Power Management in a Self-Charging Wireless Sensor Node using Solar Energy

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Abstract. In sensor networks, sensor nodes using a primary battery can perform only limited tasks because of insufficient energy supply. This is an important issue to resolve in sensor networks. Energy supplied from the sun is widely known as a proper method to complement energy shortage. Because solar energy is provided periodically and repeatedly, sensor nodes can operate for a long time. We describe a power management system that can be applied easily to energy-oriented applications needing different levels of static control, based on a solar battery and a secondary battery, to improve the energy efficiency in a wireless sensor node using solar energy.

Keywords: Power Management, Self-Charging, Wireless Sensor Node, Wireless Sensor Network

1 Introduction

In wireless sensor networks, most sensor nodes work with a battery. However, because sensor networks have to operate for a long time, poor battery capacity has to be considered. This is a very large limitation in the operation of sensors and sensor nodes.

It is possible to obtain energy from several environmental energy sources. When we use sun light, it is possible to produce power of a few mW per unit area. This is enough to operate low-power devices with small loads. In particular, solar energy has features such as high collecting efficiency, which is provided continually and in periodic cycles [1]. Recently, an energy charging module for low-cost and high-efficiency solar energy for wireless sensor networks was studied [2],[3]. Also, by controlling duty cycle according to a power profile, studies have been conducted for maintaining the best power consumption performance with several energy sources [4],[5]. The current study can provide power to wireless sensor networks with energy charging. The sensor network operation is divided into three parts: sensing the environments, processing the data acquired, and transmitting the data through wireless networks. A decision engine allows for power allocation upon consideration of the control criteria. Dynamic power management [6],[7] is now widely being studied, both for operational attributes and for energy consumption patterns for sensors. Other studies have also been done on finding much more effective energy division mechanisms based on energy models for predicting the availability of energy in periodic charge cycles [8].

2 Self-Charging Sensor Node using Solar Energy

The solar battery used provides a power level of 11mW/cm^2. The power that the solar battery produces is saved in a secondary Li-polymer battery. Li-polymer batteries have high charging and discharging efficiency (more than 99.8%) and provide the voltage (3.7V) required for sensors [9]. This battery is suitable as a secondary battery, because it has low discharge rate (less than 10%/month) and no memory effect.

The wireless sensor node used employs the first Li-polymer battery (secondary battery) and solar battery as power supplies. When the remaining energy of a secondary battery is low, we construct the power source to be turn from this battery to primary battery. Generally, RF transceivers are known as devices with the most energy consumption in wireless sensor nodes. We consider a method that provides higher transmission efficiency through utilizing spare energy by periodic battery charging. We allow wider transmission coverage to use a CC2590 range extender with additional energy consumption. The CC2590 can output a maximum of 12dBm with additional consumption of a maximum of 24mA in HGM (High gain mode).

3 Power Consumption Model

Solar energy can be produced and collected periodically, but is wasted when the storage capacity of the batteries is reached fully. We calculate the energy content required for sensor node operation and propose a utilization plan for spare energy by operational control.

3.1 Duty Cycle of Sensor Nodes

The duty cycle is divided into real operation time (T_A) into a unit time($T_A + T_S$), and can determine power consumption by the control of length of sleep time (T_S) in compared with T_A. Here, the MCU is activated during T_A. In T_A, the operation time of j-th sensor, T_{Mj}, includes the setup time and the real measuring time. Also, the transmit time and the receive time (T_T and T_R) of the RF transceiver is some variable according to the network situation and length of the control data.

The consumption powers of the MCU and j-th sensor are P_A and P_{Mj}, and the transmit/receive consumption power of RF transceiver are P_T and P_R, respectively. The consumption energy E_A that predicted for a unit active interval is as follows:

$$E_A = T_A P_A + (T_T P_T + T_R P_R) + \sum_{j=1}^{n} T_{M_j} P_{M_j} . \quad (1)$$

Here, the operating time(T_{Mj}) of j-th sensor is the entire time interval in $T_A + T_S$, or a partial time interval in the T_A according to the role that is conferred on the sensor.

