BIOS Performance and Power Tuning Guidelines for Dell PowerEdge 12th Generation Servers

Configuring the server BIOS for optimal performance and power efficiency

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Executive summary

Dell™ PowerEdge™ 12th generation servers offer many BIOS-level options in System Setup that can affect the performance of various workload types and drive significant impacts for power efficiency. Due to the expanded array of features from the Intel® Xeon® processor E5 family and Dell's enhanced platform offerings, navigating the System Setup screens can be a challenging task without understanding more about how various options can improve performance for some workloads; especially when performance and power efficiency trade-offs must be considered.

An understanding of specific BIOS options is crucial for tuning the server. This white paper measures the impact of many of these variables from a performance and power efficiency standpoint to provide general performance and power efficiency tuning guidelines. To help explain these guidelines and recommendations, this white paper lists various comparisons made between BIOS options affecting the memory subsystem, processor features, and System Profile.

Introduction

Dell PowerEdge 12th generation servers include the Intel Xeon processor E5-2400, E5-2600, and E5-4600 product families. These processor types bring up to eight cores per socket, faster memory subsystems up to 1600MT/s, up to four memory channels per socket, and PCI Express® 3.0 expansion slots. In addition, the inter-processor communication path known as Intel QuickPath Interconnect (QPI) now supports up to 8.0GT/s transfer speed.

This white paper focuses on the impact of BIOS options on a variety of general server workloads based in large part on standard industry server benchmarks. In addition, the various System Profile options available to the customer are compared from a performance and power standpoint. All testing was done on with the Intel Xeon processor E5-2600 product family, but most BIOS effects should be similar across 12th generation PowerEdge servers. The tuning guidelines in this white paper are aimed primarily at general enterprise customers, and are not applicable to specialized workloads such High Performance Computing (HPC) clusters.

BIOS features overview

This white paper focuses on three primary sections of the BIOS setup: Memory, Processor, and System Profile. Although other BIOS sections exist, these three are the primary focus areas for performance tuning, so this white paper covers these areas in-depth. Most of these BIOS options are common across 12th generation PowerEdge server platforms.

The Memory section of the BIOS Setup provides configuration options that affect the Memory Subsystem. Many of these options have a direct impact on performance or RAS features, so the key areas are covered. Elements such as Memory Mode and Node Interleaving are discussed in significant detail. See Memory Performance Guidelines for Dell PowerEdge 12th Generation Servers for a much more in-depth look at memory options and configuration guidance.

The Processor Settings Screen includes configuration options to manipulate various CPU-specific features, some of which require specific OS support to function correctly. Here, settings such as Logical Processor, Virtualization Technology, processor prefetchers, QPI Speed, and Number of Cores per Processor reside, which are explored below.

The System Profile Settings section is the last critical area for performance tuning focus. Here, the overall System Profile can be selected, which in turn governs the settings of many sub-options. These sub-options can have a great impact on overall system performance and power efficiency; so along with exploring overall System Profile choices, the impact of manipulating these sub-options are explored, which are only exposed when the Custom Power Profile is selected.

It is important to note that at the time of writing, the state of these sub-options depends on the last System Profile that was used, and that there is no true default for options such as Turbo Mode, C-States, C1E, Memory Frequency, and others found in this section.

Test methodology

Memory bandwidth was measured using a version of the common STREAM benchmark, developed by John McAlpin of the University of Virginia. The version used for this test was compiled with OpenMP (parallel) support and optimized for the new generation of Intel Xeon processors. When testing overall system memory bandwidth, optimal results are achieved by running the STREAM benchmark with one thread per physical core. Although STREAM uses four separate vector kernels during the course of measurement (Add, Scale, Copy, and Triad), the Triad value is used for the purposes of this white paper. STREAM results are returned in values of MB/sec.

Latency measurements were taken using the lat_mem_rd subtest, part of the LMBENCH benchmark. Lat_mem_rd measures memory read latency for varying memory sizes and strides. The results are reported in nanoseconds per load. The entire memory hierarchy is measured, including onboard cache latency and size, external cache latency and size, and main memory latency. For the purposes of this white paper, the focus is main memory latency. Both local and remote NUMA node main memory latency are explored with lat_mem_rd, localizing the process and forcing memory access to local or remote using the numactl tool in Linux. The last 20 lines of output from main memory measurements of lat_mem_rd are averaged, and each test is executed for three iterations. The median average result for each test type was selected to report latency results for this white paper.

In addition, the concept of "loaded latency" is explored for some configurations. This is intended to represent average memory latencies when the NUMA node is already under heavy load. The workload chosen to provide the heavy memory load is STREAM, and n-1 real cores on a single socket were used with separate single threaded STREAM processes to load the local NUMA node targeted for latency experiments. The single free core on the physical processor under test was tasked to run the latency measurement, measuring memory latency to the local NUMA node. As with other latency measurements, the last 20 lines of output were averaged to produce the final loaded latency value. Each loaded latency test was run three times, and the median loaded latency average was used for the official result.

