Dynamic Load Distribution for Performance and Energy in Mobile Storage Systems

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***Abstract*-- In this paper we propose a dynamic load distribution technique at the operating system level in mobile storage systems with a heterogeneous storage pair of a small form-factor hard disk and a flash memory, which aims at saving energy consumption as well as enhancing I/O performance. We demonstrate that the proposed technique provides better experimental results with heterogeneous mobile storage devices compared with the existing techniques through extensive simulations.**

I. INTRODUCTION

In recent years, heterogeneous storage devices have been studied much in mobile or consumer electronic devices due to the benefit of performance per cost. A pair of a small form-factor hard disk and a flash memory [1], a combination of a hard disk and MEMS-based storage [2], and a hybrid flash memory solution using multi-level cell (MLC) and single-level cell (SLC) flash memory devices [3] are good examples of heterogeneous storage devices.

In most computing systems, energy and performance are important design constraints and thus a lot of researches have been made to improve these. Pinheiro *et al*. proposed a load balancing and unbalancing algorithm to boost performance while reducing energy consumption for cluster-based systems [4]. In mobile computing systems with heterogeneous storage devices, it is crucial to control the load distribution properly, but there has been little deep investigation on how the operating systems should deal with mobile heterogeneous storage devices in the aspect of load distribution.

In this paper, we propose a dynamic load distribution technique which operates at the level of the operating system with the purpose of lowering energy consumption as well as improving performance. For this purpose, our approach is to combine two orthogonal load distributing techniques synergistically at the level of the operating system: a file placement technique called PB-PDC [1] and a device-aware buffer cache management algorithm called DAC [5]. PB-PDC focuses on saving the total energy consumption for a mobile storage system with a heterogeneous pair of a hard disk and a flash memory while DAC concentrates on enhancing the average response time per request for the same storage architecture.

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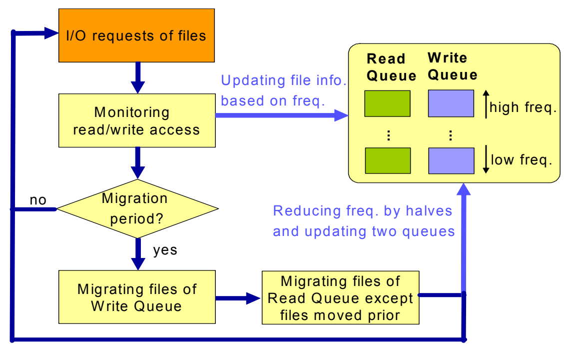

Fig. 1. Overall execution flow of PB-PDC.

II. ENERGY-AWARE LOAD DISTRIBUTION: PB-PDC

PB-PDC (pattern-based PDC), which augments the PDC (popular data concentration [6]) technique by moving frequently-accessed read and write data to separate sets of disks [1]. Because a flash memory device has low write throughput and limited erasure cycles, PB-PDC moves the popular write data to the hard disk and the popular read data to the flash memory device. When there is a conflict between popular read and write data on the same device the write data will have priority. Since PDC migrates files based on file access frequencies only, it is unaware of heterogeneity in storage devices and causes a lot of file migrations often. Thus, PB-PDC can deal with the load more efficiently.

PB-PDC maintains read and write counters for each file and monitors the frequency with which each file is written and read. If the access to the file is read (write) the read (write) counter will be increased by one. The read/write counters together with file information such as file id, file size and disk (or flash) id are managed by multi-queues arranged in descending order. Fig. 1 shows the overall execution flow of PB-PDC.

III. PERFORMANCE-AWARE LOAD DISTRIBUTION: DAC

DAC is designed for mobile computing systems with heterogeneous storage pair of a hard disk and a flash memory based on a dynamic cache partitioning method [5]. The aim of DAC is to minimize the average I/O response time by 1) adjusting the cache partition using the dynamic partitioning heuristic and 2) obtaining performance enhancement by having sequential blocks for a disk and read blocks for a flash memory to be evicted earlier within each partition. The latter (intra-partition block management) operates similarly to GreedyDual [7], but has multiple weighted values.

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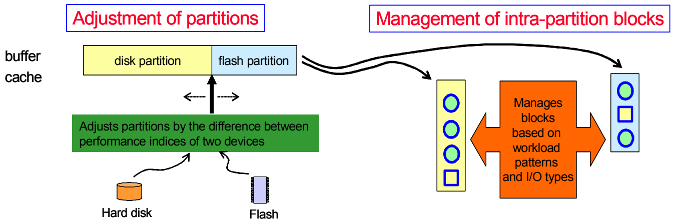

Fig. 2. Overview of DAC algorithm. DAC consists of two levels: 1) adjustment of partitions 2) management of intra-partition blocks.

