. In this context, since most of the energy is expended in transmitting the information between the sensor nodes rather than sensing, many academic and industrial efforts [3],[4],[5] focused on proposing energy-efficient routing protocols that involves several short-range multi-hop communication in lieu of direct long-range communication in relaying data between the sensor nodes. This routing strategy curtails the amount of energy spent by the sensor nodes but tends to increase the end-to-end delay involved in transfer of sensory data from the field to the sink. Certain applications such as Volcanic Monitoring are highly delay sensitive, where sensor nodes are deployed to monitor the seismic activities and emission levels of volcanic craters and data should be transmitted to the control center within a prescribed delay in observance of any unusual activity [6].

Using power control or topology control, such sensitive delay requirements can be possibly met. In topology control, the nodes transmit the sensory data using long-range radio links to distant nodes. The transfer delay incurred in such transmission is lowered as the data is relayed in fewer hops to the sink node but with higher energy consumption. A trade-off exists between the energy consumed in the data transfer and the incurred data transfer delay, thus giving rise to delay constrained, Energy-Efficient Routing Problem (DCEERP) in many WSNs applications.

The growing interest in sensor networks and continual emergence of new applications inspired various efforts in attempting to address the problem of energy-efficient, delay-constrained routing in sensor networks. The sensor nodes are heavily constrained in terms of energy consumption, delay guarantee, processing capacity and storage and hence require careful resource management. The goal of this paper is to enable the systematic design of a solar power system so that it will be possible to model and analyze hypothetical designs. We first provide a theory of solar power systems, then, based on the theory, we develop simulation tools that reflect reality.

Wireless sensor nodes are typically in the sleep state most of the time to prolong the network lifetime, but this will increase the detection delay. Wake-up the nodes in all the times, implementation of solar powered harvesting scheme instead of sleep scheduling are commonly used approaches to solve this problem. Nodes wake-up time as much as possible, so as to enhance the energy efficiency as well as satisfy the given detection delay constraint. First, we design a target prediction method based on kinematics rules and theory of probability. Then based on the prediction results, we design a novel solar-powered that reduces the frequently replacing of batteries of nodes and schedules their patterns in an integrated manner for enhancing energy efficiency. We analyze the detection delay and the detection probability, and conduct simulation-based experimental studies. Our simulation results show that energy efficiency achieves a better trade of between energy efficiency.

The rest of the paper is organized as follow, In Section II Related work, section III provides the problem statement of solar powered wireless sensor network. Then, in Section IV energy harvesting and detection delays are described. Finally, the paper is concluded in Section V.

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II. RELATEDWORK

The NiMH battery is one of the most popular types of energy storage for micro-solar power systems, because it has relatively high energy density and its charging method is simple (trickle charging). The Li-ion or Li-polymer battery has the highest energy density and high charge-to discharge efficiency. This makes the Li-ion battery a good candidate for energy storage when the micro-solar power system needs a small form factor. However, the charging mechanism of a Li-ion battery is more complicated, because it requires a dedicated charging management chip or software control to correctly control the battery. A super capacitor is a capacitor whose capacity is high enough to be used as energy storage for low-power electronic devices. While its capacity is still much smaller than other types of batteries, it's very high maximum recharge cycles allows it to be used for long-lifetime applications. Some solar power systems used multiple levels of storage that consist of a super capacitor and a Li-ion battery. The charging management is more complicated for a hybrid storage system, because it has to choose which storage to charge and when to charge. While the charging controller can be made in hardware, it can also be made in software by using the sensing and actuation capability of a sensor node.

There have been several systems for solar energy harvesting for wireless sensor networks or small embedded systems in literature. Some well known include, but are not limited to, those presented in [2]–[5].The presented architectures and implementations have demonstrated feasibility of using solar energy for powering sensor nodes in outdoor deployments. Furthermore different architectural choices have been shown, each representing different application constraints or optimization goals. Variations cover different storage technologies, such as rechargeable batteries [2], super capacitors [3] or combinations [5], different control mechanisms (e.g. software-based [5] or hardware based [2] solutions) and optimizations for performance [3] or minimum energy overhead [1]. Certain applications or locations, dimensioning of respective architectures for different situations was rarely addressed.

