Technical Note

Garbage Collection in Single-Level Cell NAND Flash Memory

Introduction

This document describes the recommended garbage collection algorithm to be implemented in the flash translation layer (FTL) software for NAND Flash memory devices.

Garbage Collection and NAND

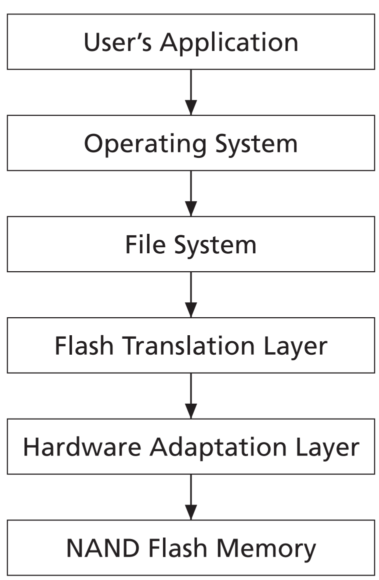
The FTL is an additional software layer between the file system and the NAND Flash memory (see Figure 1), which allows operating systems to read and write to NAND Flash memory devices in the same way as disk drives. It provides the translation from virtual to physical addresses and includes wear leveling and garbage collection software modules, which it calls when required.

NAND Flash memory has relatively long erase times, as ERASE operations are done one block at a time. With the FTL this long erase time becomes transparent because instead of erasing a block to be able to rewrite it the FTL simply writes the data to another physical page and marks the data contained in the previous physical page as invalid.

The garbage collection module is used to free this invalid memory space to allow further PROGRAM operations.

Refer to single-level cell (SLC) NAND Flash memory data sheets for the full list of NAND Flash memory devices covered by this document (see “References” on page 4).

Figure 1: Software Tool Chain



Garbage Collection

The garbage collection software copies the valid data into a new (free) area and erases the original invalid data as illustrated in Figure 2

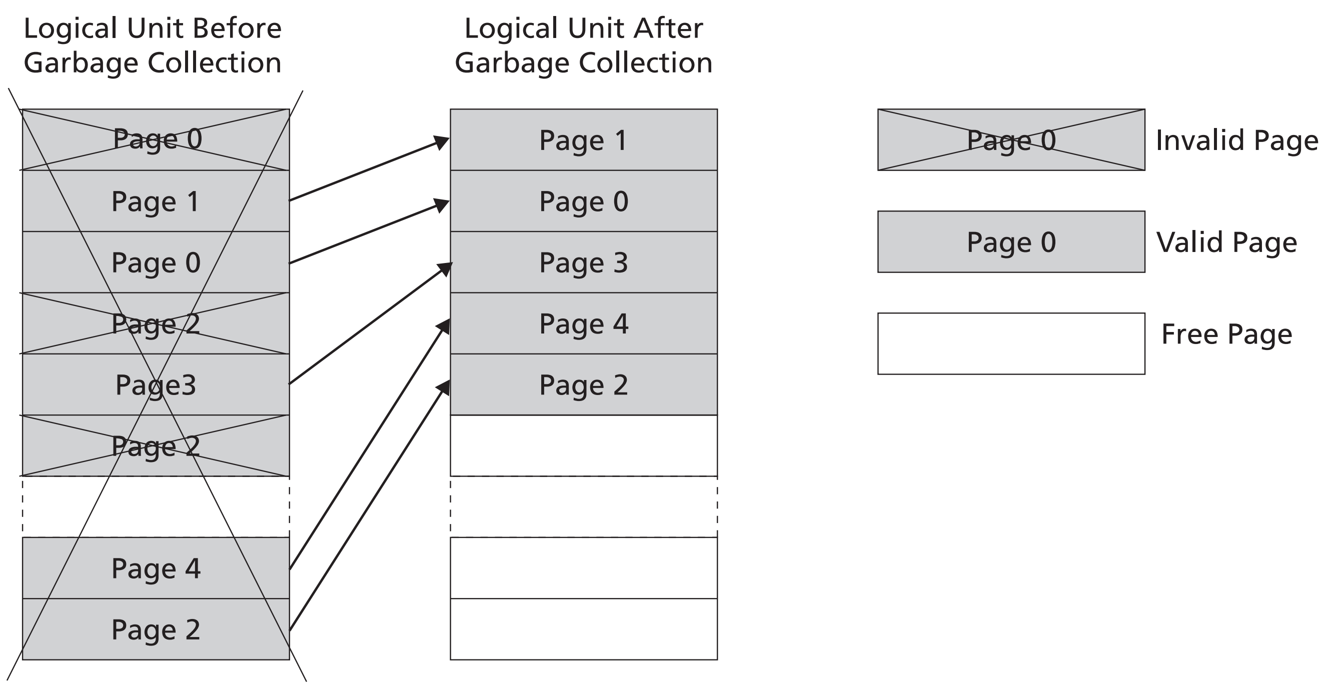
Garbage collection is performed when a virtual block is full or when the number of free pages in the whole device is lower than a specified threshold value.