SPECrate metrics from SPEC CPU2006 (hereafter referred to as SPECint_rate_base2006 and SPECfp_rate_base2006) were also chosen for performance characterization, as they are the leading industry standard CPU-centric benchmarks that use all available processor cores and threads. Each benchmark is comprised of multiple sub-benchmarks, each tailored to model different common computing tasks or scientific workloads, broken out into either integer or floating point. Both int_rate and fp_rate are throughput-based benchmarks. The "base" portion of the benchmark name indicates that a standardized set of compiler options were used to create the benchmark binaries. The SPECfp_rate_base2006 benchmark in particular can be used as a proxy for scientific workloads, and tends to be more sensitive to memory frequency and bandwidth differences than SPECint_rate_base2006. All CPU2006 measurements were conducted with the Novell® SUSE® Linux Enterprise Server (SLES) 11 SP2 operating system.

SPECjbb2005 evaluates the performance of server side Java by emulating a three-tier client/server system (with emphasis on the middle tier). The benchmark exercises the implementations of the JVM (Java Virtual Machine), JIT (Just-In-Time) compiler, garbage collection, threads and some aspects of the operating system. All logical processors on the system are exercised, and although considerable memory is allocated for the benchmark in the form of Java heap, this benchmark is generally less sensitive to memory frequency and bandwidth differences. SPECjbb2005 was run on the Microsoft® Windows Server® 2008 Enterprise Edition R2 SP1 operating system.

SPECpower_ssj2008 is the first industry standard performance-per-watt benchmark. Like SPECjbb2005, it is a Java-based benchmark with some workload similarities to JBB2005. However, the workload is run in different load levels, from 100% down to "active idle" in 10% increments. Active Idle is defined as a state where the system is ready to perform work, but there are no work requests. Performance and power data is collected for each workload interval using a separate benchmark controller system, an accepted power analyzer, and a temperature monitor. The controller system logs all power and temperature data, and communicates with the System under Test (SUT) to control workload levels and pull result files at the end of the benchmark run. SPECpower_ssj2008 was run on the Microsoft Windows Server 2008 Enterprise x64 Edition R2 SP1 operating system.

