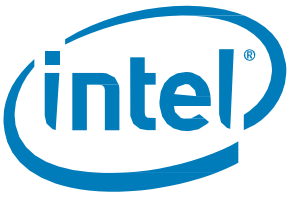

Intel® Memory Drive Technology

Set Up and Configuration Guide

August 2019
Revision 012

Document Number: 335666-012US

Revision History

Revision	Description	Date
001	• Initial release.	March 2017
002	• Revised Set Up and Configuration guidelines	April 2017
003	• Corrected Download URL & command line • Revised Recommended Configuration • Included UEFI boot support	May 2017
004	• Highlighted supported OS • Re-ordered installation steps 3 & 4	June 2017
005	• Added Common Error Code explanation • Added workloads classification for workload classes that do not benefit from Intel® Memory Drive Technology • Added a section for performance data collection (using automatic anonymous periodic statistics collection) • Added details of supported processor models for the New Intel® Xeon® Processor Scalable Family • Updates for Intel® Memory Drive Technology version 8.2.1455.x	July 2017
006	• Improved installation and configuration section, including screen shots • Added screenshots for boot and settings section • Added update and uninstallation instructions • Performance and benchmarking section	October 2017
007	• Removed dependency in UEFI Legacy VGA BIOS • Added section referring to out-of-the-box performance workload • Updates for Intel® Memory Drive Technology version 8.5.1955.x	January 2018
008	• Added support for "MDTxxxxxxxxxx" SKUs • Added support for Operating System in UEFI mode • Added documentation for new configuration options (F5) • Added instructions for collecting system information to obtain support • Added instructions for booting from the network using PXE • Updates for Intel® Memory Drive Technology version 8.6.2535.51	August 2018
009	• Reference Link correction	September 2018
010	• Benchmarking Methodology Update	January 2019
011	• Minor documentation changes in Introduction, page 5	February 2019
012	• Added Supported Processors information	August 2019

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Introduction

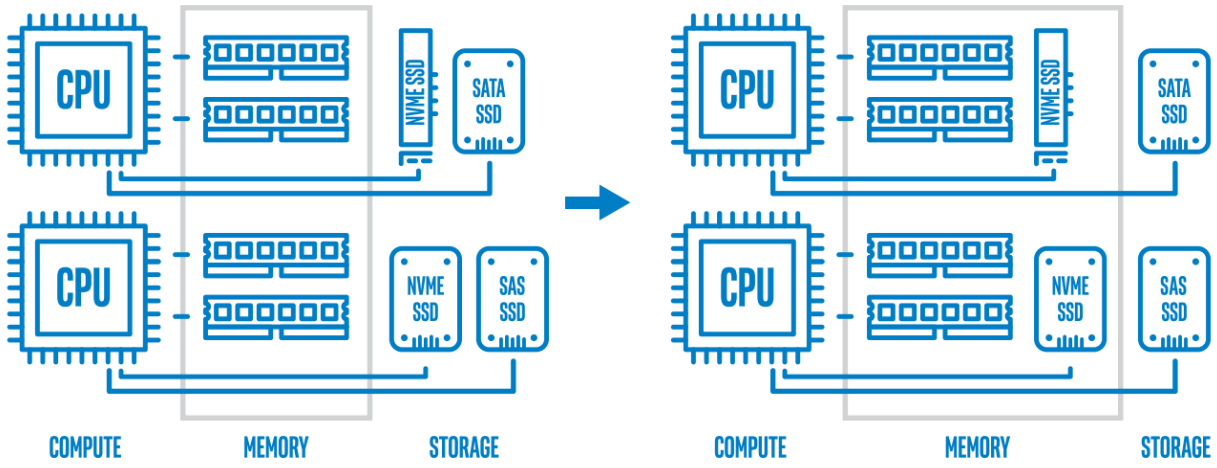
The Intel® Optane™ SSD DC P4800X can be combined with Intel® Memory Drive Technology software to enable the expansion of system memory beyond DRAM; essentially using Intel® Optane™ SSD's capacity as software-defined memory (SDM) with byte-addressable memory, instead of as block storage.

This document describes the setup, capabilities, and specifications of the Intel® Memory Drive Technology software.

The Intel® Memory Drive Technology implements software-defined memory (SDM) on-top of the Intel® Optane™ SSDs. Intel® Memory Drive Technology is optimized to take advantage of the latest Intel processors and Intel® Optane™ SSD's unique features.

As shown 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 economic benefit of SSDs, and operates transparently as volatile system memory. With Intel® Optane™ SSDs, it is available in 85GiB, 320GiB, 640GiB and 1.28TiB capacities.

Figure 1: Memory Pool with Intel® Memory Drive Technology



Intel® Memory Drive Technology offers these key features:

- Optimized for up to 8x system memory expansion[1] over installed DRAM capacity
- Low latencies and close-to DRAM performance for SDM operations
- Consistent and reliable SDM Quality of Service
- High endurance
- Designed for high-concurrency and in-memory analytics workloads

1. For example: 128GiB DRAM can be expanded up to 1024GiB based on the capacity of installed NVMe media. Higher expansion ratios may be supported, with possibly suboptimal performance.

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1 Installation and Configuration

1.1 Operating System Requirements

Intel® Memory Drive Technology supports Linux* x86 64 bit, kernel versions 2.6.32 or higher.

1. See Supported Linux distributions in "Specifications" section.
2. Intel® Memory Drive Technology also supports Open Source hypervisors such as KVM, as shipped with the major Linux distributions

1.2 Available Product Varieties

Depending on the product SKU you have ordered, Intel Memory Drive Technology comes in two varieties: either preloaded with the software-defined memory (SDM) on the NVMe drive, or to be downloaded and installed separately.

The product SKU can be identified by running the command "nvme list" or according to the product labeling.

SKU (Model String)	Intel Memory Drive Technology Software	License	Software Installation
MDTxxxxxxxxxx	Preloaded on the drive	Not required	Not required
SSDxxxxxxxxxx	Installed separately	Separate license required	See section of "Reload / Installation of Intel Memory Drive Technology Software"

If you are using the **SSDxxxxxxxxxx** SKU, or if the preloaded software was accidently deleted or corrupted, please refer to the section of "Reload / Installation of Intel Memory Drive Technology Software".

Install Intel Memory Drive Technology by connecting the Intel® Optane SSD to the appropriate PCIe slot in your system (please refer to your system's manual for information on connecting NVMe SSDs).

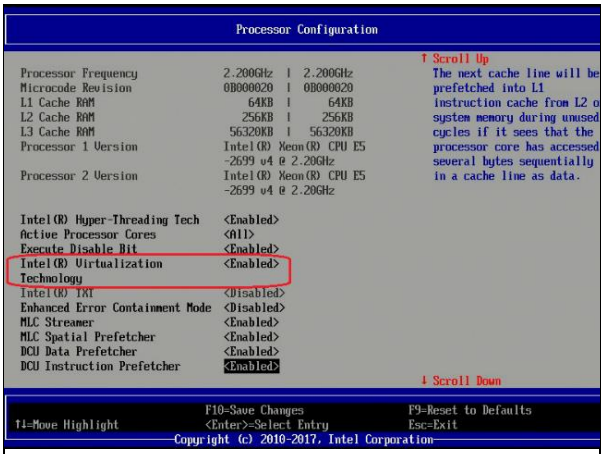
For optimal performance, Intel strongly recommends installing at-lease one Intel® Optane SSD per processor.

1.3 Configure BIOS to Support Intel® Virtualization Technology

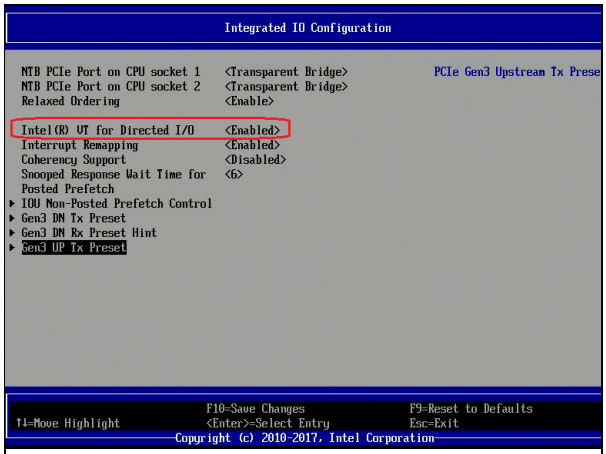
System's BIOS menus of the server onto which you install Intel® Memory Drive Technology might be different from the images below. Please verify the configuration of booting options in your system's BIOS manual.

1. To enable VT, navigate from the **Setup menu** -- > **Advanced** --> **Processor Configuration,** and set **Intel® Virtualization Technology** to **Enabled.**

2. To enable VT-D, navigate from the **Setup menu -- > Advanced --> Integrated IO configuration**, and set **Intel® Virtualization Technology for Direct I/O** to **Enabled**.



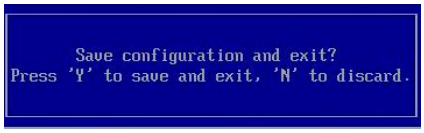
(1) Virtualization Technology (Processor Configuration)



(2) Virtualization Technology for Direct I/O

3. Press <**F10>** to save changes in BIOS configuration

4. Press **'Y'** to save and exit. Wait for the system to reboot.



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2 Booting Intel® Memory Drive Technology

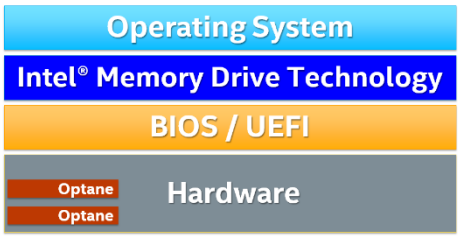
This section describes the options and steps required to deploy Intel® Memory Drive Technology.

The instructions below assume the Intel® Memory Drive Technology software is already installed on the NVMe device. If this is not the case, refer to the section "Reload / Installation of Intel Memory Drive Technology Software".

2.1 Boot order and software stack

Intel® Memory Drive Technology executes directly on the hardware and below the operating system, as described in the following diagram.

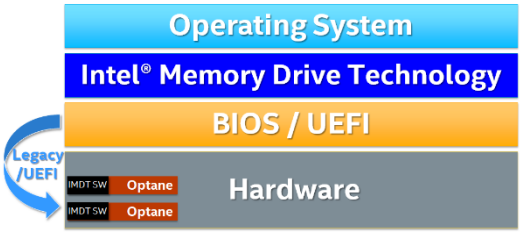
After Intel® Memory Drive Technology loads, the operating system is loaded.



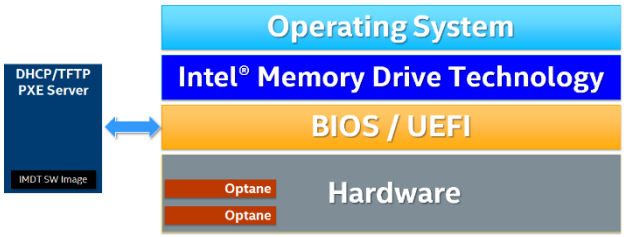
2.2 Boot Options

Intel® Memory Drive Technology software image can be configured to load in the following ways:

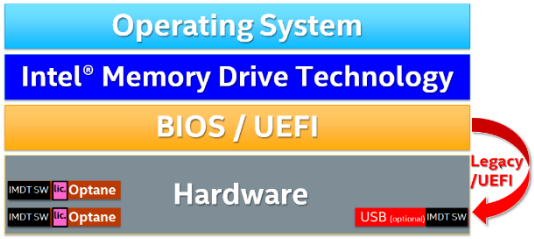
1. **Booted from a local Intel® NVMe Optane drive**
   Intel® Memory Drive Technology installed locally on a bootable Intel® Optane SSD in the system. Booting from Intel® Optane SSD may require setting the system to boot using UEFI.



2. **Booted from the network using PXE**
   Intel® Memory Drive Technology software in this case will be stateless, and will load and run directly from the PXE image. Only Legacy boot (not UEFI) is supported for PXE boot.



3. **Booted from a local bootable flash media**
   Intel® Memory Drive Technology software installed locally to a bootable flash media (such as USB flash drive), where the system BIOS is configured to boot from that device.



2.3 Booting from a Local Intel® NVMe Optane Drive

Configure the system's BIOS to boot from one of the Intel® Optane SSDs which have Intel® Memory Drive Technology installed, and once you have saved the new configuration, reboot your system.

System's BIOS menus of the server onto which you install Intel® Memory Drive Technology might be different from the images below. Please verify the configuration of booting options in your system's BIOS manual.

