Packet transmission policies for battery operated wireless sensor networks

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Abstract With the concept of “Cognitive Sense of China” and “Smart Planet” proposed, wireless sensor networking is considered to be one of the most important technologies of the new century. In wireless sensor networks, how to extend battery lifetime is a core problem. In this paper, we address the problem of designing battery-friendly packet transmission policies for wireless sensor networks. Our objective is to maximize the lifetime of batteries for wireless sensor nodes subject to certain delay constraints. We present three packet transmission schemes and evaluate them with respect to battery performance. The first scheme, based on combining multiple packets, utilizes battery charge recovery effect, which allows some charge to be recovered during long idle periods. The second scheme, based on a modified version of lazy packet scheduling, draws smoother and lower current and is battery efficient. The final scheme, based on a combination of the two previous schemes has superior battery performance at the expense of larger average packet delay. All three schemes are simulated for a wireless network framework with internet traffic, and the results were validated.

Keywords battery friendly, lazy packet, wireless sensor networks, packet transmission

1 Introduction

With the exploding development of wireless technology in the recent years, the concept of the Internet of Things and sensor networks technology are becoming increasingly important technologies. The Internet of Things is widely used in intelligent transportation, various environmental monitoring systems, intelligent utilities and many other areas. It is certain that the ubiquitous Machine to Machine (M2M) services will become feasible and will make a major change to our future daily life as well as future human society. However, most of these wireless sensor networks are battery-operated, and cannot be used indiscriminately because the batteries have limited energy sources. In this paper we focus on packet transmission schemes that maximize the battery lifetime of wireless sensor networks. Maximizing battery lifetime is a particularly difficult problem due to the non-linearity of the battery behavior. In recent years, a significant amount of work has been done studying battery characteristics [1–3] and battery models [4–7]. Reference [4] proposes an accurate analytical charge-based model for battery simulation, which is adopted in our paper. Aware of battery characteristics, several related techniques such as battery-aware routing, task scheduling, and MAC protocols have been proposed. Refs. [8,9] propose battery-aware routing algorithms to maximize the network lifetime by making full use of the battery recovery effect and rate capacity effect (See Section 2.3) respectively. In task scheduling, the algorithms in [10,11], shape the load current profile in accordance with battery properties. Another scheduling scheme that adjusts the delay of different system components of a communication system such that the discharge profile is battery-friendly has been proposed in [12]. The authors of [13] propose a novel battery aware MAC scheduling scheme which considers the nodes in the network and the contention for radio channels.
There has also been some effort in designing battery-aware packet transmission schemes [6,14,15]. The basic idea is to queue transmission requests whenever the battery’s state of charge (SOC) drops to a certain threshold. The schemes in [6,14,15] use a stochastic battery model and show how queuing the requests allows the battery to recover and results in overall battery lifetime enhancement. Based on the same model [16], proposes energy efficient transmission scheduling with the consideration of both channel coding and electro-chemical mechanism.

Another important effort in energy-efficient transmission over wireless link, referred to as lazy packet scheduling [17], turns out to be battery-aware. The basic idea is to make full use of the inter-arrival time between packets and transmit over a longer transmission period at reduced power. Transmitting at reduced power means working at lower current for a longer time, which results in better battery performance. This comes at the price of a larger buffer size and larger system delay.

In this paper, we adopt the accurate analysis battery model from [4] and present three packet transmission schemes and evaluate them with respect to battery performance. The first scheme is based on combining multiple packets; the larger the number of packets that are combined, the better the battery performance. This comes at the price of a larger buffer size and larger system delay. The second scheme is based on a modified version of lazy packet scheduling. It has better battery performance and lower runtime complexity. The last scheme is a combination of the former two schemes. Packets are grouped according to the arrival rate of 45% of the maximum arrival rate, the battery charge consumption is about 48.9% of the original consumption. However, the drawback of these schemes is the increase in the packet delay. Delay analysis shows that as the packet arrival rate reduces, the average delay per packet of the first scheme varies slightly while that of the second and third scheme increases.

Section 2 introduces the background of our work, which includes the analytical battery model, and battery characteristics. Section 3 describes the packet combining scheme along with the simulation results. Section 4 discusses battery performance of the lazy packet scheme and modified lazy packet scheme. Section 5 combines the two schemes and proposes the most battery-friendly scheme. Section 6 compares and analyzes the delays resulting from the three schemes. This paper ends with conclusions in Section 7.

2 Background

2.1 System configuration

The communication node consists of a data processing unit, an input buffer, an output buffer and a smart battery, see Fig. 1. The data processor is used for command execution and packet processing. The smart battery supplies power to the data processing unit and buffer. It also monitors the battery’s SOC, defined in Section 2.3. The input and output buffers are used for temporarily storing packets before and after their processing.

![Communication node configuration](image)

2.2 Battery model

In our work, we use an accurate analytical charge-based model for battery simulation [4]. In this model, the load profile is given in the form of a sequence of $N$ constant current values $I_1, I_2, I_3, \ldots, I_N$, where $I_k$ is the current of task $k$ at time $t_k$, and is applied for a duration $\Delta_k = t_{k+1} - t_k$. The relation between the load profile $\{I_k, \Delta_k\}$ and the battery’s lifetime $L$ is as follows:

$$
\alpha = \sum_{k=1}^{N} I_k \Delta_k + \sum_{k=1}^{N} \sum_{m=1}^{\infty} \frac{e^{-\beta m^2 (L - t_k)}}{\beta^m m^2} - \frac{e^{-\beta m^2 (L - t_k)}}{\beta^m m^2},
$$

(1)

where $\alpha$ and $\beta$ are battery parameters. The parameter $\alpha$ represents the total charge in the battery when it is fully charged. The parameter $\beta$ measures the nonlinearity of the battery and tells us how fast the diffusion process can keep up with the rate of discharge. The higher the value of $\beta$, the better the battery performs. This model has been tested extensively on real load profiles running on a Compaq ITSY pocket computer. Differences between the model predictions and the measured and simulated values were in the range of 1%–3% [4]. In our simulations, we have use $\alpha = 35220$ mA·min and $\beta = 0.637$ min$^{-1/2}$ corre-