User-Centric Prediction for Battery Lifetime of Mobile Devices

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Abstract. Today, mobile devices are being used for various applications such as making voice/video calls, browsing Internet and so on. The operating time and battery consumption spent in those activities affect the battery life of mobile devices. In this paper, we propose a method for predicting the battery lifetime of mobile devices based on usage patterns. We define the possible states of mobile devices based on their operating functions and develop a method of predicting battery lifetime based on average battery consumption and duration of each state.

Keywords: Battery Lifetime Prediction, Usage Pattern, Power Management.

1 Introduction

As mobile networks and services have been growing, mobile and battery-powered devices (e.g., a mobile handset or PDA) have emerged as important tools in our lives. However, their short battery life is one of factors that cause much inconvenience or reduce their usefulness [1]. Mechanisms to provide long and stable battery life are needed to provide mobile communication networks that are more stable. To guarantee long battery life is to minimize battery consumption by reducing needless battery usage.

The key to successfully minimizing battery consumption is accurately predicting the battery consumption of mobile devices' various operating states. Much work has focused on hardware or operating system (OS) level predictions [3], model-based battery life predictions [2], and battery consumption by a CPU when executing a particular instruction [4]; furthermore, battery lifetime has been usually predicted by static battery consumption rate which manufacturers of batteries and mobile devices have determined via experiments. It has also been predicted by the arithmetic means of the consumed power. However, previous methods have had limitations in predicting battery lifetime in terms of users' characteristics because they did not consider usage patterns. That is, every user has a different mix of voice call, data communication, and video call usage. If we assume that the usage pattern of each user is different and that it will continue on a similar basis in the future, we can predict battery lifetime on an individual basis.

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In this paper, we propose a method for predicting the battery lifetime of mobile devices based on usage patterns. We define possible states of a mobile device based on its basic operating functions. We measure the battery consumption and the operating time spent in each state. We present our method using usage patterns generated by the probability of the operating time of each state. Because the proposed method presents the battery lifetime by way of an on-line analysis based on usage patterns rather than an off-line analysis, this is more useful to users than previous methods. It enables effective battery usage and detects abnormal battery usage by comparing operating times between the normal and abnormal states.

The organization of this paper is as follows. Section 2 describes our proposed method with problem definition and solution approach. finally, conclusions and future work are drawn in Section 3.

2 Proposed Battery Lifetime Prediction Method

In this section, we present our method of battery lifetime prediction. We first present our assumptions and problem definition. We then describe our proposed method and evaluation.

2.1 Assumptions

For our proposed method, we have made the following assumptions.

- the battery consumption of mobile devices is affected by voice calls, video calls, data communication, short message service, LCD, applications, music, and waiting for calls
- we can define possible states in terms of the operating functions of mobile devices
- the average battery consumption rate of each state is different
- the probability of duration of each state is different because different users have different usage patterns
- if a users' usage pattern will be repeated and consistent over the long term, we can use Zipf's law to predict the battery lifetime, based on usage pattern

2.2 Problem Definition

We also assume that a mobile device has n possible states. First of all, some symbol descriptions and formulations are given as follows:

$$\boldsymbol{B} = (B_1, \ldots, B_n), \tag{1}$$

$$\boldsymbol{p} = (p_1, \ldots, p_n), \tag{2}$$

$$\boldsymbol{R} = (R_1, \ldots, R_n), \tag{3}$$

$$R_i = p_i \cdot B_i, \tag{4}$$

where B_i is the average battery consumption rate of the ith state, and p_i time consumption rate of the ith state, which is determined to satisfy $\sum_{i=1}^{n} p_i = 1$. Because each user has a different vector $\boldsymbol{p}$ according to the usage pattern, this vector is defined for the symbol that represents the usage pattern. R_i is the ratio of battery consumption of the ith state.

Formulation to predict battery lifetime based on usage pattern:

$$T = \frac{V}{\sum_{i=1}^{n} R_i} = \frac{V}{\sum_{i=1}^{n} p_i \cdot B_i}, \tag{5}$$

where T is the battery lifetime predicted by usage patterns, and V is the total battery quantity. Because each user has a different $\boldsymbol{p}$, every user has different lifetime for the remained battery.

2.3 Solution Approach

In this section, we describe a solution of the problem defined in Section 2.2. When a mobile device is turned on, a data-collecting process starts to gather data *vis-à-vis* the operating time and battery consumption of each state. This process records the battery and time consumptions of each state, based on timestamp. This time-series data is used to measure average battery consumption rate ($\boldsymbol{B}$) and usage patterns ($\boldsymbol{p}$). Finally, the prediction of battery lifetime, based on usage pattern, is provided based on these two vectors. First of all, we collect the time-series data for each state. To collect data for each state, we append time and battery level to a log file upon entering and exiting the state. We define a symbol for log data in the vector $\boldsymbol{D_j} = (D_j^1, D_j^2, D_j^3)$, where $\boldsymbol{D_j}$ is a vector of the jth log data, D_j^i is the time-series data of the jth log data, D^1 is a state of the mobile device, D^2 is a battery level, and D^3 is time consumption. Next, we look to calculate the average battery consumption rate and the usage pattern using time-series log data. As defined in Section 3.2, we assume that a mobile device has n possible states and the log file has m entries. We represent the total battery consumption in the vector $\boldsymbol{b} = (b_1, \ldots, b_n)$. The value of this vector is the total battery consumption of the ith state via a summation of the secod elements of each log entry which state is i. We also represent the time consumption in the vector $\boldsymbol{t} = (t_1, \ldots, t_n)$. The value of this vector is the time consumption of the ith state via a summation of the third elements of each log entry which state is i. Thus,

$$b_i = \sum_{j=1}^{m} D_j^2, \tag{6}$$

$$t_i = \sum_{j=1}^{m} D_j^3, \tag{7}$$

where $D_j^1 = i$. The average battery consumption rate and usage pattern for each user using Equations (6) and (7) are defined as $B_i = \frac{b_i}{t_i}, p_i = \frac{t_i}{\sum_{i=1}^{n} t_i}$, where B_i is the average battery consumption rate of the ith state, and p_i time consumption rate of the ith state, which is determined to satisfy $\sum_{i=1}^{n} p_i = 1$. This usage pattern represents not only the usage pattern of the past, but also the probability of spending time in each state in the future. We can predict the usage pattern using Holt-Winters Model [5,6] which predicts the future data based on time-series data. So, we can calculate the lifetime of remained remaining battery (T) by Equation (5) with $\boldsymbol{B}$ and $\boldsymbol{p}$.

3 Concluding Remarks

Predicting of the battery lifetime of mobile devices is important to successfully minimizing battery consumption at the application level. In this paper, we have proposed a prediction model based on usage patterns, such as the battery consumption rate spent in making voice calls, using data communication, or waiting for calls. We have also presented the usefulness of our proposed method as a case study. The contribution of our proposed method is to provide a stable mobile communication network through the user-centric prediction of mobile device use.

Currently, we are testing our proposed method on a mobile platform based on Intel PXA270 processor based on the ARMv4 instruction set architecture. We have already ported the embedded Linux, kernel version 2.6.15.7; because we can modify the device driver for battery and voice call on the embedded Linux, we can derive more precise values. We will present the experimental results that validate our proposed method on this mobile platform, in the extended version of this paper.

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