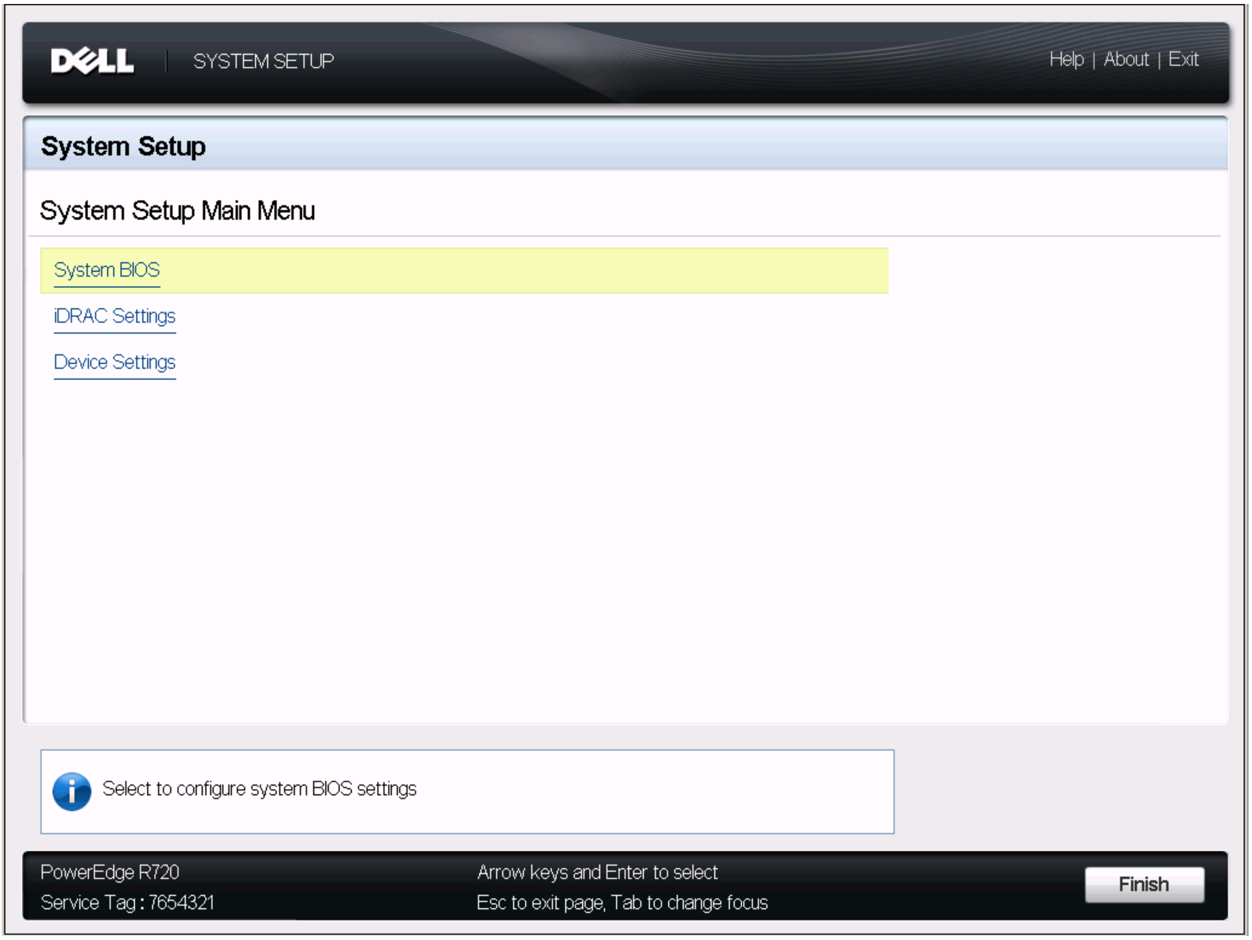
Power collection methodology

Power measurements were taken with a Yokogawa model WT210 Power Analyzer and power data was logged for all configurations tested for power consumption. The Yokogawa WT210 analyzer is the most popular power analyzer type at the time that this white paper was written that was used for the first industry standard Server Power/Performance Benchmark, SPECpower_ssj2008. The logged power data was averaged for the particular workloads that were characterized for power. Comparisons that used the SPECpower_ssj2008 benchmark required no manual intervention for power data analysis, as this benchmark integrates power collection at each load level.

BIOS Memory Settings section

The BIOS Setup screen is entered by pressing the F2 key during system power-on or reboot. The navigation interface has been considerably improved compared to previous generations of Dell PowerEdge servers, as the UEFI interface allows for both Keyboard and Mouse input. Figure 1 displays the System Setup Menu, the first menu presented to the user after pressing the F2 key. Select **System BIOS** to enter the BIOS setup screen.

Figure 1. System Setup screen



Select to configure system BIOS settings

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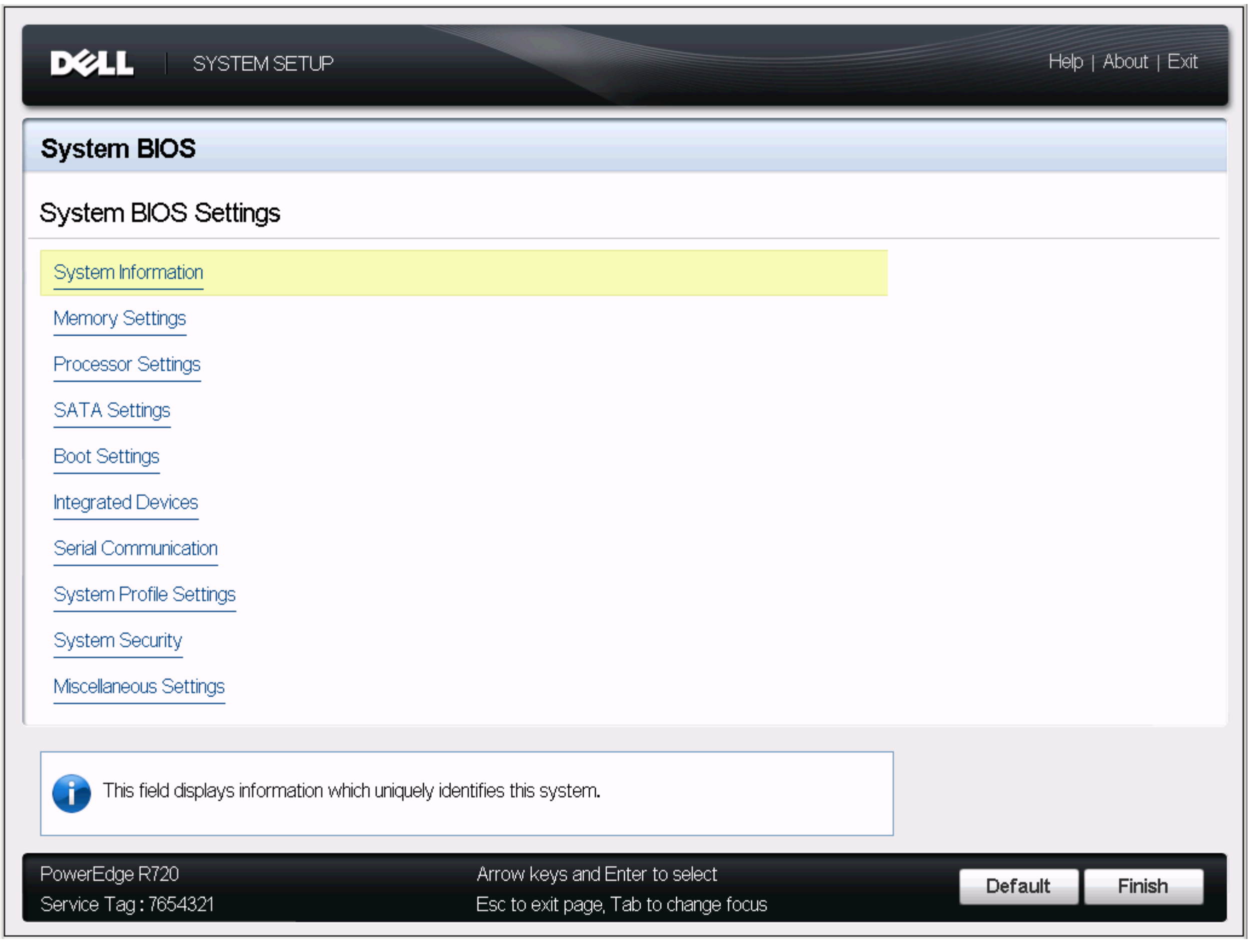
Arrow keys and Enter to select
Esc to exit page, Tab to change focus

Once the System BIOS entry has been selected, a new menu is displayed. This menu governs all system BIOS settings, and this is where all critical performance and power efficiency tuning takes place outside of OS tuning. This screen is broken up into multiple selections, each of which governs a separate set of BIOS options common to one another. There are three primary BIOS sub-menus that govern the primary options for performance and power efficiency tuning: Memory Settings, Processor Settings, and System Profile Settings. Each section is examined below.