Research on modeling complete solar energy harvesting systems is much more limited. Work related to this topic was addressed in [9], [12], [13]. In [12] analytical prediction of harvested energy and consequence for battery charge level is examined. However, the presented results show that the model is not yet accurate enough to make decisions on system scaling. The simulation tool presented in [13] addresses a similar problem as this paper does, namely sizing of modules, but concentrates on larger sized harvesting systems, which leads to different approaches and optimization goals. Jeong describes modeling and simulation of micro-scale solar power systems in [9].

III. PROBLEM STATEMENT

A. Model for a Solar Powered Sensor System

In general, any solar-powered system consists of the following six components, external environment, solar panel, input regulator, energy storage, output regulator, and load as shown in fig.1. The solar energy from the environment is collected by the solar collector and is made available for the operation of the load. The energy storage is used to buffer the varying energy income and distribute it to the load throughout the duration. The input regulator can be used to adjust the mismatch between the operating range of the solar panel and the energy storage through super capacitor, while the output regulator is used to shape the operating range of the energy storage to that of the load.

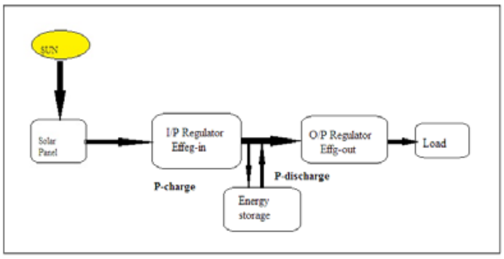

Fig. 1 solar-powered sensor system

B. Characteristics of Solar Pannel

In general, a wireless sensor node is composed of a micro-controller, communication subsystem, sensor/actuator subsystem, storage subsystem, and power subsystem. In this article, we focus on the design space of the power subsystems, viewing the rest of the system as the load. Depending on the characteristic of the energy source, the power subsystem of a wireless sensor node can be categorized into three types: (a) non rechargeable battery - powered, (b) wire-powered, and (c) renewable energy-powered. Using a non-rechargeable battery is the most common way of supplying energy to a sensor node because it is relatively inexpensive and the sensor node can be placed anywhere without requiring the existing power infrastructure to be re-wired. However, it can be problematic in that the lifetime of the sensor nodes is limited due to its limited capacity. In a wireless sensor network test bed, a wired backchannel is used for maintenance purposes, such as reprogramming and data downloading. As a side effect of using a wired backchannel, the sensor node can be powered through the wire. While wire power makes it easy to maintain a test bed, it is limited to where wiring is available. In an outdoor deployment, wire power may not be available, and making such devices weather proof or wildlife safe can add huge cost and complexity. A renewable energy-powered node runs on a renewable energy source, such as solar radiation, vibrations, human power, or air flow, and is expected to run for a long period of time without requiring the replacement of the battery. Among the various renewable energy sources, we focus on outdoor solar energy in this paper for two reasons. First, outdoor solar energy has higher power density than other renewable energy sources, and this allows us to build a solar energy harvesting system with a small form factor as shown in Table I.

TABLE I

Energy source	Power	Power Density
Outdoor Solar	135.6mW	1390uW/cm^2
Indoor Solar	2.9mW	366 uW/cm^2
Vibrations	180uW	180 uW/cm
Human Power	10mW	148 uW/cm
Wind Power	47.25mW	

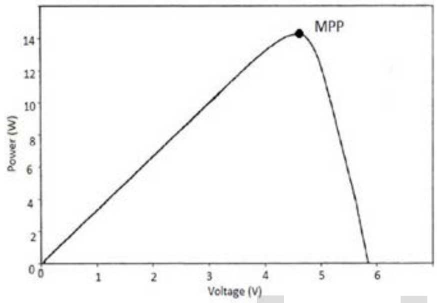

Fig. 4 Typical P-V characteristics of solar panel

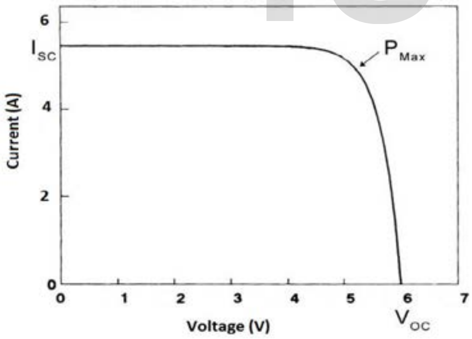

Fig. 3 Typical I-V Characteristics of solar panel

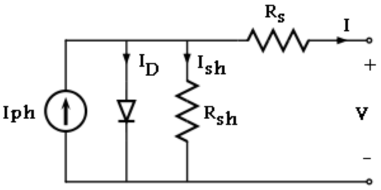

Fig. 2 PV cell equivalent circuit.

