Low Power Killer: Extending the Battery Lifespan by Reducing I/O on Mobile Devices

Se Jun Han†‡, Dong Hyun Kang†, and Young Ik Eom†
†Sungkyunkwan University, Korea ‡Samsung Electronics, Korea
{sejun.han,kkangsu,yieom}@skku.edu

***Abstract*—The I/O caused by background applications shorten the lifespan of mobile devices because they affect the behavior of power intensive hardware. Our efficient power management scheme addresses this problem by killing unnecessary applications. Our results show LPK extends the lifespan up to 9.4% compared to baseline on a real device.**

I. INTRODUCTION

In the era of mobile devices, battery lifespan has become an important design consideration because of two reasons: first, a physical extension of battery size negatively impacts mobile devices (e.g., weight and volume). Second, emerging mobile devices accelerate their power consumption by enhancing hardware resources (e.g., CPU, display, and memory). For such reasons, there are many studies to optimize power management techniques [1], [2]. However, most previous researches have been focused on CPU, GPU, memory, network, and display on mobile devices, but not on storage devices. This is because mobile devices commonly employ NAND flash storage devices (e.g., eMMC and microSD card) as the secondary storage to utilize their attractive characteristics such as low power consumption and shock resistance.

However, some researchers have recently studied to revisit the energy overhead on mobile devices. Kim et al. [3] analyzed performance of smartphone and found evidence that storage significantly affects both performance and power consumption on mobile devices. Li et al. [4] identified that storage could affect the behavior of other power intensive components (e.g., CPU and DRAM) and I/O stack, running on cpu and memory, consumes by up to 200 times more power when compared to hardware storage devices. This paper also identifies the aforementioned energy overhead through experiments on real mobile device and proposes a novel power management scheme, called LPK, that efficiently extends the battery lifespan by reducing the amount of I/O operation to be written to storage on mobile devices without any hardware support.

The remainder of this paper is organized as follows. Section II gives the energy overhead of storage caused by I/O operations. In Section III, the design of our power manament scheme is described in detail. Experiments and evaluations are presented in Section IV. Finally, the Section V gives conclusion.

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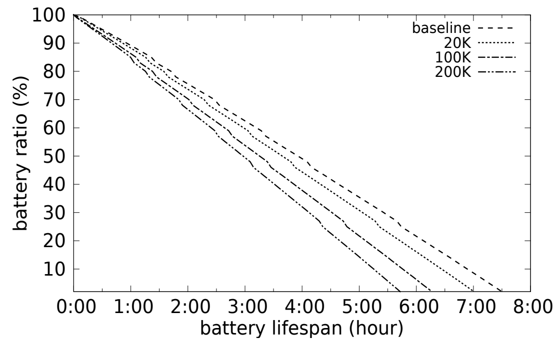

Fig. 1: Preliminary Experiment

II. HOW DO I/O OPERATIONS IMPACT THE POWER CONSUMPTION ON A MOBILE DEVICE?

In this section, we study the energy overhead of storage caused by I/O operations which is periodically generated from background applications such as email, file synchronization, version updates for applications, and SNS (Social Network Service). In order to understand energy overhead of I/O operations, we performed some experiments on a Google Nexus 7 tablet running an Android KitKat with three synthetic workloads (the 20KB, 100KB, and 200KB workloads). The workload was run for every second. Figure 1 shows the battery lifespan for *baseline*, 20KB, 100KB, and 200KB workloads, respectively. As we expected, the battery lifespan increases as the amount of I/O to be written to storage decreases. It clearly shows that periodic I/O operations can affect the behavior of other power intensive components such as CPU and DRAM because the storage on mobile devices consumes a small amount of power [4], [5]. This observation implies that LPK, which kills unnecessary background applications to eliminate periodic I/O operations, can improve the battery lifespan of mobile devices.

III. DESIGN OF LOW POWER KILLER

We propose *Low Power Killer* (LPK) power management scheme. LPK is able to achieve extension of lifespan by using two software modules. One is *monitor module* that collects I/O information, such as process ID, request size, and time, whenever an I/O operation is issued to storage. The other is *victim selector module* that selects a victim process to save power consumption caused by unnecessary background applications, when battery ratio on mobile devices becomes below a predefined threshold (e.g., 15% or 30%). More details of LPK are shown as follows.

