

Power and Performance Characteristics of USB Flash Drives

Kyle O'Brien, David C. Salyers, Aaron D. Striegel, Christian Poellabauer
Department of Computer Science and Engineering
University of Notre Dame
Notre Dame, IN 46556 USA
Email: {kobrie5, dsalyers, striegel, cpoellab}@nd.edu

Abstract

Even though their capacities are still orders of magnitude lower than those of hard disks, flash storage systems are rapidly gaining importance in energy-constrained systems. This paper focuses on USB flash drives, which can provide portable storage to mobile systems or storage to systems that otherwise do not have persistent storage opportunities (e.g., low-power sensor devices). The paper presents studies relating to power consumption, energy overheads and benefits, and performance impacts of USB flash drives. The key insights obtained from these experiments are that (i) read/write costs are not significantly greater than idle costs and (ii) the size of the flash itself has only limited bearing on energy consumption.

1 Introduction

Storage components of mobile wireless systems, including laptops, handhelds, and sensor devices, are essential for temporary and long-term preservation of information. In the recent past, solid state, or *flash* storage, has emerged as a promising alternative to hard disks. While flash memory and drives offer the potential for very low-power storage, they are still significantly smaller than available disk drives [7].

USB flash drives provide an opportunity to extend an existing mobile/wireless device with (additional) storage capacity; this is particularly important for small low-power devices that otherwise do not have any storage opportunities (e.g., TelosB motes and Crossbow Stargate wireless mesh routers). With newer areas of research such as Delay Tolerant Networking (DTN) [5], on-device flash capacities are often not enough. Finally, in the absence of designing a new device solely for their research, researchers are often faced with employing USB flash drives to meet that need. Unfortunately, the performance of said devices with regards to energy and read/write speeds is poorly understood. The

usage of flash for the network researcher is especially critical as the choice of flash can have a profound effect on the energy and performance characteristics of the overarching system or application.

Toward this end, this paper provides a comprehensive assessment of the power, energy, and performance characteristics of flash drives. Specifically, the contributions of this work can be summarized as follows:

- *Comprehensive study of USB flash drive power consumption:* This paper experimentally examines the power consumption characteristics of USB flash drives across a wide variety of considerations including manufacturer, device size, operating system, read/write blocks, and USB connection types (1.1 or 2.0).
- *Comprehensive performance studies:* Further, this paper evaluates the energy - performance tradeoff of USB flash drives, assessing the energy costs and performance numbers of various I/O accesses to a USB flash storage.

2 Experimental Methodology

The measurement results were obtained using a Fluke189 multimeter and a DSO3202A oscilloscope (200MHz bandwidth, 2 channels, 1GSa/s sample rate). The results were imported into and visualized using LabView. The USB flash drives utilized in the experiments are summarized in Table 1. While there are certainly commonalities between different drive vendors in terms of the actual underlying flash, our goal was to roughly assess the existing spectrum of flash drives with selective finer grained assessment within select individual vendors (Kingston, Sandisk).

The flash drives' power characteristics were studied on multiple host devices and operating systems:

- *Crossbow Stargate (Linux:)* Crossbow Stargate devices are frequently used as wireless mesh routers or as powerful sensing devices (Linux 2.4.19, USB 1.1).

Manufacturer	Size(s)
Axiom, Entec	1 GB
Edge, PNY	2 GB
EP	128 MB
Imation, Kanguru	512 MB
Kingston	512 MB, 1 GB, 2 GB, 4 GB
Memorex	256 MB
OCZ, Transcend	1 GB
Patriot	4 GB
Sandisk	512 MB, 2 GB, 4 GB
Simpletech, Smartmod	256 MB

Table 1. USB flash drives used in study

- *Mac mini (Mac OS X), Gateway Tablet (Windows XP), Sun x2100 Workstation (Linux 2.6):* For USB 2.0 performance across various operating systems and suspend behavior, the listed array of systems were employed.

3 Power Consumption

Figure 1 captures the power consumption of the respective USB flash drives under USB 1.1 accessed via the Linux 2.4 kernel on a Stargate Crossbow device. The figure captures the average power consumed under idle conditions, reading a significant file, and writing a significant file.

