
Garbage collection in NAND flash memories

This application note describes the garbage collection algorithm that Numonyx recommends to implement in the flash translation layer (FTL) software for NAND flash memories.

1 Introduction

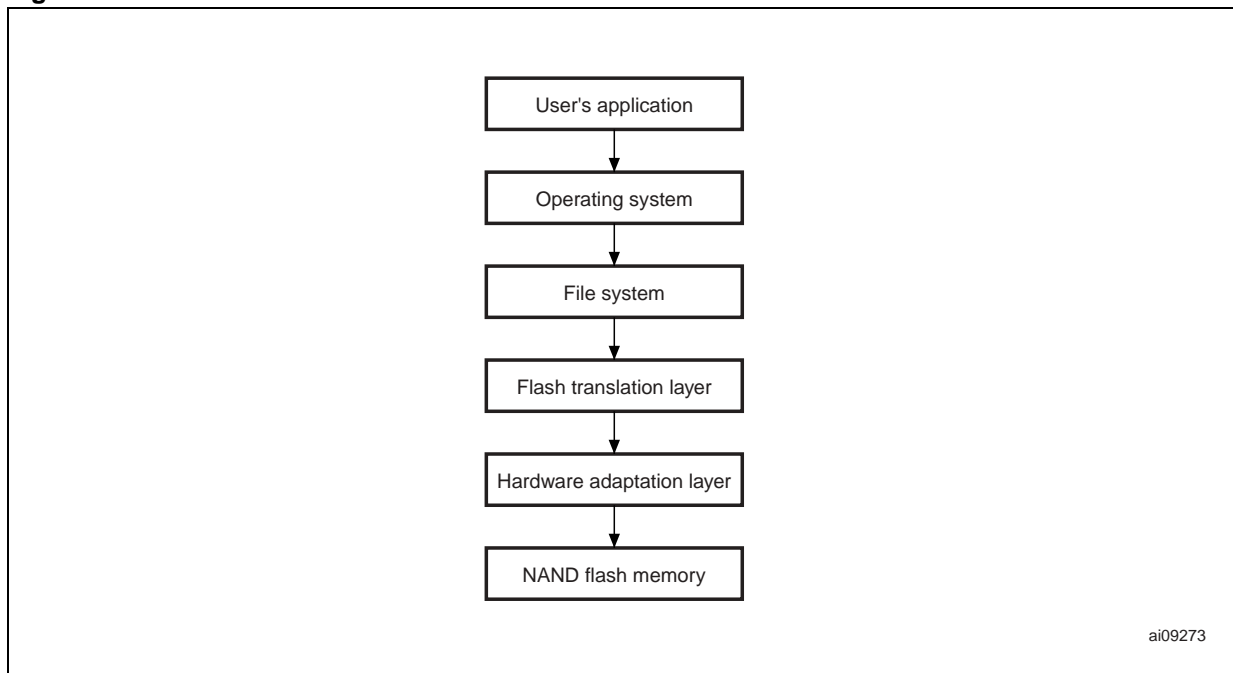
The flash translation layer is an additional software layer between the file system and the NAND flash memory (see [Figure 1](#)), which allows operating systems to read and write to NAND flash memory devices in the same way as disk drives. It provides the translation from virtual to physical addresses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

NAND flash memories have relatively long erase times, as erase operations are done one block at a time. With the flash translation layer 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, and multilevel cell large page NAND flash memory datasheets for the full list of NAND flash memories covered by this application note and for further information (see [Section 6: References](#)).

Figure 1. Software tool chain



2 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](#).