Figure 2. System BIOS Settings screen



This field displays information which uniquely identifies this system.

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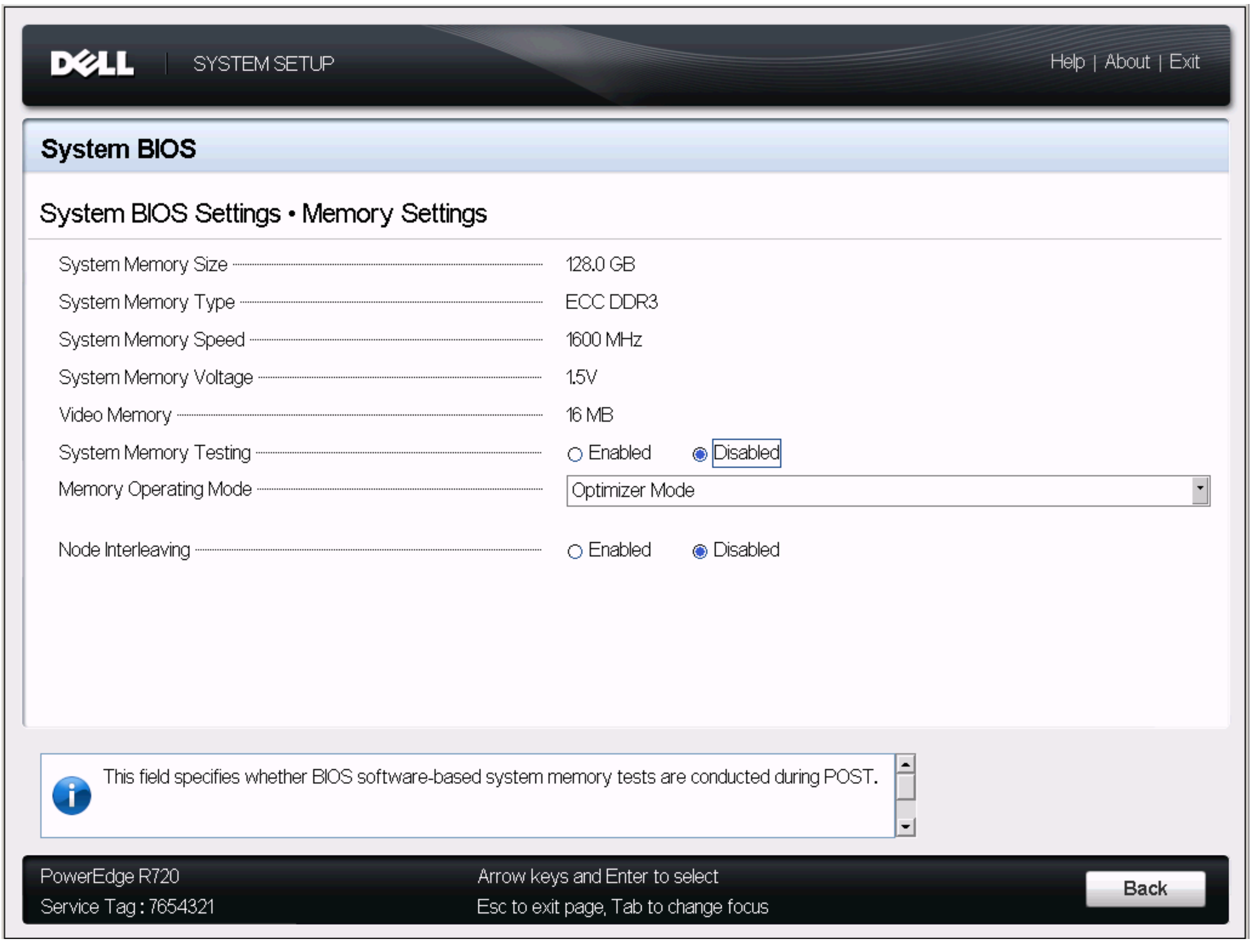
Arrow keys and Enter to select
Esc to exit page, Tab to change focus

Memory settings

The Memory Settings section of the System BIOS has two selections of interest for users wishing to tune for performance or power efficiency: **Memory Operating Mode** and **Node Interleaving**. Both of these settings can have a major impact on overall system performance, and are not generally considered power efficiency options. However, these selections can affect system performance and power.

Figure 3. Memory Settings screen



System BIOS

System BIOS Settings • Memory Settings

System Memory Size 128.0 GB

System Memory Type ECC DDR3

System Memory Speed 1600 MHz

System Memory Voltage 1.5V

Video Memory 16 MB

System Memory Testing ○ Enabled ● Disabled

Memory Operating Mode Optimizer Mode

Node Interleaving ○ Enabled ● Disabled

This field specifies whether BIOS software-based system memory tests are conducted during POST.

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Memory operating mode

Depending on how the server was ordered, the server can be running in one of several Memory Operating Modes at the time of purchase. It is important to understand the effects of these various modes from the standpoint of useable memory capacity, memory bandwidth and latency, due to their potential impact on overall application suitability and performance.