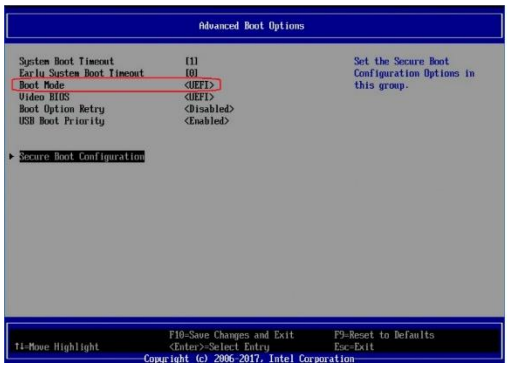
1. Reboot server.
2. To access the BIOS setup utility, press the <F2> key while the system running POST (options to continue and logo screen appears as in a figure below)

Figure 2: Access to BIOS

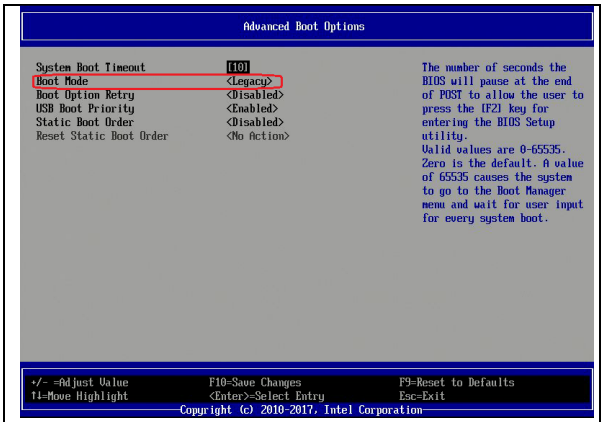
3. Navigate from the **Setup menu** -- > **Boot Maintenance Manager** --> **Advanced Boot Options**:

   If the system is capable of booting directly from the NVMe (using UEFI), set the **Boot mode** to **UEFI**.

   If the option of booting from the NVMe is ***not*** available, set the **Boot Mode** to the **Legacy**.

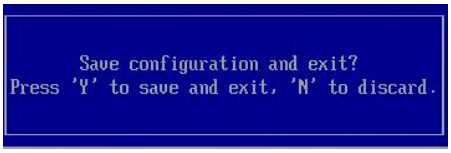


(1) UEFI boot mode



(2) Legacy boot mode

4. Press **<F10>** to save changes in the BIOS configuration.



5. Press '**Y**' to save and exit. Wait for the system to reboot.

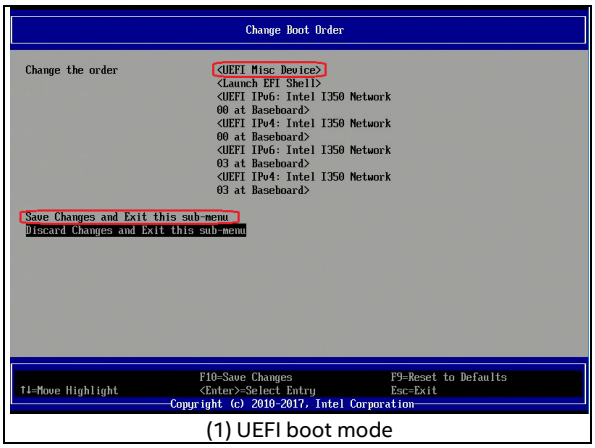
If boot mode changes were made, you'll be required to save BIOS configuration and Reboot.

6. Re-enter the BIOS setup utility, press **<F2>** while system performs POST.

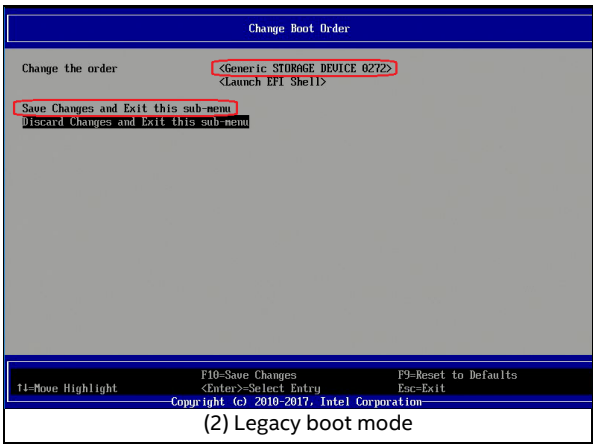
7. Navigate from the **Setup menu** -- > **Boot Maintenance Manager** --> **Change Boot Order:**

   If the system is capable of booting directly from the NVMe device (using UEFI), assign the highest boot sequence priority to the **UEFI Misc Device** by moving it to the first position in the list**.**

   If the option of booting from the NVMe device is not available, assign the highest boot sequence priority to the **USB Flash Drive** by moving it to the first position in the list**.**



(1) UEFI boot mode



(2) Legacy boot mode

8. Select menu option **Save changes and Exit this sub-menu** and press **Enter**.

2.4 Booting from the Network Using PXE

2.4.1 Obtain Latest Intel® Memory Drive Technology Installer

1. Boot to your Linux* OS system.
2. Download the Intel® Memory Drive Technology software installer from https://www.memorydrv.com/downloads/latest to a directory on the Linux system. The file name has the following format: imdt_installer-x.x.x.x.sh (e.g. imdt_installer-8.6.2535.19.sh).

   a. If the server is not connected to the internet:
   Open following link from a system connected to internet:
   https://www.memorydrv.com/downloads/latest and download imdt_installer-x.x.x.x.sh file.
   Copy the imdt_installer-x.x.x.x.sh file to a directory on the target Linux server.

   b. If the server is connected to the internet, the installer can be downloaded directly to a directory on the target Linux server using the ***wget*** *command line utility*:

```
# wget -N --content-disposition https://www.memorydrv.com/downloads/latest/imdt_installer.sh
```

3. Change the file to have executable permissions:

```
# chmod +x imdt_installer-*.sh
```

2.4.2 Image Preparation

On a system booted with any Linux 64bit OS, use the previously downloaded installer to generate the Intel® Memory Drive Technology boot image.

```
# ./imdt_installer-x.x.x.x.sh bo -p imdt_pxe.img
```

An image file named "imdt_pxe.img" will be created.

To customize the image for size, boot device, log device, and other properties – please contact support.

2.4.3 PXE Configuration Instructions

If your PXE environment is set up, skip the instructions in this section.

1. Download syslinux-x.xx.zip files at https://www.kernel.org/pub/linux/utils/boot/syslinux/
2. Copy the file memdisk from the directory \bios\memdisk in the zip file you downloaded to the default tftpboot directory (usually /tftpboot).
3. Copy the file pxelinux.0 from the directory \bios\core in the zip file you downloaded to the same directory.
4. Copy the PXE boot image created in the previous section. Image Preparation" to the same directory
5. Configure DHCP to provision the pxelinux.0 file to the target server(s). Instructions vary by DHCP server.
6. In the directory /tftpboot/pxelinux.cfg on the tftp server, create a text file named default (or name it as the MAC address of the machine that will boot IMDT), and edit it to have the following content:

```
default imdt
label imdt
kernel memdisk
append initrd=imdt_pxe.img
```

2.4.4 Configure a Server to Boot with Intel® Memory Drive Technology

1. Copy the Intel® Memory Drive Technology image you have created to the necessary location on your tftp server, to be loaded with the PXE request from the server.
2. Set PXE as the first boot device in the boot order of the system.
   This can be achieved using the BIOS setup utility, or with IPMI or other similar mechanism used for remote management of your servers.
3. Restart the server.

The server will load with Intel® Memory Drive Technology, followed by a boot of the Linux operating system (the default for IMDT is to load the operating system from the first local hard drive).

2.5 Booting from a local bootable flash media

If the option of rebooting from the NVMe device is not available, install the Intel® Memory Drive Technology software on a local bootable flash media (such as USB flash drive):

1. Refer to section “Reload / Installation of Intel Memory Drive Technology Software” to obtain the latest Intel® Memory Drive Technology software (and licenses if necessary, depending on the model you are using).
2. Install a bootable flash media in the system.
3. Run the installer with the following options and follow the on-screen instructions to accept the terms when prompted:

```
# ./imdt_installer-x.x.x.x.sh in -b

Please take a moment to read the below
================================================================================
Welcome to Intel Memory Drive Technology version 8.6.2535.19 !
--------------------------------------------------------------------------------
*  By installing and/or using this software you acknowledge that you have
read and agreed to the agreement published at
https://www.memorydrv.com/EULA.

*  Changelog is available at
https://www.memorydrv.com/downloads/latest/imdt.rel_notes.txt.

*  Parts of this program, as provided in binary form, include open source
code under one or more open source licenses. For further details and
notices please see https://www.memorydrv.com/opensource.
================================================================================
Type "accept" to accept the terms and conditions above: accept
Terms and conditions accepted.
```

4. Select the device(s) on which to install Intel Memory Drive Technology:

```
Intel Memory Drive Technology version 8.6.2535.19 found the following bootable media:

##  Block Device   Vendor and Model Number  Serial Number     Size (GB/GiB)
01  /dev/sdb        USB DISK 2.0            07A70E137887CD50  1.003 / 0.979

Please select devices to install Intel Memory Drive Technology:
- device list (1,3,4 or 1-3 or combination of both e.g. 1,2-4,5)
- all devices (a)
Devices (q or <ENTER> to quit): a
/dev/sdb (USB DISK 2.0 07A70E137887CD50): installing..
/dev/sdb (USB DISK 2.0 07A70E137887CD50): done.
Installing Intel Memory Drive Technology tools...
Intel Memory Drive Technology tools requires SUID permission to run as non-root user.
Allow Intel Memory Drive Technology tools to be run by all users (recommended) [N/y] ?y
Intel Memory Drive Technology tools installation is complete.
```

5. Configure the system BIOS to boot from the selected flash media device (e.g. USB drive in this example)
6. Reboot the system

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3 Intel® Memory Drive Technology Boot, Settings, and Diagnostics Menu

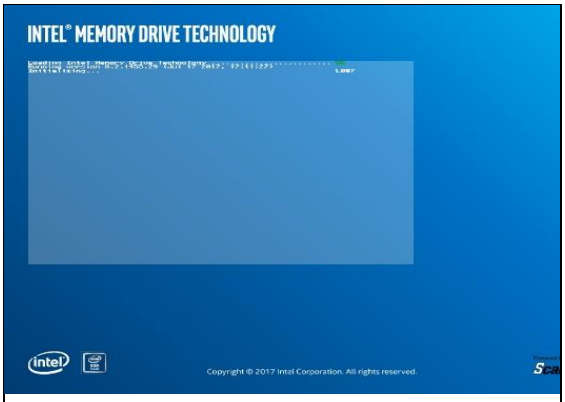
This chapter describes the boot process of Intel® Memory Drive Technology; it includes screenshots, as well as the interactive user settings and diagnostic options available during the boot process.

It is important to note that for data centers in which KVM console access is not available, Intel® Memory Drive Technology can be configured so that those outputs and controls are available through the Serial over Lan (SOL).

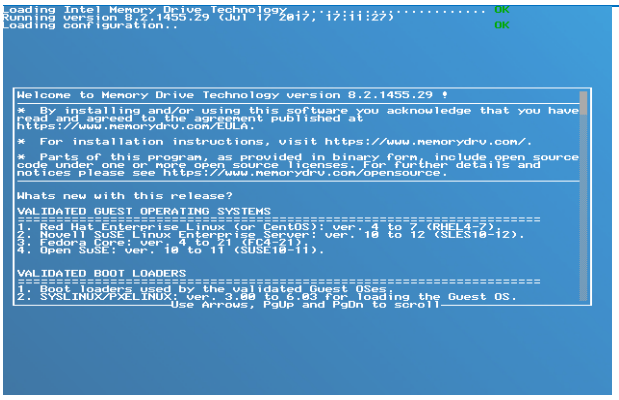
3.1 Boot Process

With BIOS set to boot Intel® Memory Drive Technology, upon reboot, your system will first show the BIOS POST screens, and will then show the following screens as it goes through the different stages of loading and booting Intel® Memory Drive Technology:

(1) Intel® Memory Drive Technology loading



(2) Intel® Memory Drive Technology boot starting



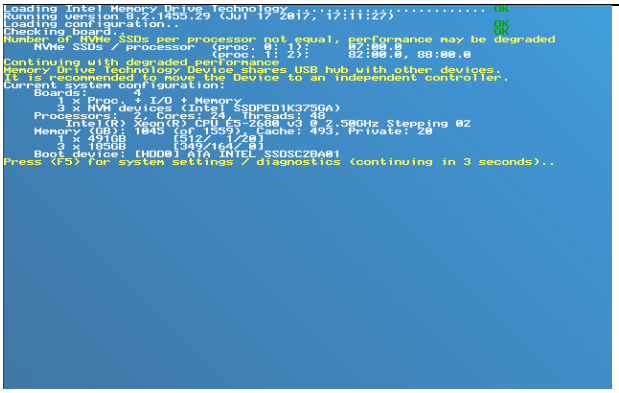
(3) Intel® Memory Drive Technology welcome screen

Use Arrows, PgUp and PgDn to scroll.

To prevent welcome screen from showing in subsequent boots, press **<F7>**.

To continue, press **<F8>**.