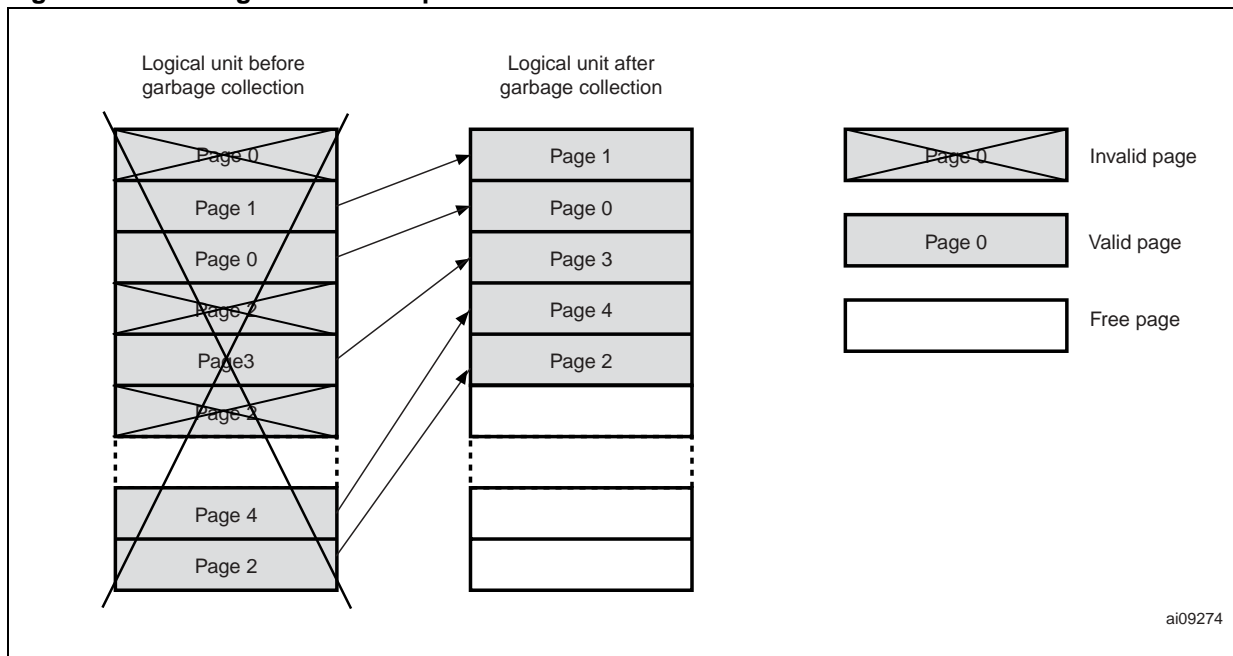
Garbage collection is performed when a virtual block is full, or the number of free pages in the whole device is lower than a specified threshold value.

The basic operations involved in garbage collection are the following:

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



3 FTL performance

The overall performance of the flash translation layer 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 the pages in the block are garbage, Egc is 1:

$$E_{gc} = \frac{\text{number of invalid pages in block}}{\text{total number of pages in block}}$$

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 is, the greater is the number of write operations to other blocks and so the lifetime of the NAND flash is reduced.

Another parameter involved in the 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 flash translation layer's sustainable throughput (the FTL's 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 has to wait for the garbage collection software to erase all the invalid blocks. This situation can only be avoided by implementing garbage collection as frequently and rapidly as possible, that is by increasing the garbage collection rate at the expense of the garbage collection efficiency (Egc).

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

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

4 Background feature

The FTL can implement a background feature which can be activated to optimize the overall performance of the flash translation layer. With this feature, the long erase times of NAND flash devices are completely 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 write or read operation 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 a low power consumption is required.

5 Conclusion

It is recommended to implement garbage collection software, in the flash translation layer, to free invalid memory space to allow further program operations. The overall performance of flash translation layer is a trade-off between the garbage collection efficiency and the garbage collection rate. The performance can also be improved by activating a background feature which allows garbage collection during the system's idle time.

Moreover, it is recommended to implement wear-leveling algorithms while it is mandatory to implement bad block management and error correction code algorithms to extend the number of program and erase cycles and to increase data retention.

6 References

The following documents related to NAND flash memories, are available on www.numonyx.com.

- NANDxxx-A single level cell small page NAND flash memory family datasheets
- NANDxxx-B single level cell large page NAND flash memory family datasheets
- NANDxxGW3CxB, NAND16GW3D2A, and NAND32GW3D4A multilevel cell large page NAND flash memory family datasheets
- AN1822: wear leveling in NAND flash memories
- AN1823: error correction code in single level cell NAND flash memories
- AN1819: bad block management in NAND flash memories.

7 Revision history

Table 1. Document revision history

Date	Revision	Changes
11-May-2004	1	Initial release.
26-Oct-2004	2	This document also applies to the NANDxxx-B devices. Table 1. Product list and Section 6: References section updated accordingly.
29-Jun -2006	3	Table 1. Product list removed. References to datasheets updated in Section 6: References .
16-Feb-2007	4	References to datasheets updated in Section 6: References .
18-Jun-2008	5	Modified Section 5: Conclusion and Section 6: References . Applied Numonyx branding.

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