$$I = I_{ph} - I_s\left(\exp\frac{q(V + R_sI)}{NKT} - 1\right) - \frac{(V + R_sI)}{R_{sh}} \quad (1)$$

The equivalent circuit of a PV cell is shown in fig. 2. It includes a current source, a diode, a series resistance and a shunt resistance [4, 5]. In this equation(1), Iphis the photocurrent, Is is the reverse saturation current of the diode, q is the electron charge, V is the voltage across the diode, K is the Boltzmann's constant, T is the junction temperature, N is the ideality factor of the diode, and Rsand Rshare the series and shunt resistors of the cell, respectively. As a result, the complete physical behavior of the PV cell is in relation with Iph, Is, Rsand Rsh, the solar radiation from the other hand. Various results obtained as shown in fig. (3-6), are according to equ (1).

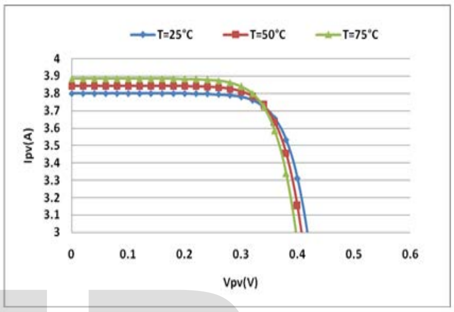

Fig. 5I-V curves for different cell temperatures.

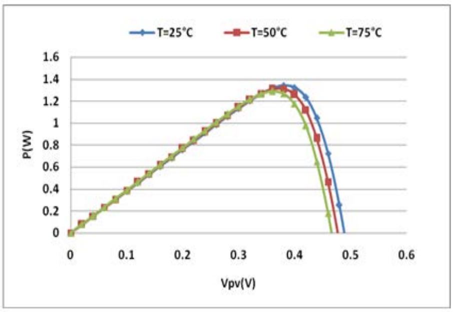

Fig. 6P-V curves for different cell temperatures

IV. ENERGY HARVESTING ANDDETECTION DELAY

A. Characterized Energy Harvesting

Batteries have much slower charge and discharge times. Super capacitors have time constant of between 1& 2 seconds. Charge Super capacitors 63.5% of its capacity in 1& 2 seconds

. A capacitor is considered as fully charged after 5 time constants. Super capacitors have much better temperature tolerance than batteries and will operate well from -40^0 c to 65^{0}c Super capacitors have much longer life cycle than batteries. Life cycles vary by brand from 1, 00,000 to 1,000,000 cycles of charge and discharge. Super capacitors have lower energy densities but their power densities are greater, in this paper we proposed super capacitors in Wireless sensor networks. Super capacitors are capable of storing joules of energy. A 50-Farad, 2.5 volt device can store at much as 156.25 joules of energy. This is not a particularly large value compared to an AA Li-Ion battery at 31,000 joules, but the Super capacitor has some advantages nonetheless. Most important is the number of charge cycles. The energy storage device in a solar powered WSN will be charged and discharged daily (if not more often) because of day/night cycles. Three years of operation will result in over 1000 charge/discharge cycles. This can cause problems for many battery families because they are limited to 500-1000 charge/discharge cycles before significantly losing capacity. Super capacitors have no such limitation and can be charged/discharged millions of times.

B. Sleep Wake up Strategies

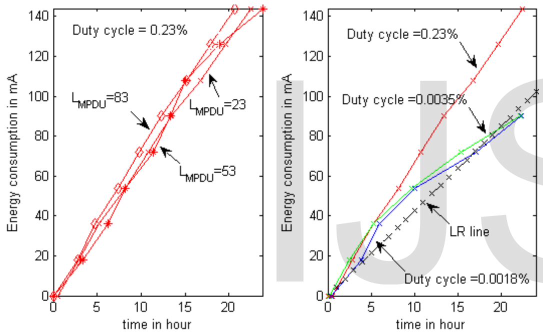

Fig 7 energy consuming pattern

Because a credible deployment of WSN is based on the energy management of sensor nodes and energy is a finite resource, different sleep and wake up polices can be used to prolong the WSN lifetime. We consider two variables (super cap l and solar radiation r) in the sleep and wake up models. When the super cap state is l and the solar radiation is r, the node can switch from the active to the sleep mode and vice versa. We use a random variable N to represent the mode of operation of the sensor (i.e., N = sleep, N = active) hence from the probability $Pa_{\rightarrow}$ s (l, r) = Prob(N (t) = sleep | N(t − 1) = active), from the sleep mode to the active mode Psa(l, r) = Prob(N(t) = active | N(t − 1) = sleep). To test our concept, we selected a hybrid model which is composed of a combination of the super cap and solar radiation models.