Note: It is also possible to accept the EULA via the operating system, by using the Intel® Memory Drive Tool: "# imdtctl –tcs".

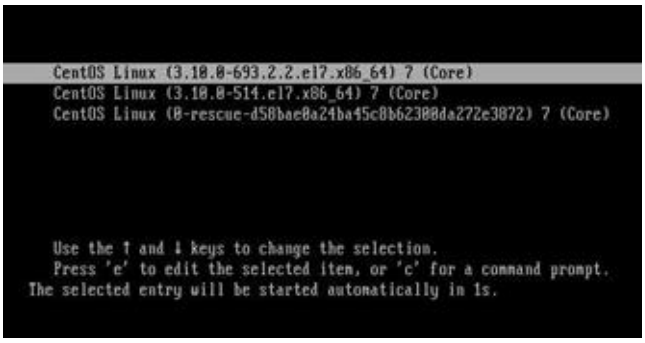


(4) Intel® Memory Drive Technology configuration report, warnings, and settings prompt

At this stage the system displays:

1. Configuration information.
2. Warning messages, if any (displayed in Yellow font), provide notifications about deviations from best practices and recommendations.
3. A prompt (in Yellow font) to press **<F5>** to optionally enter the Intel® Memory Drive Technology settings and diagnostics menu will be displayed. If no action is taken, after timeout, the Linux OS will be booted from the device defined in the configuration. For more information about Intel® Memory Drive Technology settings and diagnostics see section "System Settings and Diagnostics".

OS loads from the defined device



(5) OS loads

3.2 Verifying Successful Installation

1. After the operating system is loaded, you can verify successful installation by checking that all system memory is available using the 'free' command:

```
# free -g
              total        used        free      shared  buff/cache   available
Mem:            752          22         730           0           0         730
Swap:             0           0           0
```

2. In addition, if Intel® Memory Drive Technology Tools were already installed (see section "Installing Intel Memory Drive Technology Tools"), you can run the following command:

```
# imdtversion -vvvv
Intel Memory Drive Technology: 8.6.2535.19 (Jul 23 2018 17:03:18)
System configuration:
    Boards:      3
       1 x Proc. + I/O + Memory
       2 x NVM devices (Intel MDTPED1K375GA)
    Processors:  2, Cores: 36, Threads: 72
        Intel(R) Xeon(R) Gold 6140 CPU @ 2.30GHz Stepping 04
    Memory (MB): 713728 (of 910715), Cache: 184820, Private: 12167
       1 x 182272MB   [195301/ 1056/11973]
       1 x 265728MB   [357707/91882/   97]   0301:00.0#1
       1 x 265728MB   [357707/91882/   97]   0303:00.0#1
    Boot device: [HDD1] ATA INTEL SSDSCKJB24
Supported until: Unlimited
```

In the example above, Intel® Memory Drive Technology expanded the system memory from 128 GiB to 697 GiB, where 119.5 GiB are contributed by DRAM and 577.5 GiB contributed by Intel® Optane™ SSD. Part of the devices' capacity (60.5 GiB in that case) was allocated to be used by Intel® Memory Drive Technology software, its data structure, cache and endurance protection.

3. NVMe* SMART attributes are accessible in-band using the command below.

```
# imdtctl --pinfo=0
Device info:
        Board number: 0
        Device number: 0
        Device type: 0 (NVMe)
        Device address: 0301:00.0#1
        PCI VID:DID: 8086:2701
        PCI SVID:SDID: 8086:3904
        NUMA node: 1
Controller ID:
        Serial Number (SN): PHKS7440008Z375AGN
        Model Number (MN): INTEL MDTPED1K375GA
        Firmware Number (FR): E2010435
        Number of Namespaces (NN): 1
Namespace ID:
        Namespace Size (NSZE): 732585168
        Namespace Capacity (NCAP): 732585168
        Namespace Utilization (NUSE):  732585168
SMART / Health Information Log:
        Critical Warning: 0x0
        Composite Temperature: 45 C
        Available Spare:  100%
        Available Spare Threshold: 0%
        Percentage Used: 0%
        Data Units Read: 187746525
        Data Units Written: 113015731
        Host Read Commands: 23469025087
        Host Write Commands: 14126833200
        Controller Busy Time: 1105
        Power Cycles: 99
        Power On Hours: 311
        Unsafe Shutdowns: 95
        Media and Data Integrity Errors: 0
        Number of Error Information Log Entries: 0
License info:
        Device provisioned license
```

3.3 System Settings and Diagnostics

Intel® Memory Drive Technology provides a menu through which the user can modify a number of settings that can only be set during boot time, and persist them for subsequent boots. Additionally, there are diagnostics tools that can extract information for support purposes before the operating system loads, and those too are available in the "Diagnostics" menu.

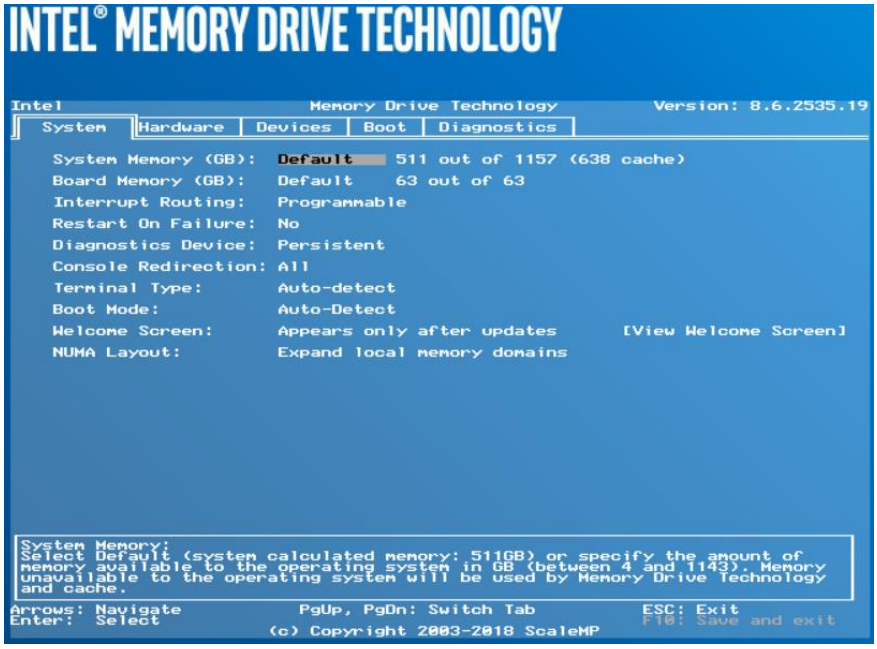
To go into the System Settings and Diagnostics menu, you should press **<F5>** when prompted during the loading of Intel® Memory Drive Technology (see the end of "Boot Process" section).

In the Settings and Diagnostics menu, there are 5 tabs. Use the Page-Up and Page-Down keys to switch tabs, and follow the context-action menu at the bottom of the screen for actions you can take at each point, and for context-related help.

"System" tab

In the "System" tab, the following can be set:

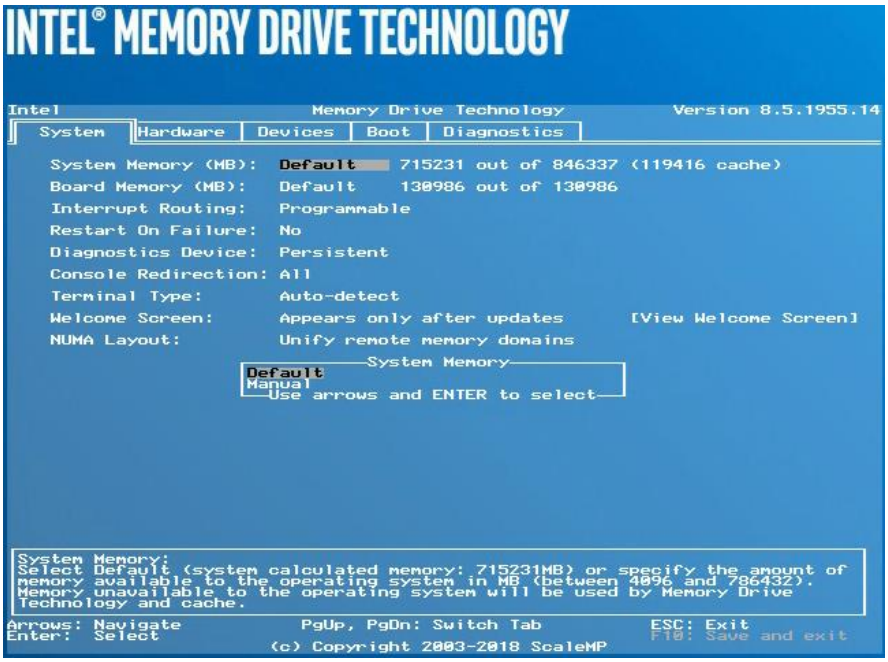
1. The total system memory available to the operating system (use the default or set it manually).
2. The amount of DRAM used (typically only changed for benchmarking)
3. To avoid system hang, the system can be set to auto-restart in the event of critical failure of a system component.
4. Toggle the diagnostics device between "Persistent" (Default) or "Serial"
5. Define the console redirection and terminal type
6. Toggle boot mode between "Auto-Detect" (Default), "UEFI" or "Legacy"
7. Toggle the display of the welcome screen between "always" and "only after updates"
8. Select the NUMA layout that Intel® Memory Drive Technology will present to the operating system



When setting the System Memory, selecting the "Default" instructs Intel® Memory Drive Technology to set the number to the optimal value for performance.

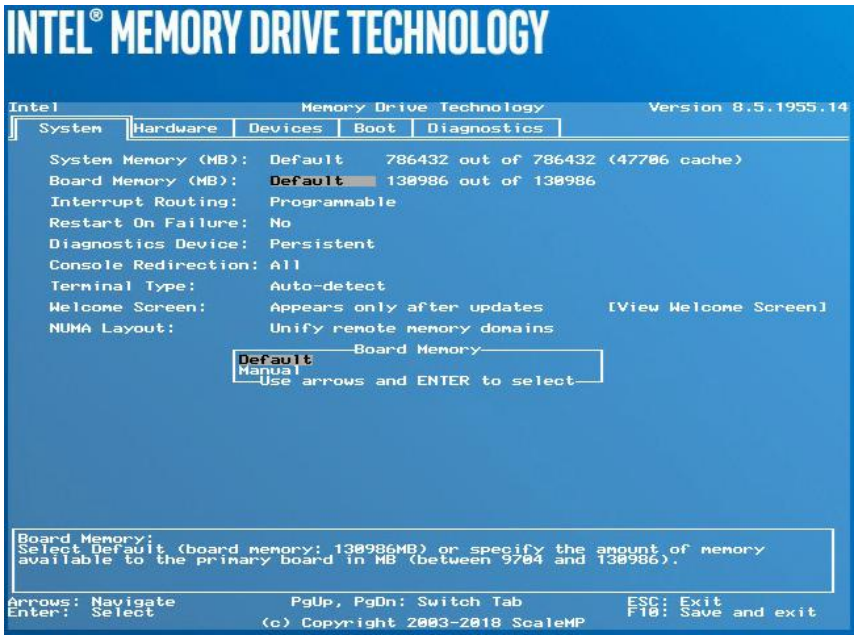
You may switch this setting to "Manual" and set any other value from the range allowed by the system.

Setting a higher number than the default value allows for larger system memory capacity, but at the expense of performance.



When setting the Board Memory used, selecting the "Default" instructs Intel® Memory Drive Technology to use the maximum amount of physical memory (DRAM) available.

You may switch this setting to "Manual" and set for a lower value, which is typically used for benchmarking to compare to a NATIVE (DRAM-only) system.

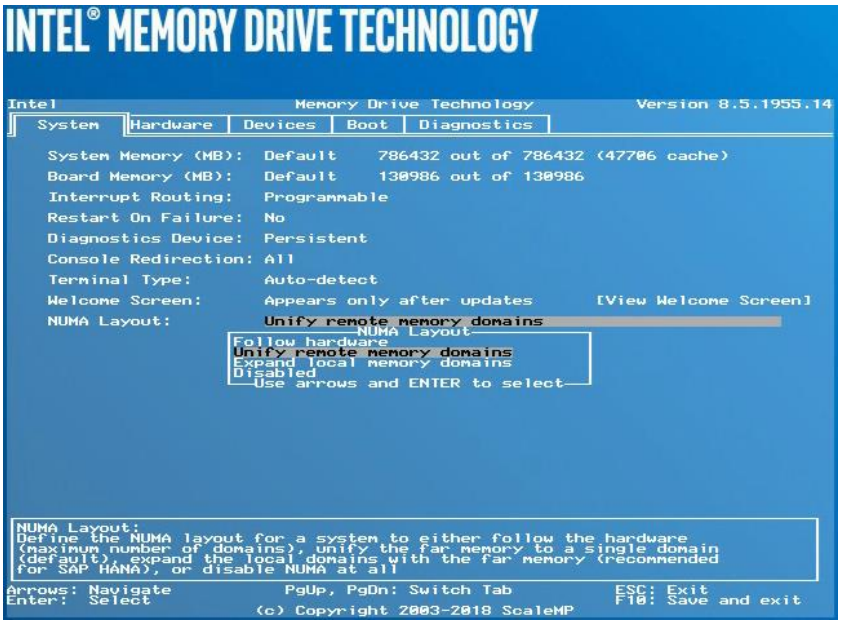


Intel® Memory Drive Technology can present the added memory gained from the Intel® Optane™ SSDs as:

1. "Unify Remote Memory domains" - present a processor-less (memory-only) NUMA domain, which is the default
2. "Expand local memory domains" - to expand each processor's memory domain with a portion of the memory made available by Intel® Optane™ SSD and Intel® Memory Drive Technology

The “Expand local memory domains” option is recommended for applications like the SAP HANA* in-memory database.