Overview of memory mode selections

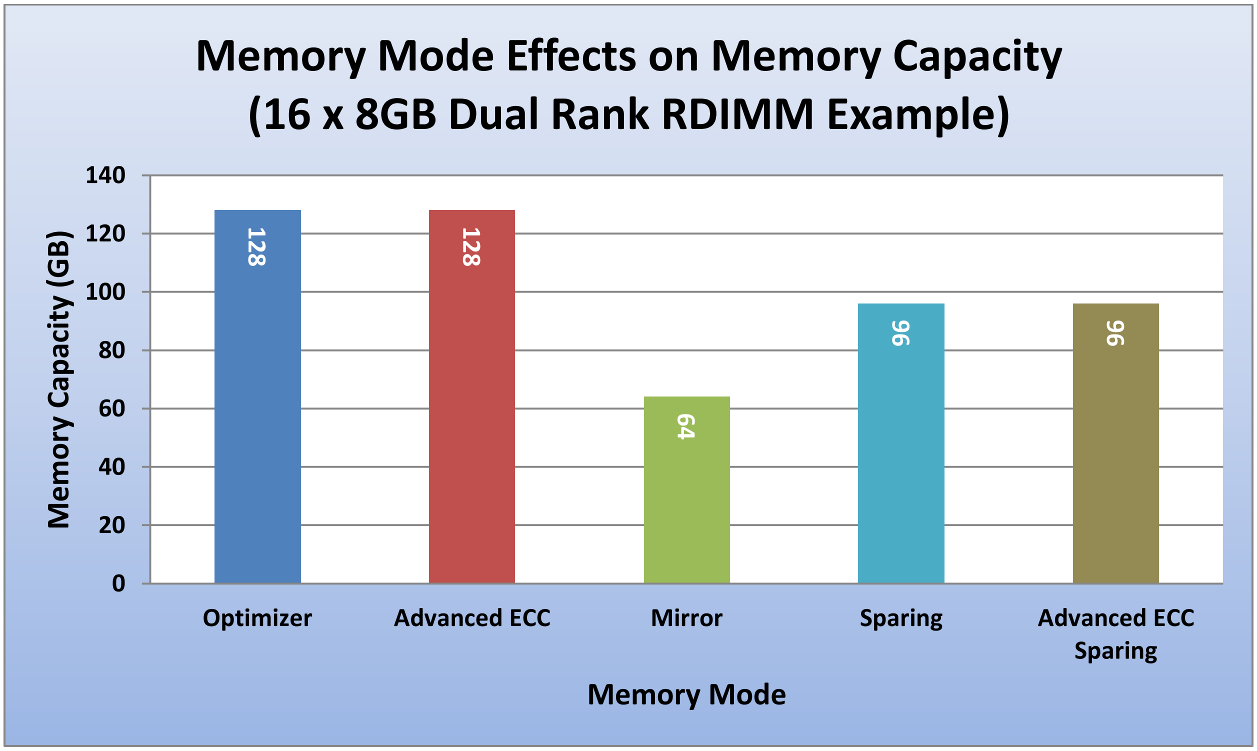
- **Optimizer Mode** — mode uses Independent channel configuration for highest memory subsystem performance. This is the default ordering configuration choice.
- **Advanced ECC Mode** — RAS feature that extends multi-bit single device error correction to x8 DRAMs, which runs pairs of memory channels in lockstep mode. There can be a substantial hit to memory performance when using this mode.
- **Spare Mode** — RAS feature that allocates one rank per channel as a spare to reduce the likelihood of correctable errors from becoming uncorrectable errors, but at a cost to memory capacity.
- **Mirror Mode** — RAS feature with paired memory channels that provide data and transmission fault-tolerance, but available memory capacity is reduced by 50 percent and system memory bandwidth will decline.

- **Spare with Advanced ECC Mode** — RAS feature that extends multi-bit single device error correction to x8 DRAMs, which runs pairs of memory channels in lockstep mode, where one memory rank per channel is used as a spare to reduce the likelihood of uncorrectable errors. There can be a substantial impact to memory performance when using this mode, and a cost to memory capacity.

If we examine the impact of memory mode selection on overall system memory available to the Operating System using a sample memory configuration of 128GB (16 x 8GB Dual Rank RDIMMs) in Figure 4, we see that both the Optimizer and Advanced ECC memory modes present all configured memory without any reduction in capacity. However, the Memory Mirror mode only presents half of the total configured memory to the operating system, and the two Sparing modes will reduce the total memory capacity based on the number of ranks populated per memory channel.

The Memory Sparing mode reserves one rank per channel to help reduce the chance of uncorrectable memory errors. Therefore, the capacity reduction for this mode is based on the total number of memory ranks populated in the system. To calculate the loss in capacity that Memory Sparing mode would cause, you must first determine the total memory capacity per channel (total populated DIMM capacity divided by the populated memory channel count), then divide this number with the total memory ranks per channel. This will give you the individual rank capacity. Multiply the individual rank capacity by n-1 total ranks per channel to give you the non-spared memory capacity per memory channel. Finally, multiply this number by the total memory channel count to get the actual usable memory capacity when rank sparing mode is enabled. The effect of this memory operating mode on overall memory capacity is dependent on the number, capacity, and rank of DIMMs populated in the system, and will necessarily vary with different memory populations.

