A MICRON
TECHNICAL MARKETING
BRIEF

Optimized Client Computing With Dynamic Write Acceleration

Dave Glen, SSD Applications Engineer

Introduction

Dynamic write acceleration is a new feature available on Micron client SSDs. This brief describes the technology and the applications for which it is intended, as well as a brief explanation of implications for applications for which this feature was not designed.

Dynamic write acceleration may or may not be enabled on a given Micron SSD, depending on form factor and capacity. For example, on the M600 client SSD, the 2.5-inch, 512GB and 1TB drives do not have the feature enabled; all other M600 capacities and form factors do have the feature enabled. Check the product data sheet to verify support for this feature.

Feature Description

To date, performance gains on MLC-based SSDs have primarily been achieved by reducing overhead and increasing parallelism in NAND to match drive performance as close as possible to the theoretical capability of the underlying hardware. Theoretical hardware capabilities are based on many factors, including capabilities of individual NAND components, quantity of NAND components, NAND Flash channel speeds and quantities.

When the number of NAND components in the SSD is limited, as may be the case with small-density SSDs, the theoretical capability of the underlying hardware may become a limitation. This can be circumvented by using a higher number of smaller-capacity NAND components to increase the amount of parallelism for the same amount of storage; however, this often adds cost because the lowest-cost-per-gigabit NAND parts also tend to be the largest-capacity parts.

Dynamic write acceleration changes this paradigm. It is engineered to enable SSD performance beyond conventional hardware capabilities. It adapts NAND usage to fit the intended user environment without sacrificing user-accessible storage capacity.

Feature Terminology

In explaining the dynamic nature of this technology, the following terms are used:

- **Logical Saturation** – The portion of user logical block addresses (LBAs) that contain data
- **Physical Saturation** – The portion of physical NAND locations that contain data
- **Interface Idle Time** – Periods of time between commands greater than 50ms
- **Acceleration Capacity** – Current availability of NAND blocks that may be used to accelerate write performance

Adaptive Use of an SSD's Native NAND Array

Advancements in NAND technology pioneered by Micron enable mode switching between MLC and SLC modes of operation at the block level. At any given time, any portion of the NAND array may be used as either high-speed SLC or high-density MLC.

Micron®

Acceleration is achieved using on-the-fly mode, switching between SLC and MLC in the firmware to create a dynamic pool of high-speed SLC NAND blocks. This performance pool changes in size and physical location in a way that leverages client computing usage environments.

When acceleration capacity is available, new data will be written in SLC NAND, which produces an increase in physical saturation greater than the corresponding increase in logical saturation because SLC is less dense than MLC.

Drive firmware may use interface idle time to reduce physical saturation and recover acceleration capacity. This process may consist of migrating data written as SLC to high-density MLC mode or removing obsolete copies of data from the NAND. The acceleration capacity that is recovered before the operation completes is dependent on runtime parameters, such as physical and logical saturation, and is optimized to balance burst performance availability and long-term drive endurance.

Since the SSD firmware may use any portion of the NAND array as either SLC or MLC, acceleration capacity is often significantly larger than competing technologies that use a static pool, or cache, for acceleration. The figure below shows the designed acceleration capacity at different levels of logical saturation, relative to a competing static cache technology. Designed acceleration capacity is used in both cases because runtime conditions may produce different high-performance capacity in either technology.

The competing technology shown uses a fixed capacity of media for acceleration, which is made available to the SSD by limiting the user-accessible capacity of the drive.In comparison, dynamic write acceleration provides high-performance capability by leveraging unused space. This approach provides maximum performance when available and maximum capacity when needed.

Impact on Intended Usage Environments

Optimized for High-Performance Client Computing

Dynamic write acceleration leverages certain characteristics found in typical client computing environments, including:

» **Host implementation of TRIM commands in all relevant hardware and software layers:** Trim is essential because it provides a mechanism

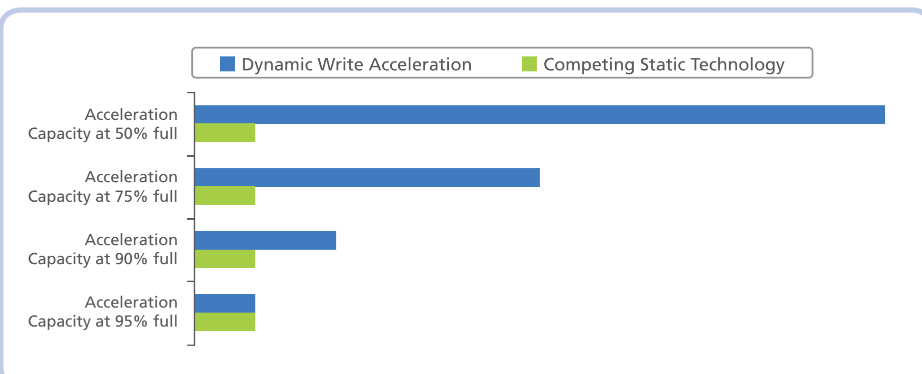

FIGURE 1: Effects of Logical Saturation on Designed Acceleration Capacity vs. Static Cache
Note: Data reflects approximate performance.