With regards to the cost of read/write over idling, the answer appears to clearly be that writing to the respective flash device when done in a bulk write (64kB blocks) does not incur a serious cost over normal read and write operations. The notable anomaly is the case of the Memorex flash device whereby power consumption is actually improved over the idle case. In short, the action of reading and/or writing for the Memorex device changes the main LED from a continual on state to one that flashes on and off, thus reducing power significantly.

In contrast, the Sandisk devices exhibit the opposite extreme of the behavior, representing a jump in total power that cannot be solely attributed to the cost of the reading and/or writing the device. Notably, the Sandisk devices possess the largest and brightest LEDs of the surveyed devices representing a notable power cost for USB 1.1 interactions. The Kingston set of devices were some of the most efficient devices in terms of average power consumption.

While the limited impact of read and write operations as well as the nearly indistinguishable cost of writing over reading were certainly interesting, the most striking aspect of the devices was the lack of engaging the low power *suspend mode* when not in use. Per the USB specification [1, 2], if a device does not see activity in the last 3.0 ms,

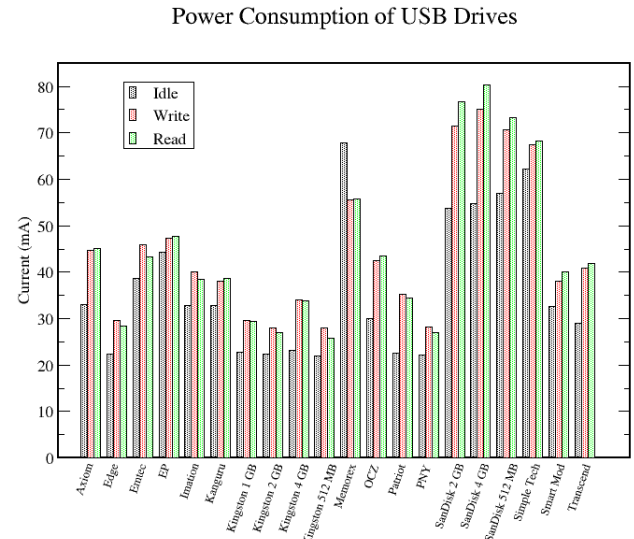


Figure 1. Power consumption of all devices - idle, read, write under USB 1.1

the device has 7.0 ms to enter a low power suspend mode where the device may use a maximum of 0.5 mA of current. Devices with remote wakeup may draw up to 2.5 mA of current. Upon further investigation of the data line itself, a 2-byte keep alive signal is sent to the flash drive devices continually, thus preventing the device from ever entering the low power mode. This keep-alive message will persist for the duration of the host running with the only exception being when the “Safely remove hardware” operation is performed under Windows. Unmounting the drive under Linux or ejecting the drive under Mac OS X did not push any of the drives into suspend mode despite repeated attempts and configurations.

3.1 Examining Write Power Consumption Further

Figure 3 examines the effect of block size averaged across all devices. In the figure, the same size file is written out using different block sizes for each respective write call. While the graph itself is not unexpected, the key transition points are interesting. A block size of 4 kB yields little performance difference versus block sizes of up to 18 kB. Once the 20 kB threshold is passed, the net write performance is quickly saturated leaving minor gains (if any) for pushing the write block size even higher. An interesting research case would be to examine the effects of writing with regards to reliability although most modern flash devices scatter writes across the flash to avoid continually rewriting the same area. We note that the 20 kB nicely captures the