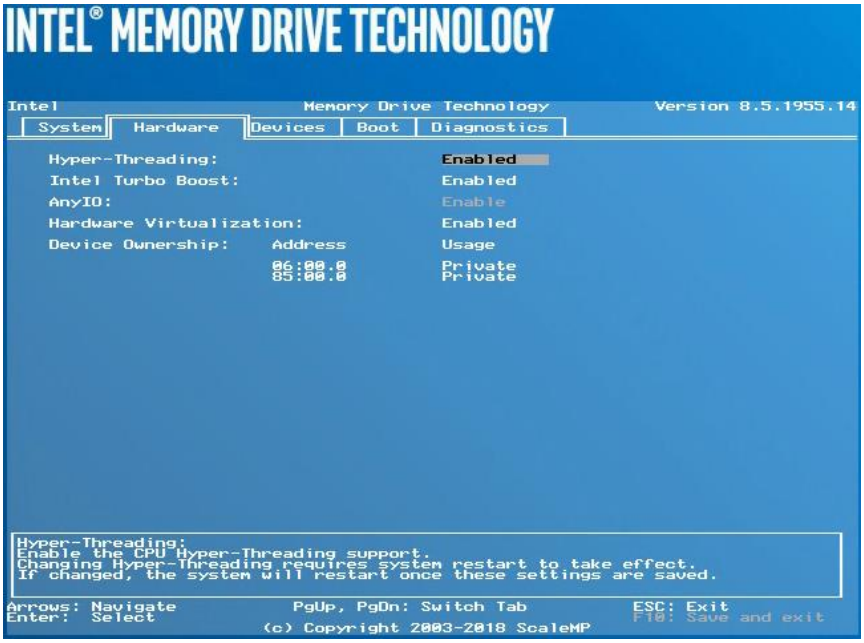
Consult application-specific documentation for the appropriate choice for your application.



“Hardware” tab

In the “Hardware” tab, the following can be set:

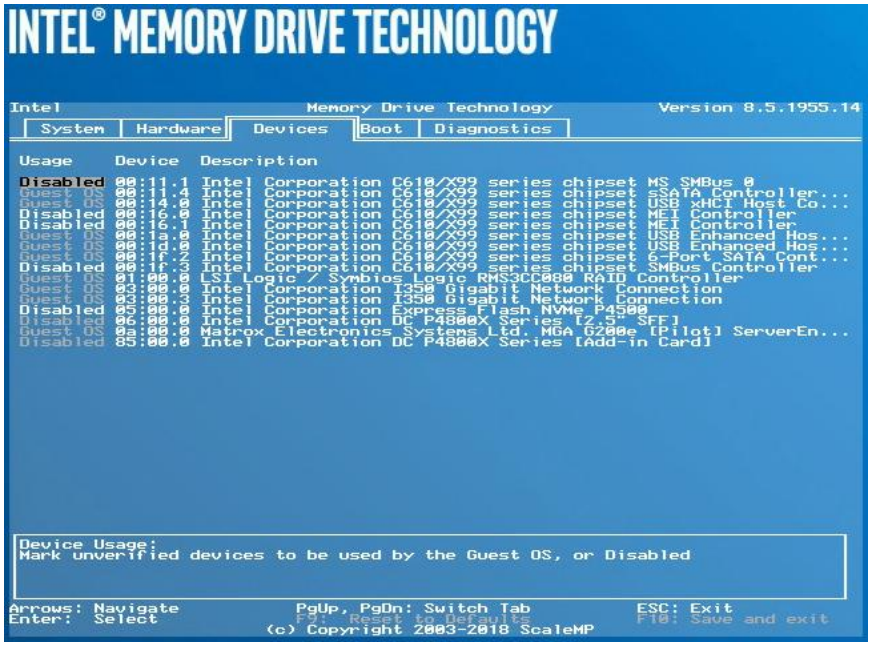
1. Intel’s processor’s: Hyperthreading
2. Turbo-boost
3. Hardware virtualization support
4. Enable or disable the use of Intel® Optane™ SSDs with valid Intel® Memory Drive Technology license as storage devices



To enable the use of untested PCI-Express cards as I/O and compute devices, use the “Devices” tab.

“Devices” tab

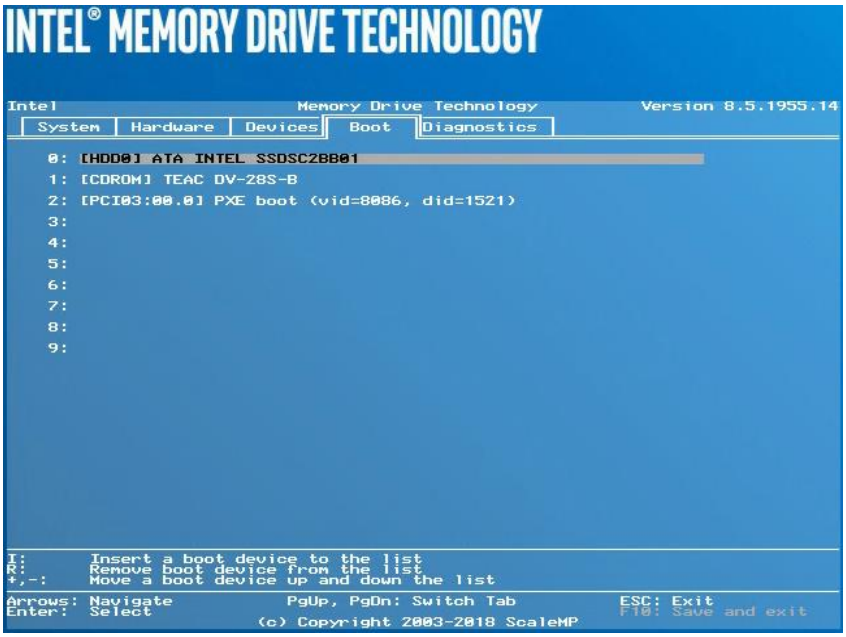
In the “Devices” tab, you can enable/disable some of the PCIe devices to be visible or not by the OS.



“Boot” tab

In the “Boot” tab, select the device to load the operating system from.

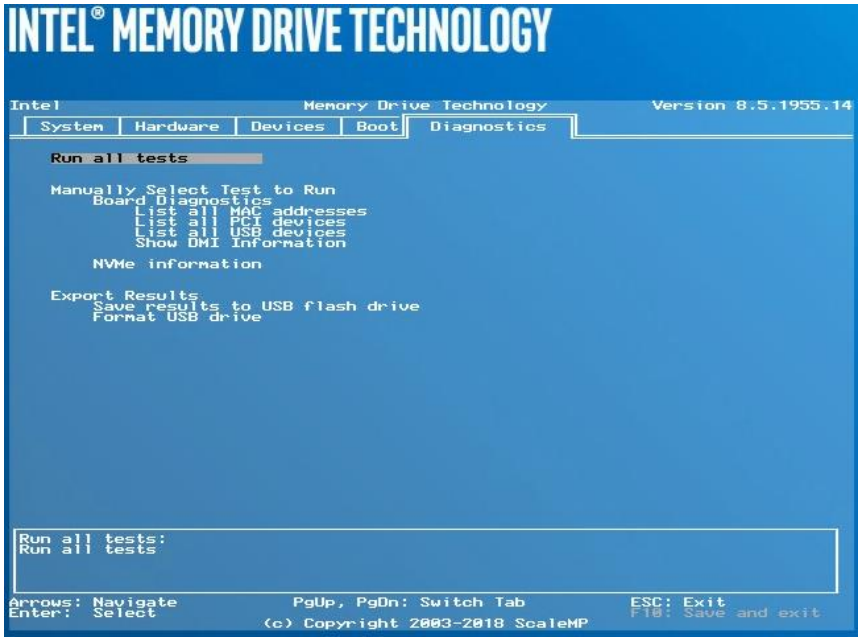
The boot device can be an optical device or a disk connected directly to the system, a SAN-connected device, a NIC if booting the OS over PXE, etc.



"Diagnostic" tab

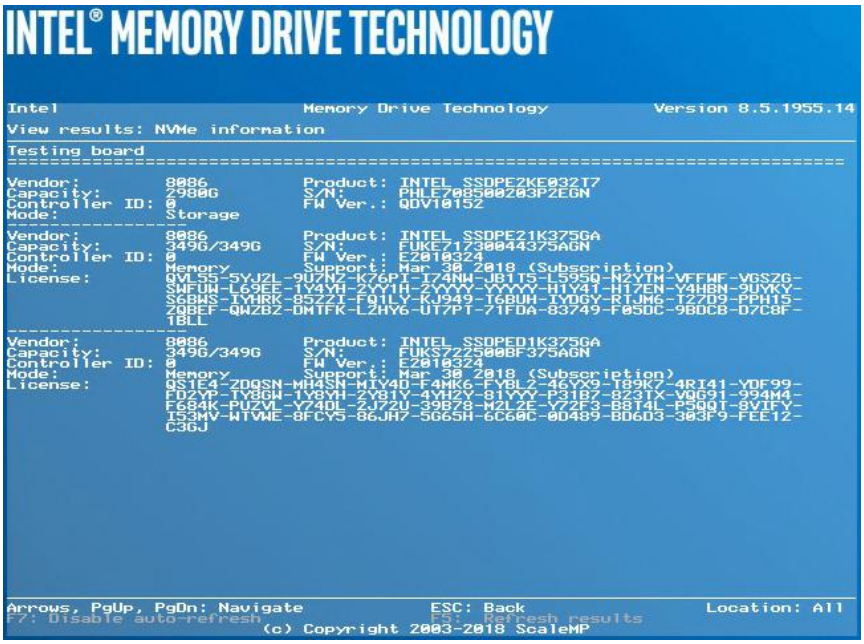
In the "Diagnostic" tab, select which diagnostics tests to run (or run "all tests").

The test results will be presented on-screen (see next screenshot). Go back to the "Diagnostics" tab and select to save the test results to a USB Flash Drive or to upload them to an FTP server using TFTP (this option requires a DHCP server on your network to assign an IP address to the diagnostics utility).



Review the diagnostic test results on-screen and navigate using the keyboard arrows and page-up/page-down keys.

To save the diagnostics results, press <ESC> to go back to the "Diagnostics" tab and choose the option you desire under "Export Results".



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4 Installing Intel Memory Drive Technology Tools

Intel® Memory Drive Technology provides a set of tools which can provide you with valuable system information, command line configuration, as well as collecting performance-related statistics.

For installing the tools:

1. Log in to the system as root.
2. Download the Intel® Memory Drive Technology software installer from https://www.memorydrv.com/downloads/latest to a directory on the target Linux server (file name format: imdt_installer-x.x.x.x.sh). It can be downloaded using the wget command line utility as follows:

```
# wget -N --content-disposition https://www.memorydrv.com/downloads/latest/imdt_installer.sh
```

3. Navigate to the directory to which you downloaded the files in step 2.
4. Make the installer file executable:

```
# chmod +x imdt_installer-x.x.x.x.sh
```

5. Run the installer as follows:

```
# ./imdt_installer-x.x.x.x.sh in -t
```

6. Read and accept the terms, by typing 'accept':

```
Please take a moment to read the below
================================================================================
Welcome to Intel Memory Drive Technology version 8.6.2535.19 !
--------------------------------------------------------------------------------
*  By installing and/or using this software you acknowledge that you have
read and agreed to the agreement published at
https://www.memorydrv.com/EULA.

*  Changelog is available at
https://www.memorydrv.com/downloads/latest/imdt.rel_notes.txt.

*  Parts of this program, as provided in binary form, include open source
code under one or more open source licenses. For further details and
notices please see https://www.memorydrv.com/opensource.
================================================================================
Type "accept" to accept the terms and conditions above: accept
Terms and conditions accepted.
Installing Intel Memory Drive Technology tools...
```

7. Decide if you want to grant all users permissions to run the tools:

```
Intel Memory Drive Technology tools requires SUID permission to run as non-root user.
Allow Intel Memory Drive Technology tools to be run by all users (recommended) [N/y] ?y
```

8. Select the location to install the tools to (default is under /usr/local), where files would be installed under the "etc"and "bin" sub-directories:

```
Please enter absolute install path for Memory Drive Technology imdt tools [/usr/local]:
Intel Memory Drive Technology tools installation is complete.
```

§

5 Updating Intel® Memory Drive Technology

Intel releases new versions of Intel® Memory Drive Technology and Intel® Memory Drive Technology tools from time to time, to include bug fixes, new features, and performance enhancements. The latest generally-available software revision can always be found at https://www.memorydrv.com/downloads/latest.