Figure 4. Memory Mode performance



In Figure 5, we see the memory mode selection impact on overall system memory bandwidth. The common default of Optimizer mode provides the highest memory performance of the five memory modes available. Following closely behind is Memory Sparing mode, which provides 90% of the memory bandwidth available to the Optimizer mode. Advanced ECC mode and Advanced ECC with Sparing both measured significant impacts to memory bandwidth, providing only 55% and 52% of the memory bandwidth offered by the Optimizer mode respectively. A special case for memory bandwidth is the Memory Mirroring mode. Our measurements showed this mode obtained 76% of the overall bandwidth of Optimizer mode, but due to the underlying complexities of this mode, the user should consider that practical memory bandwidth that their application environment will operate in will likely be closer to 50% of the Optimizer mode.

Figure 5. Memory operating modes performance

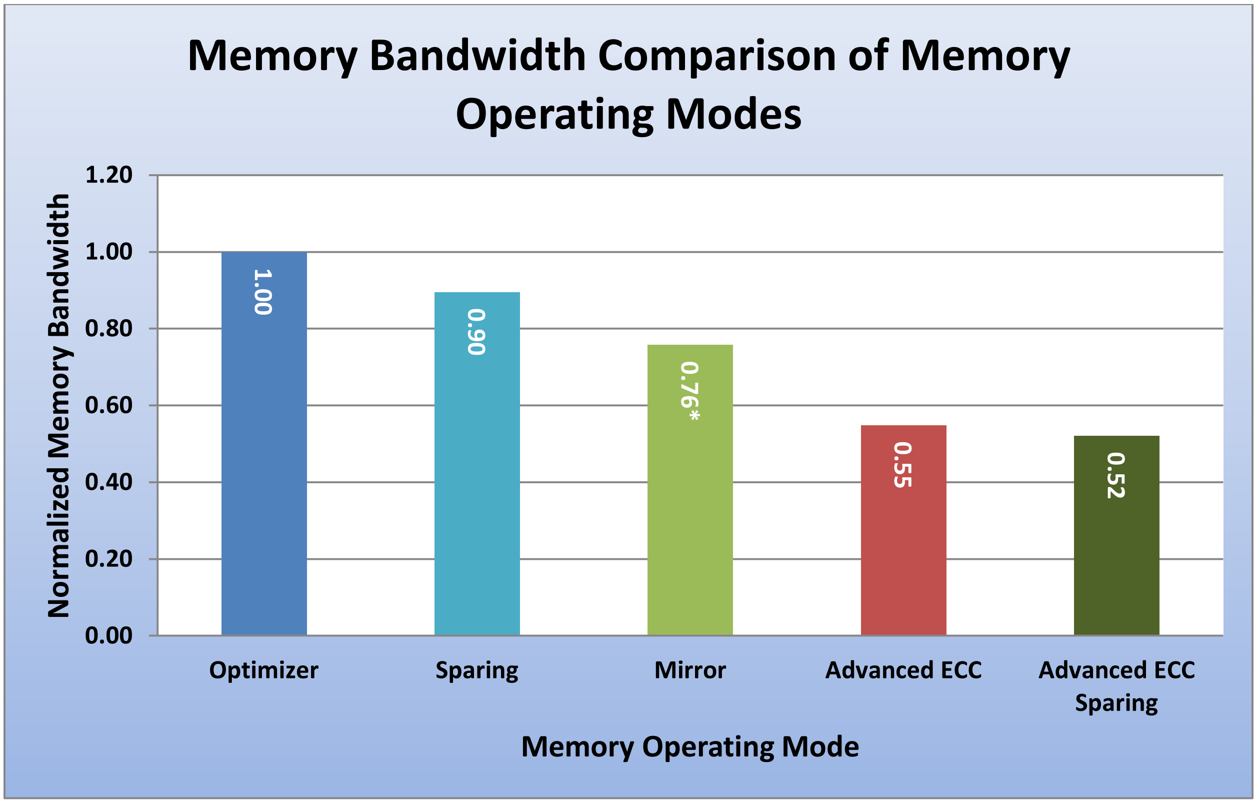
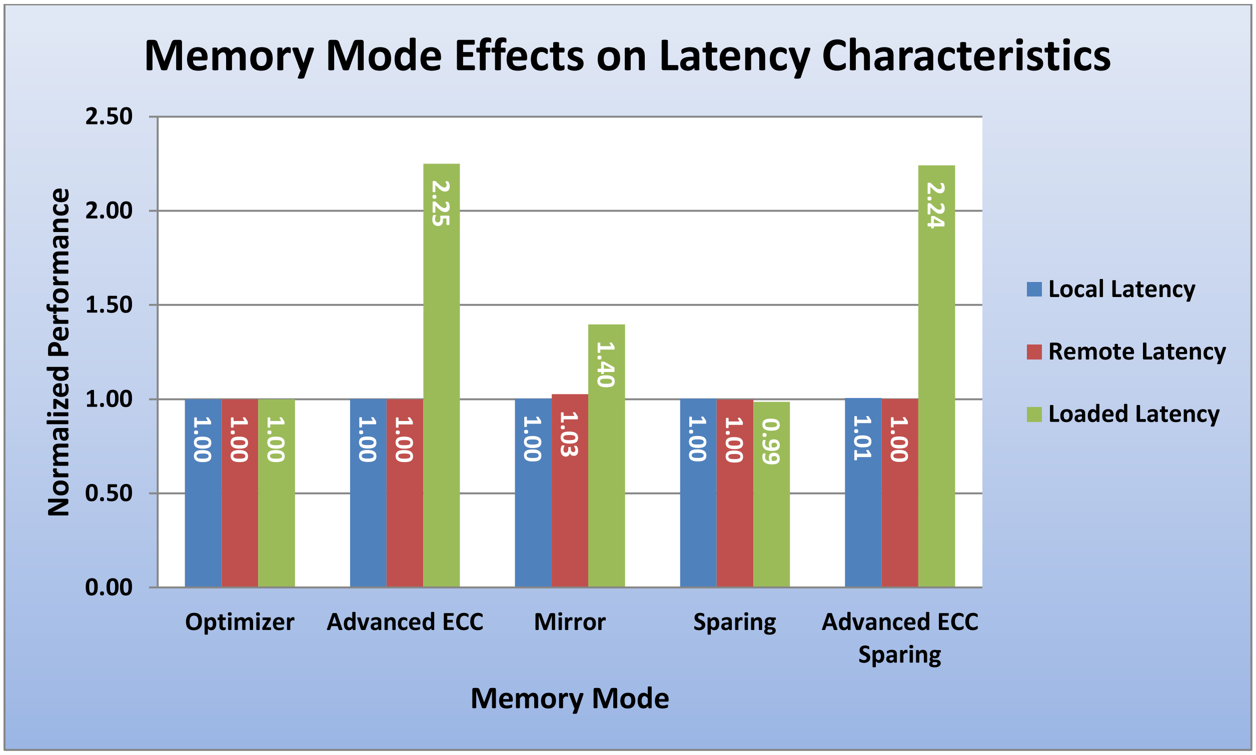