for reducing logical saturation when users delete files. Without trim, logical saturation would continue to increase as the drive is used, resulting in diminished acceleration capacity. This may occur even if the partition information shows the volume to be mostly empty.

- **Drives are operated in a non-filled state for the majority of the drive lifespan:** Maintaining a non-filled state is advantageous since acceleration capacity is linked to logical saturation. Users may still notice performance boosts with drives up to 99% filled, but the duration of the performance boosts would be reduced compared to the drive being in a less filled state.
- **Write operations tend to occur in bursts:** Burst-oriented operations are unlikely to exceed the acceleration capacity. On the other hand, if sustained write traffic continues beyond the current acceleration capacity, performance dips may occur.
- **Frequent periods of interface idle time occur between write bursts:** Interface idle time allows the drive to decrease physical saturation and increase acceleration capacity for future bursts.

From a user standpoint, these characteristics happen behind the scenes. In nearly every case, modern operating systems submit TRIM commands when files are deleted without the need for user interaction.

Leveraging these fundamental workload characteristics enables dynamic write acceleration to boost performance beyond the conventional limits of MLC hardware. The table below shows the performance gains achieved in a 128KB sequential workload for a Micron SSD with dynamic write acceleration (M600) versus one without (M510). Though there are differences between these two products, they contain the same number of NAND components and feature a similar controller, so the underlying hardware capability is comparable.

CAPACITY	PRODUCT	SEQUENTIAL WRITE (MB/s)	GAIN
128GB	M600	466	2.4X
128GB	M510	187	2.4X
256GB	M600	514	1.5X
256GB	M510	333	1.5X

TABLE 1: Sequential Write Performance Comparison

Optimized for Mobile Applications

Physical size and energy consumption are critical characteristics for mobile applications. Heat production is also critical because of space constraints. Mobile SSD form factors like the M.2 enable SSD designs to occupy an ever-shrinking physical space. As dimensions decrease, thermal considerations become critical because there is a smaller surface area available for dissipating device-generated heat.

CAPACITY	M.2 PRODUCT	SEQUENTIAL WRITE POWER (mW)	PERFORMANCE DURING MEASUREMENT (MB/s)	TIME TO WRITE 1GB OF DATA (s)	ENERGY PER GB WRITTEN (J)
128GB	M600	2287	462	2.165	4.950
128GB	M510	2155	186	5.376	11.586
256GB	M600	2566	510	1.961	5.031
256GB	M510	3025	335	2.985	9.030
512GB	M600	2562	508	1.969	5.043
512GB	M510	3794	509	1.965	7.454

TABLE 2: 128KB Sequential Write Performance/Power Comparison

During accelerated performance, data is written in high-speed SLC mode, which requires less energy to write the same amount of data compared to MLC. To demonstrate the difference, the table below shows power/performance measurements of an M.2 M600 SSD with dynamic write acceleration compared to the prior generation M510/M550 SSD without.

Reducing energy consumption also reduces the amount of heat generated by the device, producing a double benefit for mobile applications. For this reason, the M.2 and mSATA form factors have the feature enabled for all capacities on the M600.

Impact on Unintended Usage Environments

Sustained Sequential Write Traffic

Some environments consist of sustained write traffic in repeating address sequences without interface idle time for periods which may exceed the acceleration capacity of the drive. This contradicts the characteristics of high-performance client computing that the feature was designed for.

Consider the test results shown in Figure 2 below, based on a single drive fill of a 128GB M600 SSD with dynamic write acceleration. Prior to performing the test, the drive was returned to fresh out of box (FOB) conditions by performing an ATA SECURITY ERASE command, which returns logical and physical saturation to zero.

Three distinct performance regions are evident in the figure. The first is the accelerated region, which persists until 46% logical saturation or 59GB are written in total. The second is the non-acceleration region, where data is written in MLC to slow down the rate of physical saturation. The third region, starting at 58% logical saturation or 74GB written in total, occurs when the drive must transform data written as SLC into MLC mode at the same time that new data is being written by the host.