Once Intel® Memory Drive Technology is already installed and running on the system, updating to the latest version of Intel® Memory Drive Technology is a simple process. The process below updates both Intel® Memory Drive Technology and Intel® Memory Drive Technology tools:

1. Before starting the update, please make sure that Intel® Memory Drive Technology is running and that you have supported OS installed as explained in "Operating System Requirements" section.
2. Log in to the system as root.
3. Download the Intel® Memory Drive Technology software installer from https://www.memorydrv.com/downloads/latest to a directory on the target Linux server (file name format: imdt_installer-x.x.x.x.sh). It can be downloaded using the wget command line utility as follows:

```
# wget -N --content-disposition https://www.memorydrv.com/downloads/latest/imdt_installer.sh
```

4. Navigate to the directory that contains the files you downloaded in step 3.
5. Make the installer file executable:

```
# chmod +x imdt_installer-x.x.x.x.sh
```

6. Launch the license installation utility with the update flag, and follow on-screen instructions.

```
# ./imdt_installer-x.x.x.x.sh up

Please take a moment to read the below
================================================================================
Welcome to Intel Memory Drive Technology version 8.6.2535.19 !
--------------------------------------------------------------------------------
*  By installing and/or using this software you acknowledge that you have
read and agreed to the agreement published at
https://www.memorydrv.com/EULA.

*  Changelog is available at
https://www.memorydrv.com/downloads/latest/imdt.rel_notes.txt.

*  Parts of this program, as provided in binary form, include open source
code under one or more open source licenses. For further details and
notices please see https://www.memorydrv.com/opensource.
================================================================================
Type "accept" to accept the terms and conditions above: accept
Terms and conditions accepted.

Intel Memory Drive Technology update details:
* Current version: "8.6.2535.14"
* Target  version: "8.6.2535.19"

Notes:
* Make sure the system's power source is reliable.
* The update will need about 32MB available in the current directory.
* Save all of your work, and close all open programs to prevent data loss.
* Run the update program from the system console.  Do not run the update
  program remotely.
* Do not turn off or suspend the computer until the update has been
  completed.  IF YOU TURN OFF OR SUSPEND THE COMPUTER WHILE THE UPDATE IS
  STILL IN PROGRESS, the system may become unusable.
```

```
* When the update is complete, you may reboot the system.

Press "u" to update, any other key to exit:
The update of Intel® Memory Drive Technology is now complete. The new version of Intel® Memory
Drive Technology will be loaded and used once you reboot the system.
```

7. Press 'u' to start the update process

```
Writing part 1 out of 7: 100%
Writing part 2 out of 7: 100%
Writing part 3 out of 7: 100%
Writing part 4 out of 7: 100%
Writing part 5 out of 7: 100%
Writing part 6 out of 7: 100%
Writing part 7 out of 7: 100%


Intel Memory Drive Technology update is complete.

Installing Intel Memory Drive Technology tools...
Intel Memory Drive Technology tools requires SUID permission to run as non-root user.
Allow Intel Memory Drive Technology tools to be run by all users (recommended) [N/y] ?y
Memory Drive Technology tools update is complete.
```

8. Please reboot the system. The update of Intel® Memory Drive Technology is now complete. The new version of Intel® Memory Drive Technology will be loaded and used once you reboot the system.

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6 Troubleshooting

6.1 If Installation Fails

Please ensure that you are using a supported OS distribution and certified Intel NVMe SSDs. See "Specifications" section.

6.1.1 Common Installation Error Codes

During the boot process, Intel® Memory Drive Technology may issue warnings and errors to the console, in many cases using error codes. Table 1 below lists the most common error codes, their explanations, and suggested path to resolution.

Table 1: Error Codes

Error Code	Error Description	Proposed process for handling
700	Boot devices are not detected	Contact Intel Support
500	Intel® Memory Drive Technology license not found	Refer to "Reload / Installation of Intel Memory Drive Technology Software" section. If licenses expired - obtain new licenses
70x	More than one USB Flash Drive has Intel® Memory Drive Technology Installed. This error only happens when booting in Legacy mode.	Remove all removable media that installed with Intel® Memory Drive Technology software, and reinstall it again on one device only.
1257	Selected OS boot device is not bootable	Press F5 at the boot prompt of Intel® Memory Drive Technology and select it in the boot menu
801	Boot mode set to UEFI, while operating system installed in Legacy	Change boot mode to auto
802	Boot mode set to Legacy, while operating system installed in UEFI	Change boot mode to auto

6.2 Data Collection for Issue Escalation

Based on the case you are facing, collect the relevant information and report to your support contact.

Case 1 – Intel® Memory Drive Technology does not boot
• Take a console screenshot depicting the point when Intel® Memory Drive Technology boot stopped • Boot to native, and run the installer as follows: `./imdt_installer-x.x.x.x.sh si -s`
Case 2 - Intel® Memory Drive Technology boot but OS does not boot
In addition to the above, boot Intel® Memory Drive Technology, use F5 to enter Intel® Memory Drive Technology Settings menu and run diagnostics
Case 3 - Intel® Memory Drive Technology boots and OS boots, problem happens after boot
In addition to the above, after Intel® Memory Drive Technology and OS booted, execute the following and follow the instructions: `./imdt_installer-x.x.x.x.sh si -s`

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7 Reload / Installation of Intel Memory Drive Technology Software

Back up all data before beginning Intel® Memory Drive Technology Software setup. Intel® Memory Drive Technology configures PCIe-based Solid State Drive as a part of main (volatile) memory pool.

Following are the steps to set up Intel® Memory Drive Technology software for **Linux* OS**:

This manual refers to Intel® Xeon® E5 v4 based system running CentOS 7. If your platform is based on other architecture, BIOS Setup Menu options might be different, please refer to the specific system manual to configure BIOS options properly.

Before starting the installation routine please verify the Linux OS meets requirements.

Install certified PCIe-based Intel® SSD/ SSDs into the target server. For optimal performance install at-least one SSD per processor.

7.1 Obtaining the Latest Version of the Intel® Memory Drive Technology Software

1. **Log in** to the system as the **root** user.
2. Download the Intel® Memory Drive Technology software installer from https://www.memorydrv.com/downloads/latest to a directory on the target Linux server. The file name has following format: imdt_installer-x.x.x.x.sh (eg. imdt_installer-8.6.2535.19.sh).
    a. If the server is not connected to the internet:

    Open following link from a system connected to internet: https://www.memorydrv.com/downloads/latest and download imdt_installer-x.x.x.x.sh file. Copy the imdt_installer-x.x.x.x.sh file to a directory on the target Linux server.

    b. If the server is connected to the internet, the installer can be downloaded directly to a directory on the target Linux server using the ***wget*** *command line utility*:

```
# wget -N --content-disposition https://www.memorydrv.com/downloads/latest/imdt_installer.sh
```

3. Navigate to the directory that contains the file downloaded in step 4.
4. Make the installer file executable:

```
# chmod +x imdt_installer-x.x.x.x.sh
```

If you are using the embedded model (i.e. NVMe model name starts with "MDT"), you can skip to the software installation in "Installing Intel® Memory Drive Technology Software" section, otherwise continue to the following section to obtain the licenses.

7.2 Obtaining a license for Intel® Memory Drive Technology Software

This step is required for Intel® Optane SSDs with SKU SSDxxxxxxxx only.

Make sure you have been provided by Intel with software serial number per every PCIe-SSD. The Software serial number has following format: XXXX-XXXXXXXX (e.g. JUST-EXAMPLE1).

If you have not yet obtained software serial numbers, please obtain them from your Intel reseller.

1. Execute the license installation utility, and follow the instructions:

```
# ./imdt_installer-x.x.x.x.sh in -n
Intel Memory Drive Technology version x.x.x.x found the following NVMe SSDs:

##  Block Device   Vendor and Model Number  Serial Number       Size (GB/GiB)
01  /dev/nvme0n1   Intel SSDPED1K375GA      FUKS70950005375AGN    375 /   349
02  /dev/nvme1n1   Intel SSDPED1K375GA      FUKS7095000U375AGN    375 /   349

Please select devices for license generation:
- device list (1,3,4 or 1-3 or combination of both e.g. 1,2-4,5)
- all devices (a or <ENTER>)
Devices (q to quit):

Please enter software serial numbers provided by Intel one at a time (press <ENTER> to finish):
```

   The software serial number has following format: XXXX-XXXXXXXX (e.g. JUST-EXAMPLE1).

```
Please enter your email address (press <ENTER> to finish):
```

   Please enter your email address. License file will be sent to this email address.

```
Repeat your email address (press <ENTER> to finish):
```

   Repeat your email address for verification.

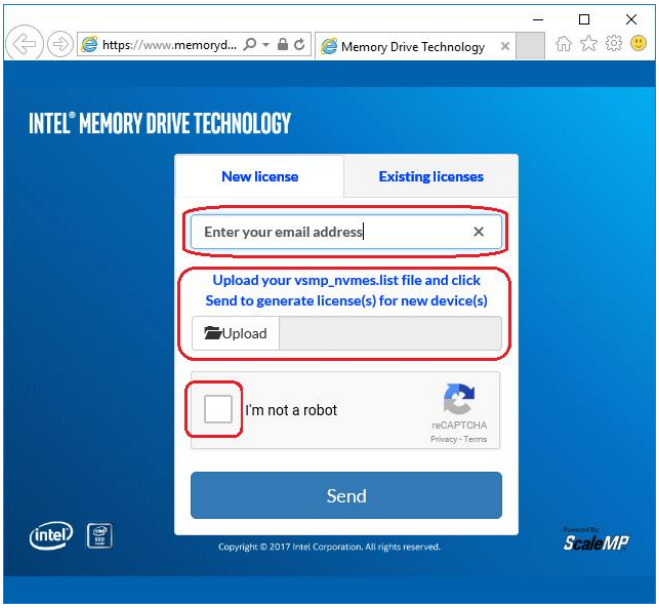
```
Selected NVMes, serial numbers, and email were saved to imdt.list.

Would you like to submit this information for activation (requires Internet access)? [Y/n]
```

   a. If the server is *connected to the internet*, select **YES** [Y] to enable the Intel® Memory Drive Technology software activation directly from the installer when, and it will automatically proceed.

   b. In case the server *is **not** connected to the internet*, or you choose to activate license through the website, you should select **NO** [N] and transfer imdt.list file to the system connected to the internet, and proceed to step 8.

2. For manual web-based activation, point your internet browser to https://www.memorydrv.com/activate, and select the "New license" tab. Submit the imdt.list, together with your email address.

Figure 3: License Activation through Web Site



3. Check the mail box for an email from *support@memorydrv.com;* if the activation process was successful, license file/files will be enclosed and will be used in the next steps. The license file has following format: IMDT_Licenses-IMDTxxxxxxxx.txt (the email may provide information for further assistance.
4. Copy received License files to a directory on the target Linux server (same directory containing imdt_installer-x.x.x.x.sh file)

The generated licenses are unique and locked to the specific SSDs you activated them for.