The strong points of the DAC algorithm come from its being device-aware as well as workload-aware: it adjusts the partition sizes based on performance indices and manages cache blocks according to worth in the aspect of performance by taking into account the access pattern, as shown in Fig. 2. Thus, we expect that DAC may improve the system performance better by dealing with load distribution efficiently in heterogeneous storage systems, compared with LRU.

IV. EXPERIMENTAL RESULTS

PB-PDC and DAC have individual power to control load distribution, but the aims are quite different. Thus, we tackle to combine these two orthogonal load distribution techniques into one to leverage energy and performance concurrently, and investigate the experimental results. Fig. 3 shows our simulator to mimic a real mobile system. We built a cache simulator over a multi-device I/O simulator and file migrater.

We demonstrated the performance of our approach through extensive simulations. We evaluated 4 combinatory pair of load distribution algorithms: PDC+LRU, PDC+DAC, PB-PDC+LRU, PB-PDC+DAC. In Fig. 4, PB-PDC+DAC show 22%-33% better average response times than PDC+LRU. By comparing PDC+DAC and PB-PDC+DAC, we notice that PB-PDC plays a good role to performance-aware load distribution. In Fig. 5, we can see similar results in the aspect of energy consumption. PB-PDC+DAC achieves the lowest energy consumption, saving 13-19% of the energy when compared with PDC+LRU. We notice that DAC also has much impact on the energy consumption after combined with PB-PDC.

V. CONCLUSION

We have proposed a dynamic load distribution technique at the operating system level in mobile storage systems with a heterogeneous storage pair of a small form-factor hard disk and a flash memory, which was found to save much energy as well as enhance performance significantly.

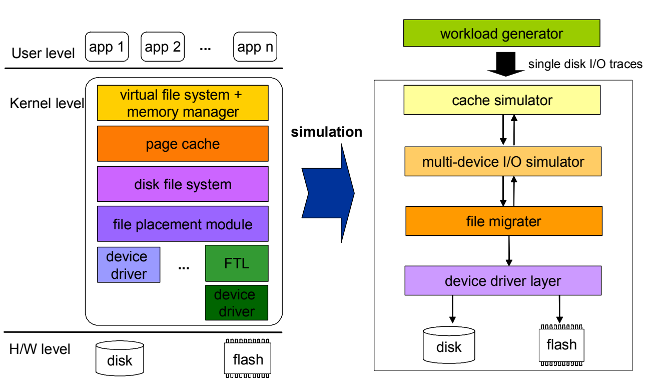

Fig. 3. Simulation architecture for a heterogeneous storage pair of a hard disk and a flash memory.

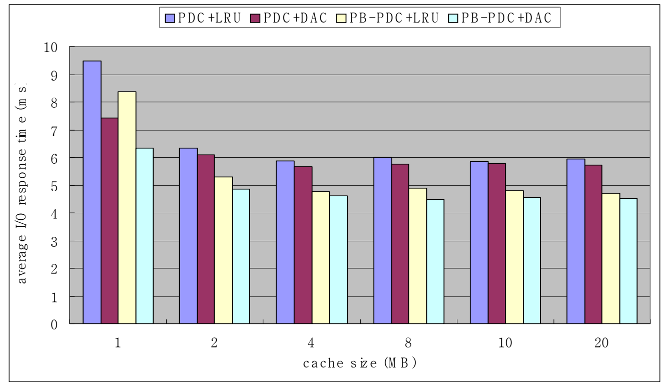

Fig. 4. Average response times of 4 combinatory pairs of load distribution algorithms.

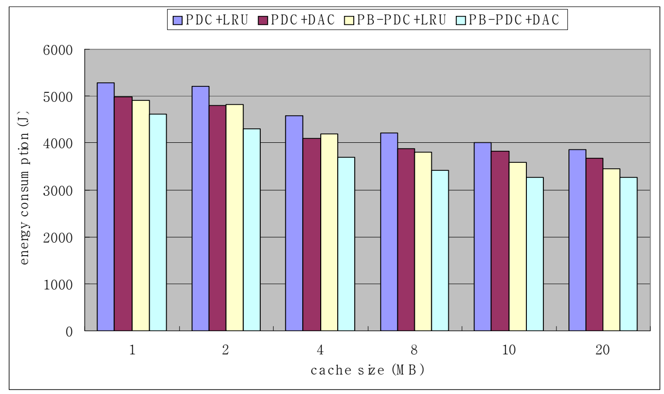

Fig. 5. Energy consumptions of 4 combinatory pairs of load distribution algorithms.

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