Intel® Memory Drive Technology

May 2017
Revision 001
## Revision History

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<td>001</td>
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1 Introduction

Intel® Memory Drive Technology is a software-defined memory (SDM) product\(^1\) that allows for the expansion of system memory beyond DRAM by defining some of the PCIe*-based Intel® Solid State Drive (SSD) capacity as memory, instead of as storage.

This document maps the suitability of Intel Memory Drive Technology for use with specific classes of applications and workloads.

The Intel Memory Drive Technology implements software-defined memory (SDM) on-top of Intel® SSDs. Intel Memory Drive technology is optimized to take advantage of the latest Intel processors, PCIe-based Intel SSDs, and the latest memory technology of the Intel® Optane™ SSDs.

As illustrated in Figure-1, Intel Memory Drive Technology executes directly on the hardware, and below the operating system, and allows for system memory to be assembled from DRAM and the PCIe-based Intel SSD. It leverages the economic benefit of SSDs, and operates transparently as volatile system memory.

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\(^1\) Technology licensed from ScaleMP®
2 Matching Applications and Workloads

Intel® Memory Drive Technology can successfully run any Linux* x86_64 Operating System, and any Linux x86 workload that is valid for said OS.

2.1 Workloads that Benefit Most from Intel Memory Drive Technology

Intel Memory Drive Technology is the most advanced implementation of a Memory Management Unit (MMU), implemented in software (SW-MMU). There are more than 20 types of algorithms used to predict, prefetch, and optimize memory and locality, as opposed to the typical single naive algorithm that is implemented in hardware (e.g. cacheline prefetch). It uses machine learning, pattern recognition, code scanning, and many other sophisticated techniques that enable Intel Memory Drive Technology to massively prefetch addresses that the CPU will need to access thousands of cycles ahead. This means that by the time the CPU needs those addresses, they are already waiting for it in DRAM.

Further, Intel Memory Drive Technology software minimizes the CPU stalls often associated with high-concurrency workloads. As a result, average performance level for random memory access is close to DRAM-level performance.

Intel Memory Drive Technology takes advantage of one or more of the following workload attributes:

1. Predictable or probability-based memory access patterns such as accesses to structured arrays - handled by prefetch algorithms.
2. Highly concurrent memory access such as parallel throughput workloads - handled through asynchronous memory load.
3. CPU intensive workloads - handled by optimizing the memory to CPU affinity throughout the run.

2.1.1 Examples of Applications Best Suited for Intel Memory Drive Technology

The following are presented as examples of application types that have the potential to benefit from Intel Memory Drive Technology, but have not necessarily been tested as of this document’s publication date.

1. Row-store or column-store in-memory databases that are used in analytics workloads, such as SAP HANA*, Oracle* 12c, MySQL*.
2. Different application classes that fit the high concurrency workloads are:
   a. Multi-tenant workloads, such as container-based virtual-shared web-hosting server, or virtualization-based partitioning, for example with KVM.
   b. Multi-threaded key-value cache such as memcached.
   c. Distributed/shared data grids and frameworks such as Apache Spark*, Apache Ignite*, Aerospike*, or Redis*.
3. Multi-threaded or multi-process linear algebra workloads with large matrices, or high performance computing workloads using OpenMP*, or parallel statistics calculations on large data.
2.2 Workloads that May Not be Well-Suited for Intel Memory Drive Technology

The Intel® Optane™ SSDs are limited by two key physical attributes, compared to DRAM:

1. Access Latency, which is in the range of 10000ns on Intel® Optane™ SSDs, compared to 100ns for DRAM.
2. Read/Write Bandwidth, which is in the range of 100 GB/s for dual-socket Intel® Xeon® memory controllers, compared to 2.3 GB/s for an Intel® Optane™ SSD.

The Intel Memory Drive Technology takes advantage of workload attributes to compensate for the disadvantages of the non-volatile memory. However, there are workloads where Intel® Memory Drive Technology advantages will not be fully utilized, mainly:

1. Low-concurrency workloads (e.g. serial workloads, single process, single threaded) — Due to the nature of low concurrency workloads, where there is only one execution thread, Intel Memory Drive Technology cannot disturb the current process to prefetch and attempt asynchronous memory management.
2. Workloads bound by memory bandwidth — With workloads stressing the memory bandwidth, the limited mixed bandwidth of the Intel® Optane™ SSD (approximately 2 GB/s) would be reached. Even with four Intel® Optane™ SSDs populated, the total aggregate bandwidth would be 8 GB/s, compared to two Intel® Xeon® E5-v4 processors capable of >100GB/s on their memory controllers' link to DRAM.

Additionally, Intel Memory Drive Technology is based on virtualization technologies; as such, workloads with a high frequency of system calls may suffer from the virtualization overhead. Making many system calls is not recommended for any workload on any memory architecture, but it would come at higher performance cost in virtualization environments.

2.2.1 Examples of Applications Least-Suited for Intel Memory Drive Technology

1. A serial program using an interpreted language, traversing a graph data structure with less than 1K of data for each vertex or edge.
2. A program resembling the “stream” memory bandwidth benchmark; constantly accessing memory and doing little compute on the fetched memory before moving over to consume new memory. See https://www.cs.virginia.edu/stream/ref.html for more information on the Stream* benchmarking tool.

2.3 Recommended Configuration

1. Minimum of 0.4GB/s per Intel® Xeon® processor is recommended. Intel® Optane™ DC P4800X provides at least 2.0GB/s, and up to 2.3GB/s per SSD.
2. Multiple SSDs can be installed with Intel Memory Drive Technology software, and can be aggregated to improve performance (optimized for the highest aggregated 4K IOPS across all devices used by Intel Memory Drive Technology).
3. Attach equal number of drives to each socket (consult system manual for PCIe* to socket mapping).
4. One smaller capacity SSD per socket will yield better performance than a larger capacity drive attached to one of multiple sockets. For example, in a dual socket system, two SSDs with Intel Memory Drive Technology with a capacity of 320GB attached to each individual socket, would perform better than a single 640GB SSD drive attached to one of the sockets.

2 For more details, see "Intel® Memory Drive Setup Configuration Guide" (document# 335666-001US)