Table 1. Power Consumption of Power Supply Mode (@3.3V)

Unit	Mode	Power
MCU(8MHz)	active	33 mW
	power down	16 uW
RF Transceiver	transmit	128 mW
(HGM, $P_{out,cc2420}$=0dBm)	receive	73.26 mW
	power down	66.33 uW

In sensor applications based on the primary battery, sensor operation and time are generally fixed [6]. Therefore, we know that the energy requirement is determined depending on the MCU active interval and the transmission time. T_T and T_R can be used to calculate approximately as follows. First, the bit rate is 250kb/sec, and the symbol transmission time is 16us according to O-QPSK modulation. The real transmission time T_T for an MPDU (MAC Protocol Data Unit) length, L_{MPDU}[Byte], is $(L_{MPDU} \times 2+(12+8+2+2))[symbol] \times 16us/symbol$, which considers the SHR/PHR length of PPDU and the lock time after STXON procedure in RF transceiver.

3.2 Energy Consuming Patterns

In a wireless sensor node, the transmission data length (L_{MPDU}) 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 E_A.

The following shows the MPDU length (L_{MPDU}) 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 T_A used in the experiment is 18.4±1.1ms, and includes the MCU's startup time (>4.1ms). T_T 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 showed 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.

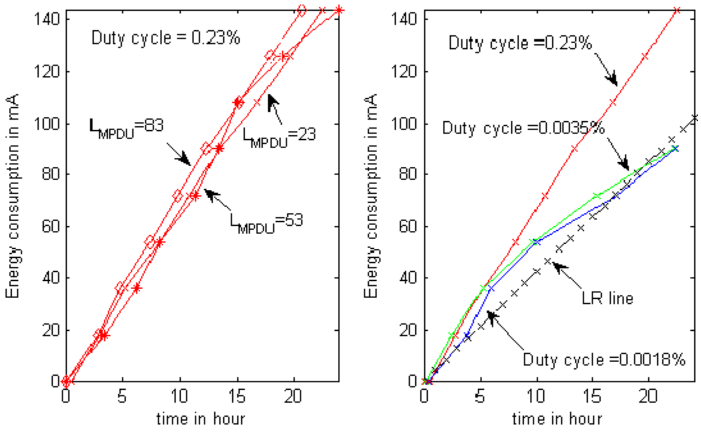

Fig. 1. The figure shows the energy consumption pattern of 23, 53, and 83byte MPDUs that includes battery change monitoring results (left) and shows the energy consumption pattern in case of transmitting to 0.23%, 0.0035%, and 0.0018% duty cycle (right).

4 Power Management Algorithm and Its Characteristics

In this chapter, we describe a power control algorithm for the wireless sensor node and its operational properties.

4.1 Control Algorithm

Because solar energy is cyclical, the action of sensor nodes must be controlled according to the available energy in the secondary battery. For example, with enough energy, it is possible to provide much more sensor and a shorter sleep time. In a poor energy state, selective sensing and delayed transmission for sensing data are necessary.

We control the sensor node power by using predicting the consumption energy of operation and the operation to be performed in the active interval. A spare energy threshold value $(TL_i, 1 \le L_i < n)$ is utilized to divide the n-level of the energy area, and operation $(O_j, 1 \le j \le n)$ is executed in the each energy area. Operation basically includes data transmission procedure after obtaining the sensing data from sensor.

Utilization of our threshold value has advantages in that the operation is easy to adjust for changing situations of energy area, and it can compensate for uncomputed error by various factors such as temperature, battery efficiency, and an individual sensor's properties.