Figure 6 illustrates that local and remote latency are generally not affected significantly by changing the available Memory Operating Modes. For measures of memory latency (measured in nanoseconds), lower measurements are better. However, under the loaded latency test, we see that Advanced ECC, Mirror Mode, and Advanced ECC with Sparing all encounter considerably higher latencies than the other modes. For Advanced ECC mode, the latencies are approximately 225% that of Optimizer mode, suggesting that there is a reduction in memory bandwidth that is increasing queuing times and driving the loaded latency measurement upwards. Similarly, Advanced ECC with Sparing encounters a reduction in loaded latency of approximately the same magnitude. The Memory Mirror mode encounters loaded latencies approximately 40% higher than Optimizer mode.

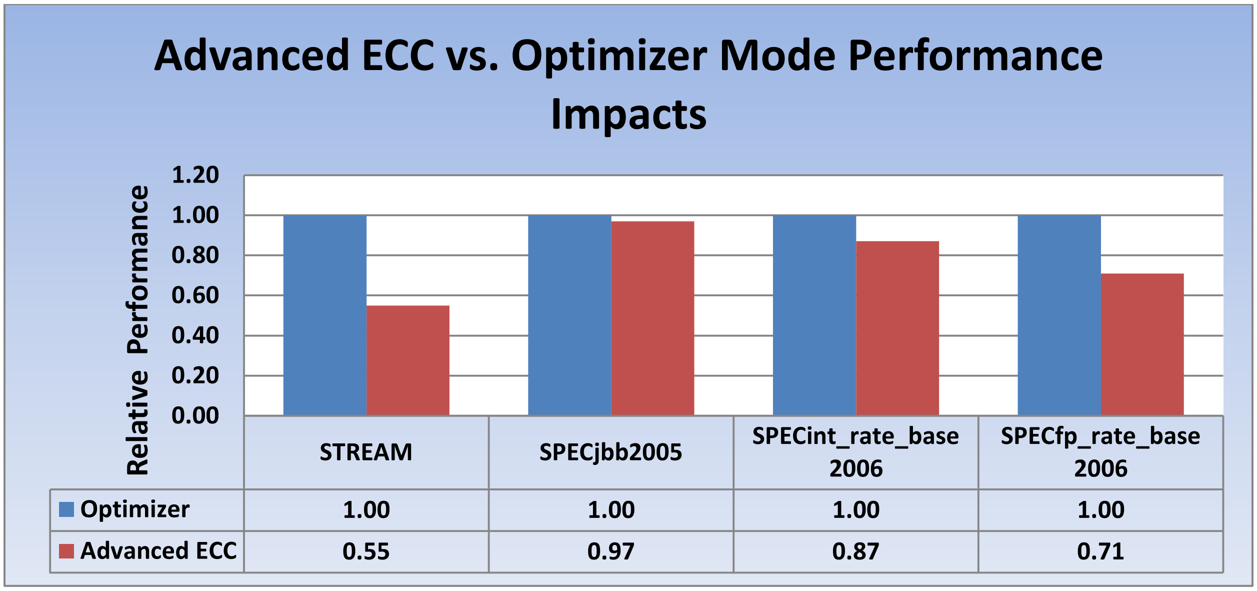
Figure 6. Comparison of memory mode effects



Performance impacts of Advanced ECC and Optimizer Mode

Because Optimizer and Advanced ECC Modes are the two most common Memory Operating Modes for customers, these two selections are compared against one another for additional performance detail. Examining Figure 7, we can see that the memory bandwidth measured in Advanced ECC mode is only 55% of that for Optimizer mode. This decline in memory bandwidth translates into other server workload impacts as well. Additionally, we can see that SPEC_int_rate_base2006 with Advanced ECC mode achieving only 87% of the performance seen with Optimizer mode. For the more memory bandwidth-sensitive SPECfp_rate_base2006 benchmark, we see Advanced ECC achieving only 71% of the performance seen with Optimizer mode. With the Java-based SPECjbb2005 benchmark, the impacts are considerably less pronounced. For SPECjbb2005, Advanced ECC mode achieves a full 97% of the performance of Optimizer mode.