C. Energy Consuming Patterns

In a wireless sensor node, the transmission data length (LMPDU) and the MCU active cycle are the major elements that have effects on power consumption. Therefore, we must consider what effects these two elements have on consumption energy EA. The following shows the MPDU (MAC Protocol Data Unit) length (LMPDU) and energy consumption patterns of an active cycle. The power consumption pattern can be measured with linear regression analysis that considers the error due to external environmental factors such as temperature. The active interval TA used in the experiment is 18.4±1.1ms, and includes the MCU's startup time (>4.1ms). TT includes not only the pure transmission time (2.10±0.96ms) but also the startup time (≒1.6ms) of the oscillator/regulator. The built-in sensors need about 303~1,394us of action time, including standby time, and application program logic and IO time between MCU-RF transceivers as overhead. In this experiment, we activated and tested sensors for a total interval. The one-day consumption power related to the sensors and sensor board is 50.0mA.

Our experiment as shown in fig. (7). That the effect of active interval variation is even larger than the MPDU length variation. That is, we can know that applying a duty cycle of 0.23% from the result, energy consumption to data length change does not change while duty cycle changes substantially, because an interval overhead that was needed at startup procedure in power-down level is relatively larger than real data process and transmission time. In small-size data environment, even higher priority must be given to the minimized duty cycle. But because a considerable time of duty cycle alleviates data validation in real time environments, it must be endure according to application.

$$p_{cavg} = V_{supply}\left(D_{I_{active}} + (1 - D)\_I_{sleep}\right) \qquad (2)$$

Fig.7The figure shows the energy consumption pattern of 23, 53, and 83byte MPDU that includes capacitor change monitoring results (left) and shows the energy consumption pattern in case of transmitting to 0.23%, 0.0035%, and 0.0018% duty cycle (right).

D. Detection Delay

Event-driven wireless sensor networks, for which events occur infrequently. In such systems, most of the energy is consumed when the radios are on, waiting for an arrival to occur. Sleep-wake scheduling is an effective mechanism to prolong the lifetime of these energy-constrained wireless sensor networks. However, sleep-wake scheduling could result in substantial delays because a transmitting node needs to wait for its next-hop relay node to wake up. An interesting line of work attempts to reduce these delays by developing any cast based packet forwarding schemes, where each node opportunistically forwards a packet to the first neighboring node that wakes up among multiple candidate nodes. In this paper, we address these challenges. We investigate the delay minimization problem given the wakeup rates of the sensor nodes, how to optimally choose the any cast forwarding policy to minimize the expected end-to -end delay from all sensor nodes to the sink.