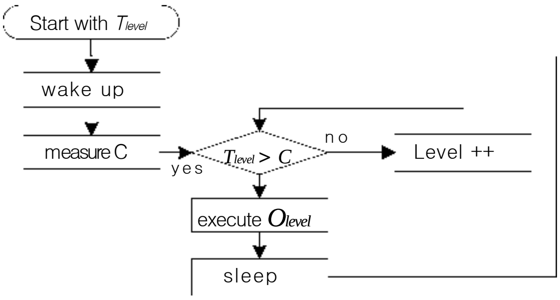

Fig. 2. The threshold value of minimum residual energy chosen based on average sunshine. The residual energy C is measured by a battery monitoring sensor and has a range between 0 and 100%. The sleep level turns off the power supply to save power during T_S

4.2 Characteristics of Control Algorithms

We analyze an example regarding how the available energy changes by solar energy charging, how the data transmission changes, and how the transmission cycle changes. The size of the solar battery equipped at the sensor node is 60x150mm, and it can provide a maximum of 4.5 volts and 1 watt of power. The secondary battery that is equipped to save charging energy has 1,800mA of capacity.

In figure, the first section ($T_{L1} \leq C < T_{L2}$) performs sensing and data transmission of a basic cycle (8sec). By the second section ($C < T_{L1}$), the N-th sensing and data transmission consist of an 8sec$\times 2^n$ cycle.

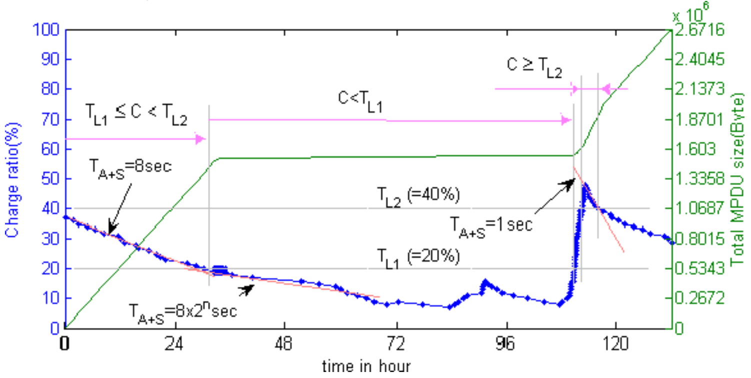

Fig. 3. Energy monitoring results for 131 hours. The initial residual battery is 38%, and the sensor node's operation is divided into 5 sections and is controlled.

The fourth section ($C \geq T_{L2}$) performs an even shorter cycle, and many sensing action because it can utilize the sufficient energy. Therefore we know that amount of transmission data is enlarged even larger than pervious section. In last section, basic cycle's sensing and data transmission is performed as first section again.

The threshold values, T_{L1}(=20%) and T_{L2}(=40%), are the boundaries of the energy area. O_3 is the operation to sense the surrounding environment in 1 second of a cycle

($T_{1,A+S}$) and to transmits the sensing data immediately. O_2 transmits sensing data in 8 seconds of a basic cycle $_{(T_{8,A+S})}$. In O_1, data sensing and transmission performs at time $_{(T_{8,A+S}}$)x2^n, when n-th wakeup procedure occurs. And then n increased by 1.

The second section $C_{<\ TL1}$ has an energy consumption rate that is decreased to 25% compared with the previous section, because of the expansion of the active cycle (T_{A+S}). Also, we can know that the transmission period is minimized regardless of emergency situations in this section. We can see that this method can be instantly adapted in the change of the surrounding environment, and easily provides energy-oriented application development.

5 Conclusion

Wireless sensor nodes using solar energy need a method that distributes energy effectively. We have described a power consumption model that similar to the real environments, as well as a control algorithm based on this model. Our model cannot only operate for a long time but can also relieve energy constraints.

We expect that the results of this paper can be utilized to easily apply various power control mechanisms, according to the intrinsic judgment of an application as an example of effective power control that use solar energy.

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