Context-aware Global Power Management for Mobile Devices Balancing Battery Outage and User Experience

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1. INTRODUCTION

Energy conservation on mobile devices is now more important than ever due to the increasing benefits that smartphones provide to our daily life. However, most existing power management approaches either focus narrowly on a particular sub-system of the mobile device such as the sensor system [2], the phone display [1], or the positioning system [3]. While these approaches provide valuable techniques to improve the energy efficiency of individual subcomponents on mobile devices, their main drawback is that they provide no *global* framework to avoid battery outage for end users while maximizing user experience as much as possible.

In this paper, we present a smart context-aware global power management system, to meet the mobile device's expected battery life while compromising end user experience as little as possible. We take into account users' typical phone usage and energy consumption patterns, and user experience preferences for various smartphone components. Our approach uses a Markov Decision Process (MDP) model to control the energy consumption of various components. The key challenge in formulating our energy management problem as a MDP is to properly define the user **states**, power-saving **actions** and a **reward** for each action that achieve our power management goals.

As a proof-of-concept, we manage the energy consumption of both the display and GPS on the phone. We incorporate time of day, user context (phone usage, location, and mobility) and current battery level as composite **states**, and setting various screen brightness levels and GPS sampling intervals as **actions**. The **reward** function that maps each action to a reward value encourages higher user experience when sufficient energy is available, and encourages power-saving actions when necessary to guarantee that the target battery lifetime is reached without outage: when battery outage occurs before the end of day we assign a reward of $-\infty$, otherwise we reward power-saving actions with a higher user experience values based on their definitions under different contexts in Table 1.

2. EXPERIMENTAL EVALUATION

We evaluate our approach through real-world smartphone data traces collected from 10 users over 2 months. We collect timestamped data of user interaction with the phone, GPS locations, and battery levels using our data collection Android app called EasyTrack. We use the Monsoon power meter to profile the power consumption of the screen and GPS under different brightness levels and sampling intervals respectively.

To evaluate the performance of our approach, for each user and each day, we first extract the segments of time when the battery is discharging, and perform power-saving actions every minute based on the current observation state (time of day, context and battery level) and the corresponding action in our MDP policy π learned from historical context data. π maps each possible state during the discharging period to a corresponding sampling interval for the GPS and display brightness. We replay the actions of the MDP policy, resulting in a specific average user experience and a gradual reduction in battery energy; when the battery energy drained by the GPS and display exceeds a pre-defined budget, we define that an outage has occurred and record the time when the battery outage first occurred.

(a) $U_{display}$

Brightness level	Indoor space	Outdoor space
20%	1	$-\infty$
40%	2	$-\infty$
60%	3	1
80%	4	3
100%	5	5

(b) U_{gps}

Sampling interval	Low mobility	High mobility
60 secs	1	$-\infty$
30 secs	3	$-\infty$
10 secs	5	1
5 secs	5	3
1 sec	5	5

Table 1: Defined user experience values under different contexts.

We compared our approach with a fixed user experience policy that sets three possible fixed, user experience values: min (1), mid (3) and max (5) based on the definitions in Table 1. We categorize our 10 users into three groups, namely light, moderate and heavy users based on thresholding the average outage time under fixed max user experience (5). We show that our approach: (i) eliminates *all* frustrating battery outage events for light, moderate,and heavy phone users, and (ii) improves user experience by 20% for light users, maintains the same user experience for moderate users, and degrades user experience by 23% for heavy smartphone users.

3. ONGOING WORK

We presented our preliminary system design and evaluation of our global power management scheme to balance battery outage and user experience. A key challenge with our approach is to appropriately define the user experience for each hardware component; our current definition in table 1 should be modified to account for dynamic user preferences based on context and individual user needs. We are currently working on a field study to determine the appropriate user experience definition. In the future, we plan to implement the energy management policies on smartphones to obtain user feedback on the service, including additional hardware modules such as the CPU, 3G, and WiFi in our power management architecture.

4. REFERENCES

[1] M. Dong and L. Zhong. Chameleon: a color-adaptive web browser for mobile oled displays. In *ACM MobiSys*, 2011.
[2] S. Nath. Ace: exploiting correlation for energy-efficient and continuous context sensing. In *ACM MobiSys*, 2012.
[3] Z. Zhuang, K.-H. Kim, and J. P. Singh. Improving energy efficiency of location sensing on smartphones. In *ACM MobiSys*, 2010.

[*]This work was performed while Chenren Xu was at Samsung Research America.