7.3 Installing Intel® Memory Drive Technology Software

1. **Install** the Intel® Memory Drive Technology **software** (provided by *support@memorydrv.com*) to the selected Intel SSDs. The process may take few minutes as the SSDs will be formatted during this process.
   If you are using the embedded model (i.e. NVMe SKU "MDTxxxxxxxxx"), run the following command:

```
# ./imdt_installer-x.x.x.x.sh in -n
```

   Otherwise, run the following command with the license file you have obtained in the previous section

```
# ./imdt_installer-x.x.x.x.sh in -n IMDT_Licenses-IMDTxxxxxxxx.txt
```

2. Review and accept the terms and conditions by typing "**accept**":

```
Please take a moment to read the below
================================================================================
Welcome to Intel Memory Drive Technology version 8.6.2535.19 !
--------------------------------------------------------------------------------
*  By installing and/or using this software you acknowledge that you have
read and agreed to the agreement published at
https://www.memorydrv.com/EULA.

*  Changelog is available at
https://www.memorydrv.com/downloads/latest/imdt.rel_notes.txt.

*  Parts of this program, as provided in binary form, include open source
code under one or more open source licenses. For further details and
notices please see https://www.memorydrv.com/opensource.
================================================================================
Type "accept" to accept the terms and conditions above: accept

Terms and conditions accepted.
```

3. Verify the list of devices to install:

```
Intel Memory Drive Technology NVMe SSD licensing status:

##  Block Device   Vendor and Model Number  Serial Number       Size (GB/GiB)  License
01  /dev/nvme0n1   Intel SSDPED1K187GA      FUKS643600KL187AGN    187 /   174  Available
02  /dev/nvme3n1   Intel SSDPED1K187GA      FUKS6436007X187AGN    187 /   174  Available

Press 'y' to install available licenses and Memory Drive Technology:
```

4. Press **[y]** to install the available licenses and the Intel® Memory Drive Technology software. The installer will report once the installation process successfully completed.

```
Starting license and software installation...
--------------------------------------------------------------------------------------------------
----------------------------------Installation status-----------------------------------------
--------------------------------------------------------------------------------------------
/dev/nvme0n1
[==================================================================================================
==========================================================] (100%) Done
```

```
/dev/nvme3n1
[==========================================================================================================
==========================================================] (100%) Done
```

5. ***Intel® Memory Drive Technology Tools were installed at /usr/local/{bin,etc} during installation of Intel® Memory Drive Technology.***

```
Installing Intel Memory Drive Technology tools...
```

6. Decide if you want to grant all users permissions to run the tools:

```
Intel Memory Drive Technology tools requires SUID permission to run as non-root user.
Allow Intel Memory Drive Technology tools to be run by all users (recommended) [N/y] ?y
```

7. Select the location to install the tools to (default is under /usr/local), where files would be installed under the “etc” and “bin” sub-directories:

```
Please enter absolute install path for Memory Drive Technology imdt tools [/usr/local]:
Intel Memory Drive Technology tools installation is complete.
```

8. If you need to manually install the tools for any reason – see “Installing Intel Memory Drive Technology Tools” section.

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8 Workload and Platform Selection

8.1 Workloads that Benefit Most from Intel® Memory Drive Technology

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. For example, row- or column-store in-memory databases used in analytics workloads.
2. Highly concurrent memory access such as parallel throughput workloads - handled through asynchronous memory load. For example, container-based virtual-shared web-hosting server, or a multi-threaded key-value cache such as *memcached*.
3. CPU intensive workloads - handled by optimizing the memory to CPU affinity throughout the run. For example, multi-threaded linear algebra workloads with large matrices, or parallel statistics calculations on large data.

8.1.1 Examples of applications best-fitting Intel® Memory Drive Technology

1. Row- or column-store in-memory databases used in analytics workloads, such as MySQL*.
2. Different application classes which fit the high concurrency
    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

8.2 Workloads that do not Benefit from Intel® Memory Drive Technology

1. Low-concurrency workloads (e.g. serial workloads: single process, single threaded) - with low concurrency workloads, even if Intel® Memory Drive Technology can prefetch or try asynchronous memory management, there is only one execution thread, and wait-time for memory will reduce the compute efficiency of the workloads.
2. Workloads bound by memory bandwidth - stressing the memory bandwidth: Intel® Optane™ memory's bandwidth of approximately 2GB/s would be reached. Even if four Intel® Optane™ SSDs are installed, the total aggregate bandwidth would be approx. 8GB/s. This would be much lower than two Intel® Xeon® processors memory bandwidth of >100GB/s on their memory controllers' link to DRAM.
3. Workloads with a high frequency of system calls may suffer from the virtualization overhead.

8.2.1 Examples of Workloads which do not suit 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

8.3 Recommended Hardware Configuration

1. Strongly recommended: Attach equal number of drives to each socket (consult system manual for PCIe to socket mapping). Less than one drive per socket would result in inferior performance.
2. Multiple SSDs can be installed with Intel® Memory Drive Technology software, and can be aggregated to improve performance (optimize for the highest aggregated 4K IOPS across all devices used by Intel® Memory Drive Technology).
3. One smaller capacity drive per each socket will yield better performance than a single larger capacity drive attached to one of multiple sockets. For example, in a dual socket system, two SSD drives with Intel® Memory Drive Technology with capacity of 320GiB attached to each socket, would perform better than a single 640GiB SSD drive attached to one of the sockets.

8.4 DRAM to SSD Ratio for Intel® Memory Drive Technology

Intel® Memory Drive Technology uses part of the overall capacity (DRAM + Intel® Memory Drive Technology) for caching, prefetching, and endurance protection. Thus, adding capacity in either DRAM or Intel® Memory Drive Technology may result in lower increase or no increase at all in the system memory available for the OS. This can be overridden by changing Intel® Memory Drive Technology system memory settings at boot time (F5 – System Settings) from Automatic to Manual. For example, when set to Automatic:

1. With two 320GiB drives on a system with 128GiB of DRAM, a DRAM capacity increase to 192Gib, will result in improved performance, however the system memory available for the OS will remain the same.
2. With 128GiB of DRAM on a system with three 320GiB drives, an increase in number of drives to four, will result in improved performance, however the system memory available for the OS will remain the same.

Tables 2 and 3 indicate the total SDM capacity for specific DRAM and Intel® Optane™ SSD configurations, optimized for performance. Using a higher number of devices for the same total capacity increases performance.

Tables 4 and 5 indicate the total maximum SDM capacity that can be achieved; however it may result in sub-optimal performance.

Actual system memory capacity may vary by ±3% compared to the tables below. Some valid, but less frequent, configurations are not listed above. For example, it is allowed to have a quad-socket system with less than 2TB system memory, or an octa-socket system with less than 8TB system memory.

Table 2: Performance-optimized Software-defined Memory (SDM) capacity for Intel® Optane™ SSDs and Intel® Xeon® E5 v3/v4 processors

Optimized	DRAM	Sockets	2	2	2	2	2	2	2	2	2	4	4	4	4	8	8
		Channels	4	4	4	4	4	4	4	4	4	8	8	8	8	8	8
		DPC	1	2	3	2	3	2	3	2	3	2	3	2	3	2	3
		DIMM size (GiB)	8	8	8	16	16	32	32	64	64	32	32	64	64	64	64
Devices	Device Size (GiB)	Total size (GiB)	64	128	192	256	384	512	768	1024	1536	2048	3072	4096	6144	8192	12288
2	85	170	186	298	362	426	554	682	938								
3	85	255	279	383	447	511	639	767	1023								
4	85	340	373	373	532	596	724	852	1108								
5	85	425	466	466	466	681	809	937	1193								
6	85	510	512	559	559	766	894	1022	1278								
7	85	595	512	652	652	652	979	1107	1363								
8	85	680	512	745	745	745	1064	1192	1448								
2	320	640	512	698	698	698	1024	1152	1408	1664	2176						
3	320	960	512	1024	1048	1048	1048	1472	1728	1984	2496						
4	320	1280	512	1024	1397	1397	1397	1397	2048	2304	2816	3328	4352	5376	7424		
5	320	1600	512	1024	1536	1746	1746	1746	1746	2624	3136	3648	4672	5696	7744		
6	320	1920	512	1024	1536	2048	2095	2095	2095	2944	3456	3968	4992	6016	8064		
7	320	2240	512	1024	1536	2048	2445	2445	2445	2445	3776	4288	5312	6336	8384		
8	320	2560	512	1024	1536	2048	2794	2794	2794	2794	4096	4608	5632	6656	8704	10752	14848
2	640	1280	512	1024	1397	1397	1397	1397	2048	2304	2816						
3	640	1920	512	1024	1536	2048	2095	2095	2095	2944	3456						
4	640	2560	512	1024	1536	2048	2794	2794	2794	2794	4096	4608	5632	6656	8704		
5	640	3200	512	1024	1536	2048	3072	3492	3492	3492	3492	5248	6272	7296	9344		
6	640	3840	512	1024	1536	2048	3072	4096	4191	4191	4191	5888	6912	7936	9984		
7	640	4480	512	1024	1536	2048	3072	4096	4889	4889	4889	4889	7552	8576	10624		
8	640	5120	512	1024	1536	2048	3072	4096	5588	5588	5588	5588	8192	9216	11264	13312	17408
2	1280	2560	512	1024	1536	2048	2794	2794	2794	2794	4096						
3	1280	3840	512	1024	1536	2048	3072	4096	4191	4191	4191						
4	1280	5120	512	1024	1536	2048	3072	4096	5588	5588	5588	5588	8192	9216	11264		
5	1280	6400	512	1024	1536	2048	3072	4096	6144	6985	6985	6985	6985	10496	12544		
6	1280	7680	512	1024	1536	2048	3072	4096	6144	8192	8382	8382	8382	11776	13824		
7	1280	8960	512	1024	1536	2048	3072	4096	6144	8192	9779	9779	9779	9779	15104		
8	1280	10240	512	1024	1536	2048	3072	4096	6144	8192	11176	11176	11176	11176	16384	18432	22528
10	1280	12800	512	1024	1536	2048	3072	4096	6144	8192	12288	13970	13970	13970	13970	20992	25088
12	1280	15360	512	1024	1536	2048	3072	4096	6144	8192	12288	16384	16764	16764	16764	23552	27648
14	1280	17920	512	1024	1536	2048	3072	4096	6144	8192	12288	16384	19558	19558	19558	19558	30208
16	1280	20480	512	1024	1536	2048	3072	4096	6144	8192	12288	16384	22352	22352	22352	22352	32768

*Numbers in green indicate that the full capacity of DRAM and Intel® Optane™ memory can be used.

Table 3: Performance-optimized Software-defined Memory (SDM) capacity for Intel® Optane™ SSDs and Intel® Xeon® Scalable Processors

Optimized	DRAM	Sockets	2	2	2	2	2	4	4	4	4	4	8	8	8	8	8
		Channels	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
		DPC	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
		DIMM size (GiB)	8	8	16	32	64	8	8	16	32	64	8	8	16	32	64
Devices	Device Size (GiB)	Total size (GiB)	96	192	384	768	1536	192	384	768	1536	3072	384	768	1536	3072	6144
2	85	170	266	362	554	938											
3	85	255	279	447	639	1023											
4	85	340	373	532	724	1108											
5	85	425	466	466	809	1193											
6	85	510	559	559	894	1278											
7	85	595	652	652	979	1363											
8	85	680	745	745	1064	1448											
2	320	640	698	698	1024	1408	2176										
3	320	960	768	1048	1048	1728	2496										
4	320	1280	768	1397	1397	2048	2816	1397	1397	2048	2816	4352					
5	320	1600	768	1536	1746	1746	3136	1536	1746	1746	3136	4672					
6	320	1920	768	1536	2095	2095	3456	1536	2095	2095	3456	4992					
7	320	2240	768	1536	2445	2445	3776	1536	2445	2445	3776	5312					
8	320	2560	768	1536	2794	2794	4096	1536	2794	2794	4096	5632	2794	2794	4096	5632	8704
2	640	1280	768	1397	1397	2048	2816										
3	640	1920	768	1536	2095	2095	3456										
4	640	2560	768	1536	2794	2794	4096	1536	2794	2794	4096	5632					
5	640	3200	768	1536	3072	3492	3492	1536	3072	3492	3492	6272					
6	640	3840	768	1536	3072	4191	4191	1536	3072	4191	4191	6912					
7	640	4480	768	1536	3072	4889	4889	1536	3072	4889	4889	7552					
8	640	5120	768	1536	3072	5588	5588	1536	3072	5588	5588	8192	3072	5588	5588	8192	11264
2	1280	2560	768	1536	2794	2794	4096										
3	1280	3840	768	1536	3072	4191	4191										
4	1280	5120	768	1536	3072	5588	5588	1536	3072	5588	5588	8192					
5	1280	6400	768	1536	3072	6144	6985	1536	3072	6144	6985	6985					
6	1280	7680	768	1536	3072	6144	8382	1536	3072	6144	8382	8382					
7	1280	8960	768	1536	3072	6144	9779	1536	3072	6144	9779	9779					
8	1280	10240	768	1536	3072	6144	11176	1536	3072	6144	11176	11176	3072	6144	11176	11176	16384
10	1280	12800	768	1536	3072	6144	12288	1536	3072	6144	12288	13970	3072	6144	12288	13970	13970
12	1280	15360	768	1536	3072	6144	12288	1536	3072	6144	12288	16764	3072	6144	12288	16764	16764
14	1280	17920	768	1536	3072	6144	12288	1536	3072	6144	12288	19558	3072	6144	12288	19558	19558
16	1280	20480	768	1536	3072	6144	12288	1536	3072	6144	12288	22352	3072	6144	12288	22352	22352

*Numbers in green indicate that the full capacity of DRAM and Intel® Optane™ memory can be used.