The basic operations involved in garbage collection are:

1. The virtual blocks meeting the conditions are selected for erasure.
2. The valid physical pages are copied into a free area.
3. The selected physical blocks are erased.

As virtual blocks can contain more than one physical block, the garbage collection may erase more than one physical block.

Figure 2: Garbage Collection Operation



FTL Performance

The overall performance of the FTL directly depends on when and how free space is maintained.

When the garbage collection software erases a virtual block so that it can be used again, the garbage collection efficiency (Egc) for that block is defined as the ratio of the number of invalid pages in the block to the total number of pages in the block. When all pages in the block are garbage, Egc is 1:

$$Egc = \frac{\text{number of invalid pages in Block}}{\text{total number of pages in Block}}$$

When the garbage collection efficiency for a block is low, a large number of pages must be copied into other blocks before erasing the block. The greater the number of pages to be copied the greater the number of WRITE operations to other blocks, which reduces the lifetime of the NAND Flash device.

Another parameter for garbage collection performance is the amount of free area in the device. Freeing enough memory space to accommodate data immediately when the host requests it can improve the FTL's sustainable throughput. Sustainable throughput is the READ/WRITE throughput, taking into account the FTL software overhead.

In other words, when the number of data pages to be written exceeds the number of free pages, the host must wait for the garbage collection software to erase all invalid blocks. This can only be avoided by implementing garbage collection as frequently and rapidly as possible by increasing the garbage collection rate at the expense of the garbage collection efficiency (Egc).

The FTL performance is determined by the trade-off between the garbage collection rate and garbage collection efficiency.

Buffering can be used to improve garbage collection performance and reduce the number of garbage collection operations at the same time.

Background Feature

An FTL can implement a background feature that can be activated to optimize the overall performance of the FTL. With this feature, the long erase times of NAND Flash devices are transparent as the garbage collection is activated during the system's idle time. In this way, the FTL erases pages to free memory space automatically, and not only when the number of data pages to be written exceeds the number of free pages.

When the FTL is not performing any READ or WRITE operations on the NAND Flash, the power consumption will not be reduced if garbage collection is activated. Therefore, it is not recommended to use garbage collection with the background feature activated in systems where low power consumption is required.

References

The following documents related to NAND Flash memory are available on www.micron.com:

- NANDxxx-A Single-Level Cell Small Page NAND Flash memory family data sheets
- NANDxxx-B Single-Level Cell Large Page NAND Flash memory family data sheets
- How to use the FTL and HAL software modules to manage data in Single Level Cell NAND Flash memory
- Wear Leveling in Single-Level Cell NAND Flash Memory
- Error Correction Code in Single-Level Cell NAND Flash Memory
- Bad Block management in Single-Level Cell NAND Flash Memory

Conclusion

Implementing garbage collection in the FTL is recommended to free invalid memory space to allow further PROGRAM operations. The overall performance of FTL is a trade-off between garbage collection efficiency and garbage collection rate. Performance can be improved by activating a background feature, which enables garbage collection during the system's idle time.

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