A. I/O Operation Monitoring

Whenever an I/O operation is submited to storage, the *monitor module of LPK* gathers the I/O information and handles

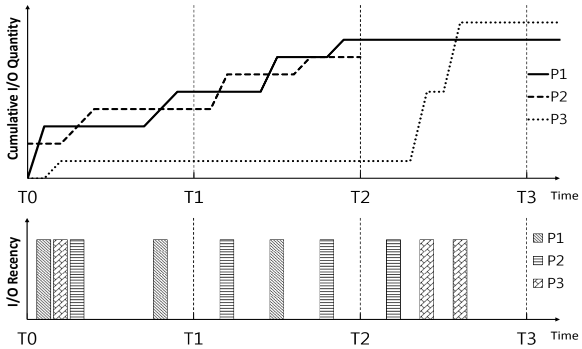

Fig. 2: An example of LPK operations

TABLE I: extra I/O overhead

	facebook	dropbox	gmail
extra I/O overhead	882.08KB	382.67KB	183.27KB

an I/O quantity table and I/O recency table to give information on selecting I/O intensive processes, which are running background. The I/O quantity table keeps the cumulative I/O quantity for each process and then sorts it according to the amount of I/O operation. The I/O recency table maintains a list in the *Least Recently Used (LRU)* manner for predicting the future usage of processes.

B. Victim Selection

When the *victim selector module of LPK* is triggered, it tries to find a victim process. To efficiently select a victim, the *victim selector module* first checks the I/O quantity table to find I/O intensive processes, because the battery lifespan decreases as the amount of I/O to be written to storage increases (Figure 1). After that, the *victim selector module* selects which I/O intensive processes in the background will not be reused with the I/O recency table and then it kills the selected process for saving power consumption. This selection has an important impact on performance and lifespan of mobile devices because reloading a process that is killed by *victim selector module* can incur extra I/O overhead (Table I).

Figure 2 illustrates an example of LPK operations which shows how LPK selects a victim process. As shown in Figure 2, assume that I/O operations are issued from process 1 (P1), process 2 (P2), and process 3 (P3), and the I/O quantity and recency tables are given as in the Table II and Table III, respectively. In this example, P1 most recently issues an I/O operation to storage and the total amount of I/O operation is 8 within the (T0, T2) period. Therefore, when the *victim selector module* is triggered at T2, it first regards P1 as a victim process based on I/O quantity. However, *victim selector module* selects P2 as a victim process instead of P1 because we assume that the last I/O operation of P1 was issued from user by running P1. Finally, the *victim selector module* kills P2 to eliminate unnecessary power consumption caused by periodic I/O operations of background process.

IV. Performance Evaluation

To verify the proposed power management scheme, we implemented LPK on Linux Kernel 3.4.0 and evaluated its lifespan on the Google Nexus 7 tablet equipped with Qualcomm

TABLE II: I/O quantity table

I/O quantity	Process
8	P1
7	P2
1	P3

TABLE III: I/O recency table

I/O recency	Process
1	P1
2	P2
3	P3

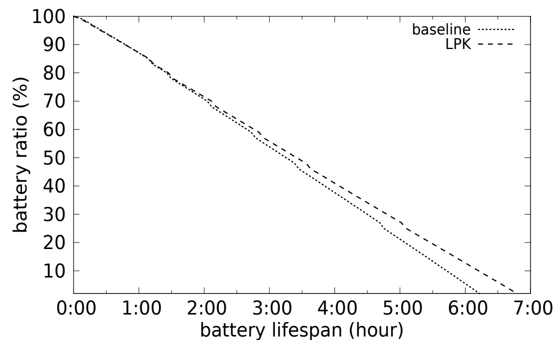

Fig. 3: Evaluation result

Snapdragon S4 Pro APQ8064 processor CPU, 2GB main memory, 16GB storage, and 3950 mAh battery. For comparison, we changed display option and turned off network modules, such as Bluetooth and Wi-Fi, in order to avoid device interference. In order to evaluate the worst case battery lifespan, we developed various processes, which generate synthetic I/O operations, and measured *baseline* with running them over different period of time (e.g., 20, 10, 5, and 1 second). Figure 3 shows the comparison results of the battery lifespan between *baseline* and LPK. The X-axis represents the measured battery lifespan of the device, and the Y-axis represents the available battery ratio. As shown in Figure 3, the LPK efficiently extends the battery lifespan by up to 9.4% compared to the *baseline*. This results clearly show that periodically generated I/O operations caused by background applications negatively affect the lifespan of real mobile devices.

V. Conclusion

In this paper, we propose a novel power management scheme, called LPK, that kills unnecessary background applications for reducing periodic I/O operations to be written to storage on mobile devices. To efficiently kill background applications, LPK selects victim processes via two software components such as *monitor module* and *victim selector module*. Experimental results show that LPK efficiently improves the battery lifespan by up to 9.4% compared to *baseline* on a real mobile device. We also believe LPK can be widely adopted for expanding the battery lifespan because it does not require any hardware support.

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