Table 4: Maximum Software-defined Memory (SDM) capacity for Intel® Optane™ SSDs and Intel® Xeon® E5 v3/v4 processors

Max		Sockets	2	2	2	2	2	2	2	2	2	4	4	4	4	8	8
	DRAM	Channels	4	4	4	4	4	4	4	4	4	8	8	8	8	8	8
		DPC	1	2	3	2	3	2	3	2	3	2	3	2	3	2	3
		DIMM size (GiB)	8	8	8	16	16	32	32	64	64	32	32	64	64	64	64
Devices	Device Size (GiB)	Total size (GiB)	64	128	192	256	384	512	768	1024	1536	2048	3072	4096	6144	8192	12288
2	85	170	234	298	362	426	554	682	938								
3	85	255	319	383	447	511	639	767	1023								
4	85	340	404	468	532	596	724	852	1108								
5	85	425	489	553	617	681	809	937	1193								
6	85	510	574	638	702	766	894	1022	1278								
7	85	595	659	723	787	851	979	1107	1363								
8	85	680	744	808	872	936	1064	1192	1448								
1	320	320	384	448	512	576	704	832	1088	1344	1856	2368	3392	4416	6464	8512	12608
2	320	640	704	768	832	896	1024	1152	1408	1664	2176	2688	3712	4736	6784	8832	12928
3	320	960	1024	1088	1152	1216	1344	1472	1728	1984	2496	3008	4032	5056	7104	9152	13248
4	320	1280	1344	1408	1472	1536	1664	1792	2048	2304	2816	3328	4352	5376	7424	9472	13568
5	320	1600	1664	1728	1792	1856	1984	2112	2368	2624	3136	3648	4672	5696	7744	9792	13888
6	320	1920	1984	2048	2112	2176	2304	2432	2688	2944	3456	3968	4992	6016	8064	10112	14208
7	320	2240	2304	2368	2432	2496	2624	2752	3008	3264	3776	4288	5312	6336	8384	10432	14528
8	320	2560	2624	2688	2752	2816	2944	3072	3328	3584	4096	4608	5632	6656	8704	10752	14848
1	640	640	704	768	832	896	1024	1152	1408	1664	2176	2688	3712	4736	6784	8832	12928
2	640	1280	1344	1408	1472	1536	1664	1792	2048	2304	2816	3328	4352	5376	7424	9472	13568
3	640	1920	1984	2048	2112	2176	2304	2432	2688	2944	3456	3968	4992	6016	8064	10112	14208
4	640	2560	2624	2688	2752	2816	2944	3072	3328	3584	4096	4608	5632	6656	8704	10752	14848
5	640	3200	3264	3328	3392	3456	3584	3712	3968	4224	4736	5248	6272	7296	9344	11392	15488
6	640	3840	3904	3968	4032	4096	4224	4352	4608	4864	5376	5888	6912	7936	9984	12032	16128
7	640	4480	4032	4608	4672	4736	4864	4992	5248	5504	6016	6528	7552	8576	10624	12672	16768
8	640	5120	4032	5248	5312	5376	5504	5632	5888	6144	6656	7168	8192	9216	11264	13312	17408
1	1280	1280	1344	1408	1472	1536	1664	1792	2048	2304	2816	3328	4352	5376	7424	9472	13568
2	1280	2560	2624	2688	2752	2816	2944	3072	3328	3584	4096	4608	5632	6656	8704	10752	14848
3	1280	3840	3904	3968	4032	4096	4224	4352	4608	4864	5376	5888	6912	7936	9984	12032	16128
4	1280	5120	4032	5248	5312	5376	5504	5632	5888	6144	6656	7168	8192	9216	11264	13312	17408
5	1280	6400	4032	6528	6592	6656	6784	6912	7168	7424	7936	8448	9472	10496	12544	14592	18688
6	1280	7680	4032	7808	7872	7936	8064	8192	8448	8704	9216	9728	10752	11776	13824	15872	19968
7	1280	8960	4032	8064	9152	9216	9344	9472	9728	9984	10496	11008	12032	13056	15104	17152	21248
8	1280	10240	4032	8064	10432	10496	10624	10752	11008	11264	11776	12288	13312	14336	16384	18432	22528
10	1280	12800	4032	8064	12096	13056	13184	13312	13568	13824	14336	14848	15872	16896	18944	20992	25088
12	1280	15360	4032	8064	12096	15616	15744	15872	16128	16384	16896	17408	18432	19456	21504	23552	27648
14	1280	17920	4032	8064	12096	16128	18304	18432	18688	18944	19456	19968	20992	22016	24064	26112	30208
16	1280	20480	4032	8064	12096	16128	20864	20992	21248	21504	22016	22528	23552	24576	26624	28672	32768

*Numbers in green indicate that the full capacity of DRAM and Intel® Optane™ memory can be used.

Table 5: Maximum Software-defined Memory (SDM) capacity for Intel® Optane™ SSDs and Intel® Xeon® Scalable Processors

Optimized	DRAM	Sockets	2	2	2	2	2	4	4	4	4	4	8	8	8	8	8
		Channels	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
		DPC	1	2	2	2	2	1	2	2	2	2	1	2	2	2	2
		DIMM size (GiB)	8	8	16	32	64	8	8	16	32	64	8	8	16	32	64
Devices	Device Size (GiB)	Total size (GiB)	96	192	384	768	1536	192	384	768	1536	3072	384	768	1536	3072	6144
2	320	640	736	832	1024	1408	2176										
3	320	960	1056	1152	1344	1728	2496										
4	320	1280	1376	1472	1664	2048	2816	1472	1664	2048	2816	4352					
5	320	1600	1696	1792	1984	2368	3136	1792	1984	2368	3136	4672					
6	320	1920	2016	2112	2304	2688	3456	2112	2304	2688	3456	4992					
7	320	2240	2336	2432	2624	3008	3776	2432	2624	3008	3776	5312					
8	320	2560	2656	2752	2944	3328	4096	2752	2944	3328	4096	5632	2944	3328	4096	5632	8704
2	640	1280	1376	1472	1664	2048	2816										
3	640	1920	2016	2112	2304	2688	3456										
4	640	2560	2656	2752	2944	3328	4096	2752	2944	3328	4096	5632					
5	640	3200	3296	3392	3584	3968	4736	3392	3584	3968	4736	6272					
6	640	3840	3936	4032	4224	4608	5376	4032	4224	4608	5376	6912					
7	640	4480	4576	4672	4864	5248	6016	4672	4864	5248	6016	7552					
8	640	5120	5216	5312	5504	5888	6656	5312	5504	5888	6656	8192	5504	5888	6656	8192	11264
2	1280	2560	2656	2752	2944	3328	4096										
3	1280	3840	3936	4032	4224	4608	5376										
4	1280	5120	5216	5312	5504	5888	6656	5312	5504	5888	6656	8192					
5	1280	6400	6048	6592	6784	7168	7936	6144	6784	7168	7936	9472					
6	1280	7680	6048	7872	8064	8448	9216	6144	8064	8448	9216	10752					
7	1280	8960	6048	9152	9344	9728	10496	6144	9344	9728	10496	12032					
8	1280	10240	6048	10432	10624	11008	11776	6144	10624	11008	11776	13312	6336	11008	11776	13312	16384
10	1280	12800	6048	12096	13184	13568	14336	6144	12288	13568	14336	15872	6336	12672	14336	15872	18944
12	1280	15360	6048	12096	15744	16128	16896	6144	12288	16128	16896	18432	6336	12672	16896	18432	21504
14	1280	17920	6048	12096	18304	18688	19456	6144	12288	18688	19456	20992	6336	12672	19456	20992	24064
16	1280	20480	6048	12096	20864	21248	22016	6144	12288	21248	22016	23552	6336	12672	22016	23552	26624

*Numbers in green indicate that the full capacity of DRAM and Intel® Optane™ memory can be used.

§

9 Performance and Benchmarking

Like with any technology, there are correct and incorrect ways to use Intel® Memory Drive Technology. This chapter describes best-practices for using Intel® Memory Drive Technology in order to achieve the best possible performance out of a system using Intel® Memory Drive Technology, for a given hardware configuration.

9.1 End User License Agreement

Please be sure to read the End User License Agreement (EULA) before executing or publishing benchmark results, to make sure you are complying with all rules and regulations. A copy of the EULA can be found here: www.memorydrv.com/EULA

9.2 Setting up the Hardware and Software Stacks

Please make sure to follow the manufacturer's manual with regards to optimal system configuration for performance (e.g. number of DIMMs per channel, BIOS performance settings, etc.)

Please make sure to follow the guidelines listed in section of "Recommended Hardware Configuration"8.3, so that the hardware will be properly set up. Further, please make sure you follow the rest of the guidelines in "9 Workload and Platform Selection" with regards to fitting classes of workload to use with Intel® Memory Drive Technology, OS and memory allocator settings, application settings, etc.

Once the hardware is ready, please keep in mind:

1. If using multiple machines for benchmark/comparison, there should not be any difference between the machines other than the amount of DRAM (for example, OS version and settings, BIOS version and settings, etc. must all be the same).
2. If using the same machine for comparing Intel® Memory Drive Technology to non- Intel® Memory Drive Technology, then either (1) use the software options to limit the amount of DRAM available to Intel® Memory Drive Technology (See section "System Settings and Diagnostics", under "System Settings" for "Board Memory" settings), or, (2) if you prefer to physically reduce the amount of memory on the server, please make sure that you keep an optimized setup (if you are reducing 768GB in 24 x 32GB DIMMs to have only 128GB, make sure that you follow Intel's guidelines for your server model in terms of DIMM population (you will need to use multiple smaller DIMMs to populate same number of channels etc.)

9.3 Optimized Workload Settings

This section lists generic recommendations for software stack setup in an environment using Intel® Memory Drive Technology

9.3.1 Memory Settings, Memory Allocators

It is recommended that memory allocators be configured to use large pages (as example Linux Transparent Huge Pages (THP)), while correctly configuring them to (1) save on memory use, and (2) avoid memory fragmentation. For example, if your application was precompiled with the default libc allocator or with jemalloc, or makes use of them using the OS dynamic linker, please use the following guidelines:

1. For jemalloc, ensure THP operation is maintained by running the command:

```
# ln -sf 'lg_dirty_mult:-1' /etc/malloc.conf
```

2. For libc, the following environment variables may be useful to increase memory allocation size by the application, and to reduce virtualization overheads:

```
# export MALLOC_TOP_PAD_=$((16777216))
# export MALLOC_TRIM_THRESHOLD_=$((16777216))
```

9.3.2 Application Settings

Parallelism or concurrency yield great benefits with Intel® Memory Drive Technology. Make sure your application is configured to use many threads where available, in order to process data. CPU over-subscription increases the throughput of the product, as it allows issuing multiple fetch requests from the Intel® Optane™ SSD concurrently.

9.4 Out-of-the-box Workloads

In order to easily test the performance of the system, an out-of-the-box workload is provided.

9.4.1 Large Memory Compute Intensive Workload

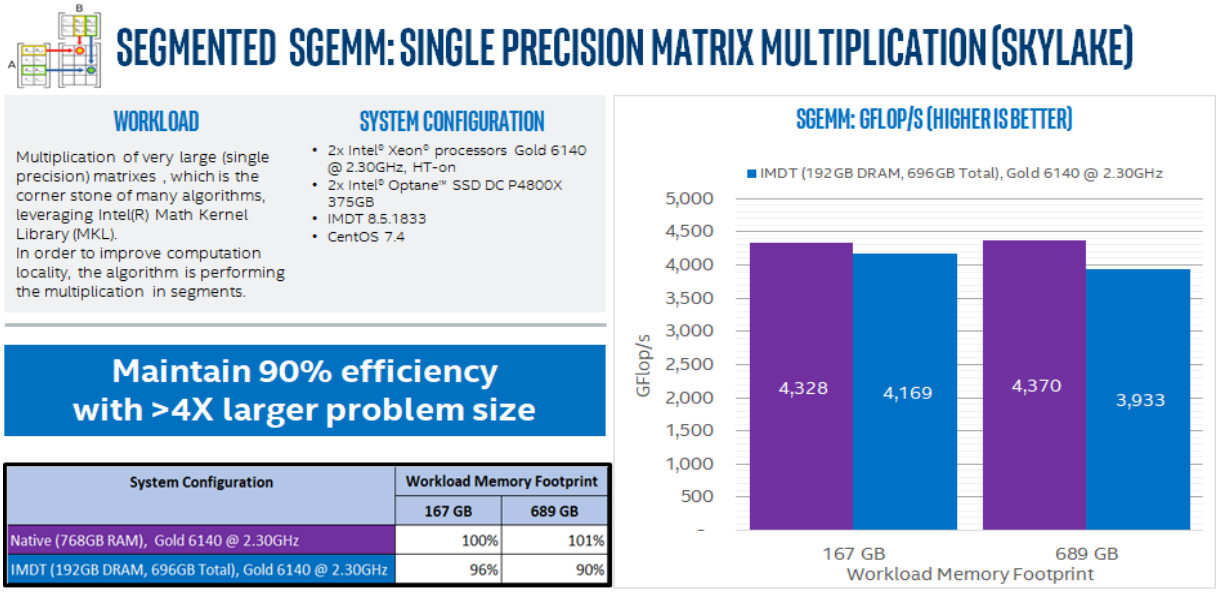
This large memory workload demonstrates multiplication of very large matrices, which is the corner stone of many algorithms, leveraging Intel® Math Kernel Library (MKL).