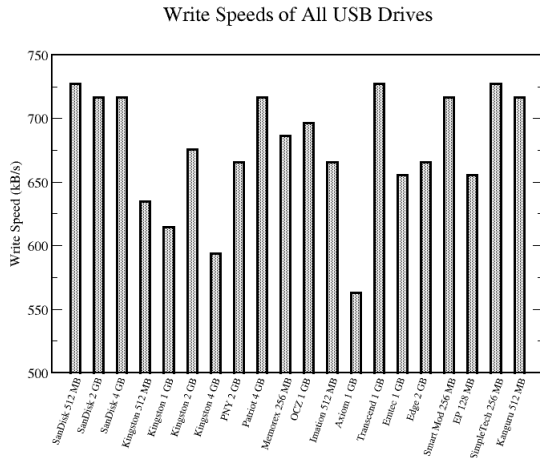


Figure 2. Write speed - USB 1.1 - 100 MB file

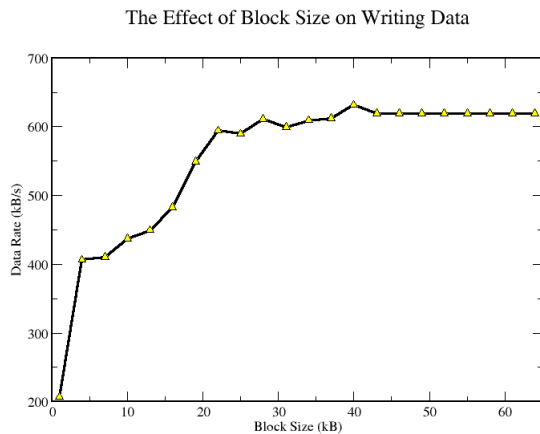


Figure 3. Effect of block size USB 1.1

static content of many popular websites for the purposes of on-device caching in the flash itself [6].

3.2 Varying Device Size

Figure 4 examines the effect of device size on the overall power consumption of a specific series of devices, namely variations within the Kingston devices. Due to the significantly larger power consumption of the Sandisk devices, only the Kingston devices are highlighted in the graph. In fact, the Sandisk devices demonstrated power savings when switching to larger devices (i.e. gains in efficiency) over smaller devices.

While there is a slight general increasing trend for idle power, the read/write power consumption is relatively inconclusive until the 4 GB device. The cost of increasing

size appears to be largely masked and only of significant consequence with the largest device size. Hence, from the perspective of the network researcher, the selection of a 2 GB device has little energy cost with significant flexibility improvements over a 512 MB or 1 GB device. Further study is warranted regarding if the trend continues for newly emergent 8 GB and larger devices.

3.3 USB 1.1 vs. USB 2.0

Although support for USB 2.0 in small scale embedded devices is less common, the increased speed for USB 2.0 (480 Mb/s) versus USB 1.1 (12 Mb/s) has significant appeal as wireless network speeds are continually increasing. While the performance of USB 2.0 is considerably better than USB 1.1 in terms of write performance (16.97 MB/s peak write performance versus roughly 700 KB/s under USB 1.1), the average power consumption is well over double during the write operation itself as well as during idle periods.

Table 2 illustrates the power consumption of the Patriot 4 GB drive across various combinations of platforms, operating systems, and USB connectivity. Interesting observations from the graph are that the power cost at idle time or during a read or write (read is omitted due to its similar performance to a write operation) are consistent despite variations in platform, CPU/motherboard, and operating system. While this is to be expected given that USB is a well understood standard, the tightness of the numbers across platforms was somewhat surprising.

Although USB 2.0 performance is significantly increased over USB 1.1, the idle power consumption is quite troubling given the fact that suspend is never engaged despite long idle periods on the device itself (barring cases where the OS hibernates or sleeps). Unless the application strictly needs the improved performance (i.e. caching content from an 802.11 draft n link versus an 802.11g or 802.11b link), the idle power consumption of USB 2.0 makes it quite costly relative to USB 1.1.

4 Related Work

In the direct area of USB flash drives, very little previous work exists in characterizing the power of the devices. To the best of our knowledge, ours is the first work to directly assess USB flash drive performance with regards to energy characteristics. We comment briefly on several of the more recent related works that consider flash for the purpose of energy savings.