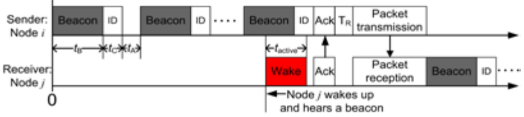

Fig. 8 System model

We consider a wireless sensor network with N nodes. Let N denote the set of all nodes in the network. Each sensor node is in charge of both detecting events and relaying packets. If a node detects an event, the node packs the event information into a packet, and delivers the packet to a sink s via multi hop relaying. We assume in this paper that there is a single sink; however, the analysis can be generalized to the case with multiple sinks. To reduce this delay, we use an any cast forwarding scheme as described in Fig. 8. Let C_i denote the set of nodes in the transmission range of node i. suppose that node i has a packet and it needs to pick up a node in its transmission range C_i to relay the packet. Each node i maintain a list of nodes that node i intends to use as a forwarder. We call the set of such nodes as the forwarding set, which is denoted by f_i for node i. In addition, each node j is also assumed to maintain a list of nodes i that use node j as a forwarder (i.e., j ε f_i). As shown in Fig. 8, node i start sending a beacon signal and an ID signal, successively. All nodes in C_i hear these signals, regardless of whom these signals are intended for. A node j that wakes up during the beacon signal or the ID signal will check if it is in the forwarding set of node i. If it is, node j sends one acknowledgement after the ID signal ends. After each ID signal, node i checks whether there is any acknowledgement from the nodes in f_i. If no acknowledgement is detected, node i repeats the beacon-ID signaling and acknowledgement-detection processes until it hears one. On the other hand, if there is an acknowledgement, it may take additional time for node i to identify which node acknowledge the beacon-ID signals, especially when there are multiple nodes that wake up at the same time. Let t_R denote the resolution period, during which time node I identifies which nodes have sent acknowledgements. If there are multiple awake nodes, node i chooses one node among them that will forward the packet. After the resolution period, the chosen node receives the packet from node i during the packet transmission period t_P , and then starts the beacon- ID-signaling and acknowledgement-detection processes to find the next forwarder. Since nodes consume energy when awake, t_{active} should be as small as possible. However, t_{active} has to be larger than t_A because otherwise a neighboring node could wake up after an ID signal and could return to sleep before the next beacon signal. In this paper, we set $t_{active}= t_A$ so that nodes cannot miss on-going beacon-ID signals and also can reduce the energy consumption for staying awake.

E. Minimization of Delays

In this section, we consider how each node should choose its any cast policy (A,B) to minimize the delay $D_i(\vec{p}A,B)$, when the awake probabilities $\binom{\to}{p}$ are given. We relax the fixed awake-probability assumption to solve Problem (P). The delay-minimization problem is an instance of the stochastic shortest path (SSP) problem, where the sensor node that holds the packet corresponds to the 'state' and the delay corresponds to the 'cost' to be minimized. The sink then corresponds to the terminal state, where the cost (delay) is incurred. Let $i_{0,}$ $i_{1,}$ i_2 be the sequence of nodes that successively relay the packet from the source node i_0 to sink node s. Note that the sequence is random because at each hop, the first node in the forwarding set that wakes up will be chosen as a next-hop node. If the packet reaches sink s after K hops, we have $i_h = s$ for $h > K$. Let $d_j(\vec{p}A,B)$, be the expected one-hop delay at node j under the any cast policy (A,B), that is, the expected delay from the time the packet reaches node j to the time it is forwarded to the next-hop node. Then, the end to- end delay $D_i(\vec{p}A,B)$, from node i can be expressed as $D_i\left(\vec{p},A,B\right) = E\left[\sum_{k=0}^{\infty} d_{ik}(\vec{p}A,B),\right]$.

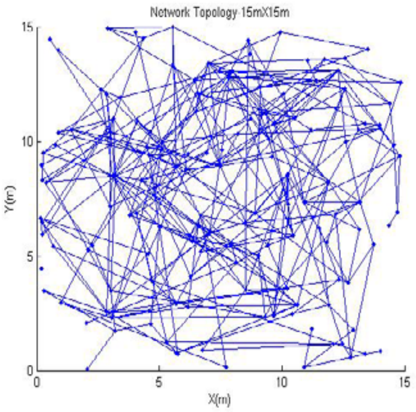

Fig. 9 Node deployment and network topology

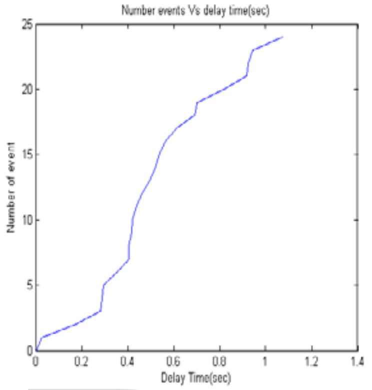

Fig. 10 Number of event Vs Delay (sec), ƛ =25

V. CONCLSION

We presented an approach to optimize the performance of energy harvesting systems subject to solar energy system. For enhancing energy efficiency, we designed a novel approach by reducing the number of sleep nodes and at any time all the sensor nodes are awakened in order to implementing solar energy .In case of sun light is darkened , the charging time of super capacitor is quite less compare to conventional capacitor and also the power density is very high. So, from the knowledge of different branch parameter of super capacitor the exact behavior and response can be predicted. From the charging and discharging time, the internal parameter has been calculated and which will be helpful for designing the charging and discharging circuit. In order to replace battery with super capacitor. Based on our analysis, a network will be able to minimize the energy consumption when satisfying a given delay constraint.

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