The workload can be used to test your system performance for:

- **Memory Replacement:** Performing an "apples-to-apples" comparison of (1) a "Native" (i.e. DRAM only) system, with (2) a system using lower DRAM augmented with Intel® Optane™ SSD and Intel® Memory Drive Technology, where "(2)" would be a cost-effective alternative to DRAM
- **Memory Expansion:** validate that a workload with a memory footprint higher than DRAM capacity can successfully execute with near-DRAM performance by expanding the system memory with Intel® Optane™ SSDs and Intel® Memory Drive Technology

To perform the test:

1. Obtain and configure the publicly available workload (See https://github.com/ScaleMP/SEG_SGEMM)
2. Run the workload on a "Native" (i.e. DRAM only) system, and collect the results
3. Run the workload on a system with Intel® Optane™ SSDs and Intel® Memory Drive Technology configured, and collect the results



9.5 Intel® Memory Drive Technology Tuning

Virtually all server systems these days use Non-Uniform Memory Architecture (NUMA). By default, most Xeon-based servers would present N number of NUMA nodes where N is the number of Xeon sockets in the system. While this architecture is widespread, some applications were programmed to be NUMA-aware, while others are not, and some applications execute faster with a lower number of NUMA domain. The default for Intel® Memory Drive Technology is to present N+1 NUMA domains (the existing N on the server, plus the added memory from Intel® Optane™ SSD and Intel® Memory Drive Technology). Use "**Expand local memory domains**" in F5 (System Settings) to reduce the number of NUMA nodes from N+1 to N. Some Linux kernels may not support allocation of hugepages for the added node, and use of hugepages is recommended with Intel® Memory Drive Technology for popular applications, such as Oracle.

Additionally, some applications are inherently not-NUMA aware, for example serial applications having only one execution thread. For this kind of applications, it is recommended that you execute the following command to disable NUMA awareness (the below is not needed when using "**Expand local memory domains**" in F5 - System Settings):

```
# idmtctl --nna=on
```

9.6 Performance Data Collection

Intel® Memory Drive Technology provides tools for collecting performance-related statistics. The tools are installed into /usr/local/{etc,bin} on the machine the installer was running on. To manually install the tools see "Installing Intel Memory Drive Technology Tools" section.

To activate periodic statistics data collection, use the following command, which records the counters every 60 seconds into a /tmp/stats (make sure this directory is not ramfs/tmpfs, but rather a directory located on a direct-attached storage device):

```
# mkdir /tmp/stats; cd /tmp/stats; imdtstat --outfile 60
```

To start the performance collection at boot, add the following to your crontab file (with crontab -e):

```
@reboot     (cd /tmp/stats && /usr/local/bin/imdtstat --outfile 60)
```

After workload is completed, share a zipped/tar archive of the files collected, or the target directory (/tmp/stats in the example above), and share it with the Intel support team.

9.7 Benchmarking Methodology

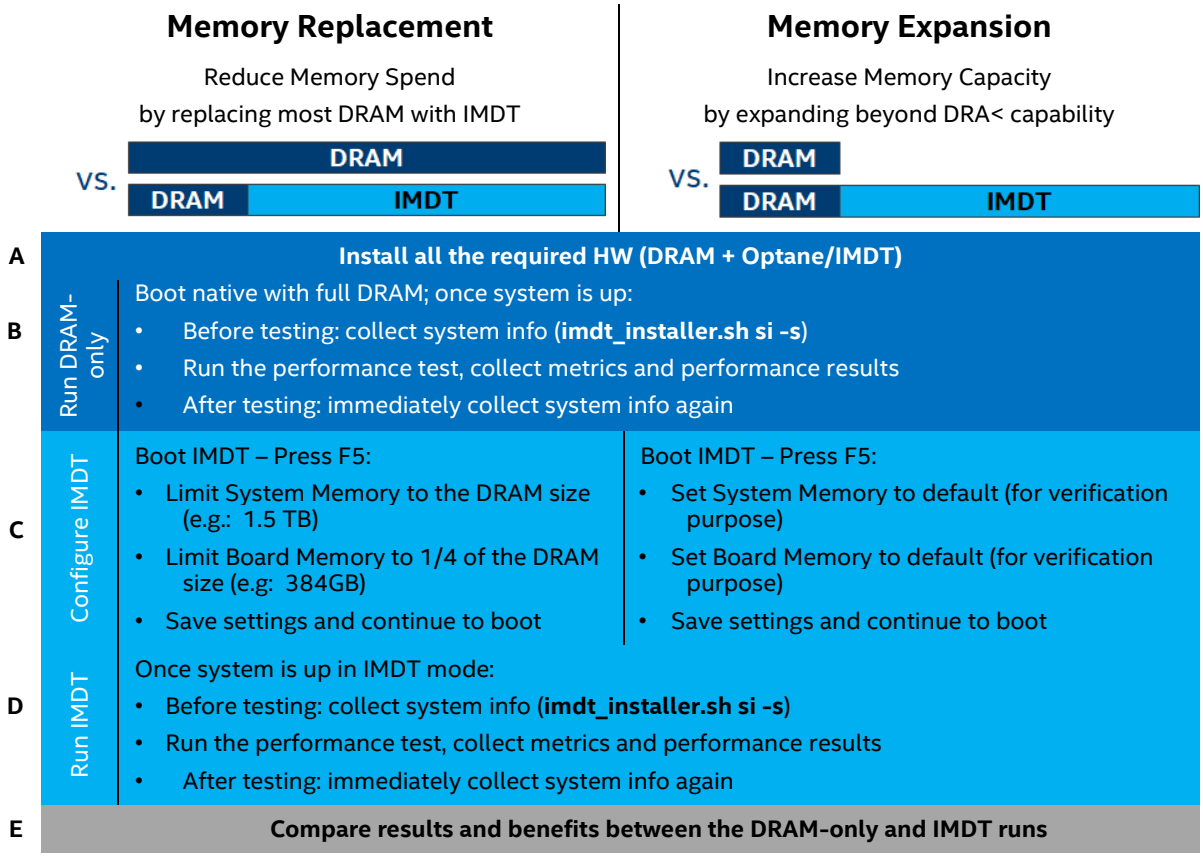
The combination of Intel® Optane™ SSD and Intel® Memory Drive Technology is aimed at providing DRAM-like functionality and performance. In light of that, there are two main relevant user benefits:

- **Reduce** memory spend: by replacing most DRAM with IMDT -> **Memory Replacement**
- **Increase** memory capacity: by expanding beyond DRAM capacity -> **Memory Expansion**

This section provides detailed instructions on benchmarking each use case.

Memory Replacement	Memory Expansion
Reduce Memory Spend by replacing most DRAM with IMDT 	Increase Memory Capacity by expanding beyond DRA< capability 
In cases where an application requires a large amount of memory, which can still be accomplished using DRAM but for a high cost; it is possible replace most of that DRAM with IMDT to achieve a significantly improved overall solution cost. In order to benchmark such a scenario, an "apples-to-apples" comparison is suitable, where the same system should be used, where a DRAM-only configuration (e.g. 1.5TB DRAM), would be compared to a 4x expansion (384GB DRAM + 2 X 640GB IMDT devices). Achieving near DRAM performance, would demonstrate significant cost savings. To ensure apples-to-apples comparison, it is important to use the same number of DIMMs, to achieve the same memory bandwidth; this can be obtained by using smaller DIMMs, or in an easier way to reduce the amount of DRAM used as a system configuration parameter (See Setting up the Hardware and Software Stacks").	In certain cases, an application requires that all data would reside in-memory, otherwise it would not be able to process it (e.g. in-memory databases). In other cases, although an application does not fit into the memory of one server, it is possible for the application to span across multiple servers, but this results in low utilization of CPUs and/or I/O. The goal here is to demonstrate that a server with higher amount of memory (i.e. expanded with IMDT), can successfully run the workload that is otherwise not possible to run on a server with a smaller amount of memory, and while doing so within acceptable level of performance.
To evaluate DRAM vs. IMDT, use the same machine for comparison	
• Ensure optimal hardware configuration (DIMMs per channel, etc.) • Control DRAM usage via IMDT settings (total memory should be Identical)	• Successfully complete running large workload with IMDT, while failing with DRAM-only • Ability to increased CPU utilization, get more done on same node (e.g. run more VMs on it)

9.7.1 Detailed steps



9.7.2 Expected Result Spectrum

Intel® Memory Drive Technology was architected, designed, and implemented to provide close-to-DRAM performance. Thus, most testing and validation is focused on comparing the performance of specific workloads when using a DRAM-only system (a.k.a. "Native" or "bare-metal" system) and a system using mixed DRAM and Intel® Memory Drive Technology. The native setup serves as a "glass ceiling" of sorts and Intel® Memory Drive Technology is expected to deliver at least 75% of that performance for fitting workloads (Intel® Memory Drive Technology has even shown to sometimes perform even better than DRAM for some workloads).

While some customers focus on the performance of the workload, it is also commonplace to see benchmarks focus on value, e.g. price/performance, overall cost reduction/savings, etc. For example, a customer might wish to compute the overall cost to run a given application requiring 40TB of memory and generating a minimal throughput of 10M transactions per second.

9.7.3 Choice of Workload for Benchmark

Review "Workloads that Benefit Most from Intel® Memory Drive Technology" section of this document; it is recommended that you ensure that your intended workload indeed qualifies as a workload fitting use of Intel® Memory Drive Technology. Additionally, make sure that you have all the information needed to optimally configure your workload (increase thread-count, etc.)

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10 Uninstalling Intel® Memory Drive Technology

To use Intel® Optane™ SSDs as storage devices, after they were used with Intel® Memory Drive Technology, change the boot order to load the operating system instead of loading Intel® Memory Drive Technology (which was loaded either from USB Flash Drive or the NVMe drives). You may need to format the device to remove partitions created by Intel® Memory Drive Technology installer.

The Intel® Memory Drive Technology Tools require manual removal. Use the command below to remove Intel® Memory Drive Technology Tools

```
# rm /usr/local/{bin,etc}/imdt*
```

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11 Specifications

Capacity	85GiB, 320GiB, 640GiB, 1.28TiB[1,2]
Form Factors	PCIe* 3.0 x4 Add-in-Card (AIC); Half-height, Half-length, Low-profile U.2 (2.5-inch x 15mm height)
Boot Option	Intel® Memory Drive Technology software[3] supports UEFI boot, or alternatively requires a bootable media. Supported protocols: IDE, UHCI, and EHCI.
Operating Systems	Intel Memory Drive Technology supports Legacy and UEFI Mode for the operating system. RHEL/CentOS* 6.5, 6.6, 6.7, 6.8, 6.9, 7.0, 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7 SLES* 11 SP4, 12, 12 SP1, 12 SP2 Ubuntu* 16.04-18.10 For an updated list of operating systems, please refer to latest release notes (imdt-x.x.x.x.rel_notes.pdf) at: https://www.memorydrv.com/downloads/latest Intel® Memory Drive Technology software[3] supports UEFI boot, or alternatively requires a bootable media. Supported protocols: IDE, UHCI, and EHCI.
Operating Systems (Basic installation and compatibility)	Open SuSE: ver. 10 to 11 (SUSE10-11)
Operating Systems (Basic installation)	Fedora* Core: ver. 4 to 29 (FC4-29) Citrix XenServer: 7.5 (XEN)
Supported Processors	Intel® Core™ i7-98xx, i7-78xx Intel® Core™ i9-99xx, i9-98xx, i9-79xx Intel® Xeon® E5-x6xx v3 or later, E7-x8xx v3 or later Intel® Xeon® Processor Scalable Performance Family
Maximum Processor Sockets	8
Maximum Software-defined Memory	64 TiB[1]
Recommended DRAM Expansion	Up to 8x[4]
Power	Refer to Intel® Optane™ SSD P4800X Series Product Specification
Temperature Specification	Refer to Intel® Optane™ SSD P4800X Series Product Specification
Data Retention	Power off – Not Applicable, IMDT Memory is volatile.
Hot-plug	Hot-plug is not supported Other PCIe NVMe SSD hot plug support capability is same as non IMDT mode
Intel® VROC/VMD Technology	Supported
Compliance	Refer to Intel® Optane™ SSD P4800X Series Product Specification
Certifications and Declarations	UL*, CE*, C-Tick*, BSMI*, KCC*, VCCI*, CAN/CSA*
Product Ecological Compliance	RoHS*, WEEE*

NOTES:

1. GiB = 1,073,741,824 bytes, TiB = 1,099,511,627,776 bytes
2. Total physical capacity is 375GB or 750GB. Total usable capacity towards extended memory is 320 GiB or 640 GiB respectively.
3. Technology licensed from ScaleMP*
4. For example: 128GiB DRAM can be expanded up to 1024GiB based on the capacity of NVMe media installed. Higher expansion ratios may be supported, with possibly suboptimal performance
5. Local ambient temperature is measured at the inlet to the SSD
6. LFM (Linear Feet per Minute) airflow measured at the approach area of the SSD
7. CFM (Cubic Feet per Minute) airflow measured at the approach area of the SSD
8. Please contact your Intel representative for details on the non-operating temperature range

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