The notion of energy-awareness with regards to multimedia and mobile computing is a concept that has seen considerable research [8]. In [7], Singleton, Nathuji, and Schwan explore algorithms to manage flash allocation as a

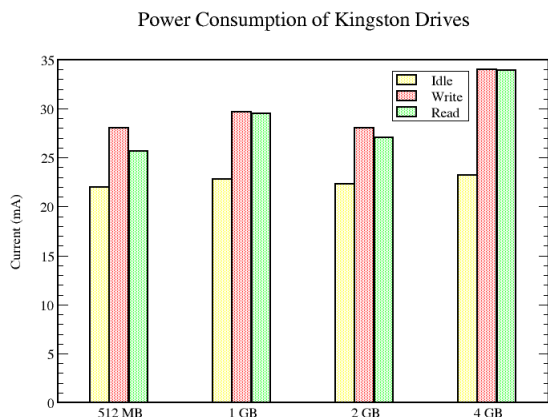


Figure 4. Effect of varying flash size - USB 1.1

cache for disk access. Similarly, Bisson and Brandt in [3] examined similar aspects to allow for improved disk spin down for reduced energy consumption. Chen, Jiang, and Zhang propose SmartSaver in [4] for using flash as a pre-fetch and cache for web content for mobile nodes. These works simply represent a small subset of the works examining the applicability of flash. Notably, the end result in nearly of the work is that to actually provide the flash itself, a USB flash drive is used whose characteristics are assumed to roughly mirror actual on-device flash.

Specifically, the emergence of Delay Tolerant Networking [5] as a subject of much research is especially notable. Critically, if a researcher assumes that the flash device operate in a manner as power efficient as normal OS operations (i.e. the drive will suspend if not used), the end result will be a distorted picture of the true energy savings offered by flash. Moreover, the characterization of the true costs of resuming and suspending the flash device make the development of better performing suspend/resume operations a necessary component for the research community as a whole.

5 Conclusion

In conclusion, this work represented one of the first works to comprehensively address the power consumption of USB flash drives across a multitude of combinations of manufacturer, connecting host, and connection type. Notably, the most striking results are that: (i) reads and writes while more expensive are not significantly more expensive than normal idle operation, (ii) raw performance often does not translate to overall energy savings (faster write performance vs. overall energy efficiency, USB 1.1 idle vs. USB 2.0 idle, etc.).

Platform - OS	USB	Idle (mA)	Write (mA)
Stargate / Linux 2.4	1.1	22.37	34
x86 Workstation / Linux 2.6	2.0	50.88	100.5
x86 Tablet / Windows XP	2.0	50.84	105.5
PPC Mac Mini / Mac OS X	1.1	22.4	34.5
x86 Mac Mini / Mac OS X	2.0	50.95	110.0

Table 2. Comparison of USB 1.1 vs. USB 2.0 for various OS / platforms for the Patriot 4 GB flash drive

This work was partially supported by the National Science Foundation as part of an REU project through grant CNS03-47392. Equipment support was provided in part by a DURIP grant and a Notre Dame Faculty Grant.

References

- [1] USB 1.1 specification. 1996.
- [2] USB 2.0 specification. Apr. 2000.
- [3] T. Bisson and S. Brandt. Reducing energy consumption using a non-volatile storage cache. In *Proc. of RTAS 05*, 2005.
- [4] F. Chen, S. Jiang, and X. Zhang. SmartSaver: turning flash drive into a disk energy saver for mobile computers. In *Proc. of ISLPED*, Tegernsee, Germany, Oct. 2006.
- [5] K. Fall. A delay tolerant networking architecture for challenged Internets. In *Proc. of ACM SIGCOMM*, Aug. 2003.
- [6] X. Li, D. Salyers, and A. Striegel. Improving packet caching scalability through the concept of an explicit end of data marker. In *Proc. of IEEE HotWeb*, Boston, MA., Nov. 2006.
- [7] L. Singleton, R. Nathuji, and K. Schwan. Flash on disk for low-power multimedia computing. In *Proc. of MMCN*, San Jose, CA, Jan. 2007.
- [8] F. Zheng, N. Garg, S. Sobti, C. Zhang, R. Joseph, A. Krishnamurthy, and R. Wang. Considering the energy consumption of mobile storage alternatives. In *Proc. of MASCOTS*, 2003.