If the drive were filled a second time in the same address sequence, without first decreasing logical and physical saturation, performance results would alternate between regions 2 and 3.

Without dynamic write acceleration, performance in a sequential fill from an FOB state would correspond to consistent region 2 behavior, without the accelerated region 1 or the reduced region 3. Subsequent drive fills performed in the same write address sequence as the first fill would also result in continuous region 2 behavior.

Sustained Random Write Traffic

Sustained random write traffic is fundamentally different than sustained sequential write traffic because in the case of sequential traffic, the address sequences repeat, while address sequences from random access do not.

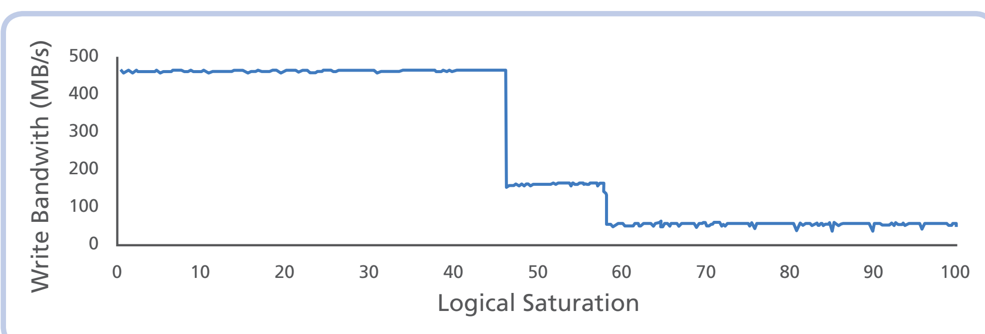

FIGURE 2: Sustained Sequential Write Traffic on 128Gb M600 SSD for One Drive Fill

Note: Data reflects approximate performance.

NAND devices can write a single page (typically between 4KB and 16KB at a time) but can only erase data in NAND block increments, where a NAND block can contain hundreds of pages. Repeating address patterns may result in a full block of NAND containing obsolete copies of data, so an ERASE operation can occur without affecting valid data. Random address patterns, on the other hand, result in NAND blocks which contain a mix of valid and obsolete data, so valid data must be relocated before the block may be erased. Relocating valid data and erasing NAND blocks is accomplished in SSD firmware by a process known as garbage collection. Garbage collection is necessary in sustained random workloads regardless of the presence of dynamic write acceleration.

At the onset of data traffic, write performance would correspond to sustained sequential behavior, with an accelerated region, followed by a middle MLC-only region, and a reduced third region where SLC-to-MLC migration is performed during host write activity. Thereafter, sustained random write traffic would produce NAND blocks that contain a mixture of obsolete and valid data, and garbage collection would occur.

Because write acceleration is not performed during garbage collection, dynamic write acceleration does not impact steady state random write performance. Dynamic write acceleration may impact the transitional period from an FOB condition to a steady state condition, however.

Drive Endurance

Write amplification (WA) is a phenomenon where the amount of data written from the host to the SSD and the amount of data written to the NAND internal to the SSD become different. This phenomenon is caused by a multitude of factors, many of which are application and environment specific. Write amplification factor (WAF) is a ratio of the amount of data written by the host and the amount of data written to the NAND by the SSD.

Dynamic write acceleration may contribute to WAF because data may first be written as SLC and later be rewritten as MLC. The magnitude of the difference in WAF is an additive factor between zero and two, depending on runtime conditions. Provided conditions occur such that a given piece of user data is written as SLC and is neither trimmed nor rewritten before the later migration to MLC, the additive factor in WAF for that data would be two. If the user data was rewritten or trimmed before SLC-to-MLC migration, or if the data was originally written as MLC (as would be the case for sustained workloads), the additive factor for that data would be zero.

Traditional contributors to high write amplification factors, including io-alignment, garbage collection in random environments, and volatile drive write cache settings, are not known to be affected by dynamic write acceleration.

For drives that enable the feature, we compensate for the potential of slightly elevated WAF by using proprietary NAND trims to optimize for 50% more NAND endurance than SSDs that do not feature dynamic write acceleration. In the case of the M600, the result is superior client performance, in addition to the best product endurance that Micron has ever offered on a client SSD to date.

Because WAF can vary based on application properties, with or without dynamic write acceleration, customers using any client SSD in a non-client-oriented application should perform testing to validate WAF in the intended application.

Conclusion

Dynamic write acceleration is a new and unique technology that uses Micron's achievements in NAND technology to produce dramatic improvements in energy consumption and performance beyond the capabilities of conventional hardware by leveraging key characteristics of client computing operating environments.