Figure 7. Memory latency impacts of memory modes



	STREAM	SPECjbb2005	SPECint_rate_base 2006	SPECfp_rate_base 2006
🟦 Optimizer	1.00	1.00	1.00	1.00
🟥 Advanced ECC	0.55	0.97	0.87	0.71

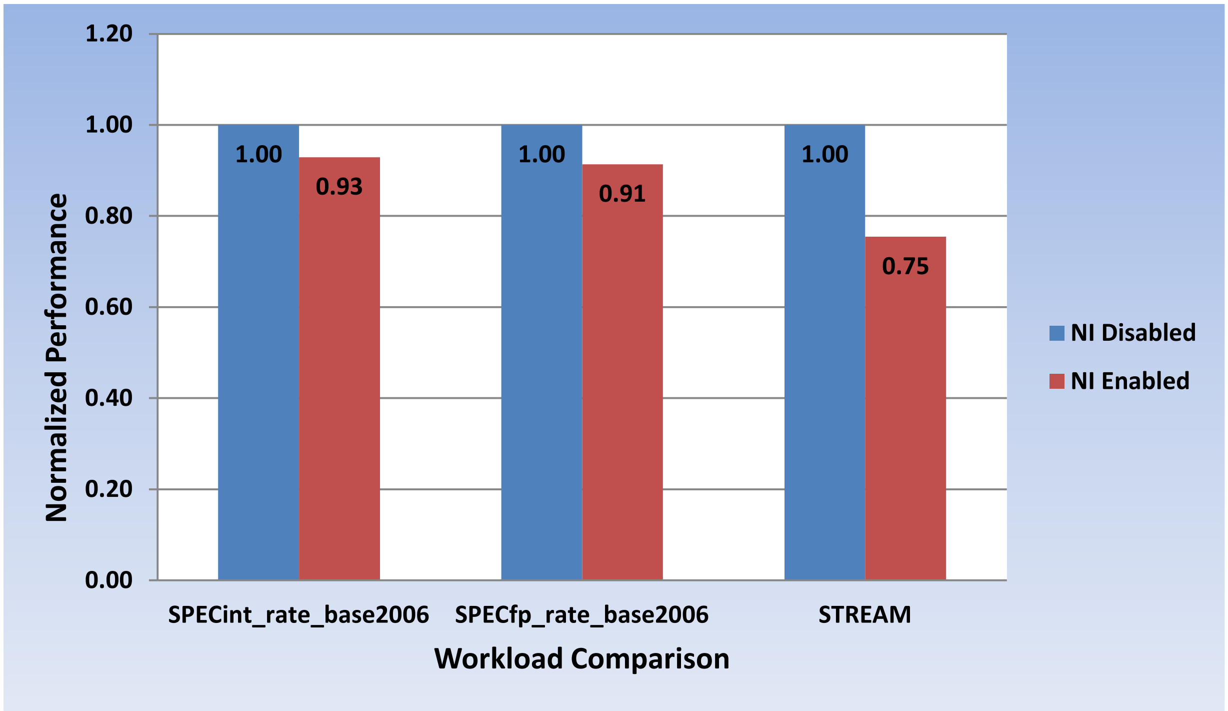
Node Interleaving

Another option in the Memory Settings screen of the BIOS is Node Interleaving. This option is disabled by default, which means that NUMA mode is enabled. Conversely, enabling Node Interleaving means the memory is interleaved between memory nodes, and there is no NUMA presentation to the operating system. Most modern operating systems have been NUMA-aware for many years, and schedulers have been optimized to ensure memory allocations are localized to the correct (closest) NUMA node. However, these schedulers are not perfect, and to achieve maximum performance with a given workload (especially for benchmarks), manual intervention may be required to "pin" workload processes and threads to specific cores, ensuring that memory is always allocated to the local NUMA node for any given logical processor.

For some applications, where the memory required is larger than the memory available in a single memory node (such as very large databases), the memory allocation must necessarily occur on the remote node as well. It is in cases such as this, or for other applications that cannot be easily localized to a single socket/NUMA node combination, where enabling Node Interleaving could have positive effects. Enabling Node Interleaving was most common several years ago when NUMA was a relatively recent arrival to x86 servers and operating systems were not as NUMA aware. However, this situation has radically improved, and today the number of customers that need to enable Node Interleave is diminishing. Note that enabling Node Interleaving is not supported for 4P E5-4600 configurations.

In Figure 8, we see that by enabling Node Interleaving, the following effects become apparent. Memory bandwidth, as measured with the STREAM tool, decreases by almost 25%. The performance decline on SPECint_rate_base2006 and SPECfp_rate_base2006 are less pronounced: 7%, and 8.6% respectively.

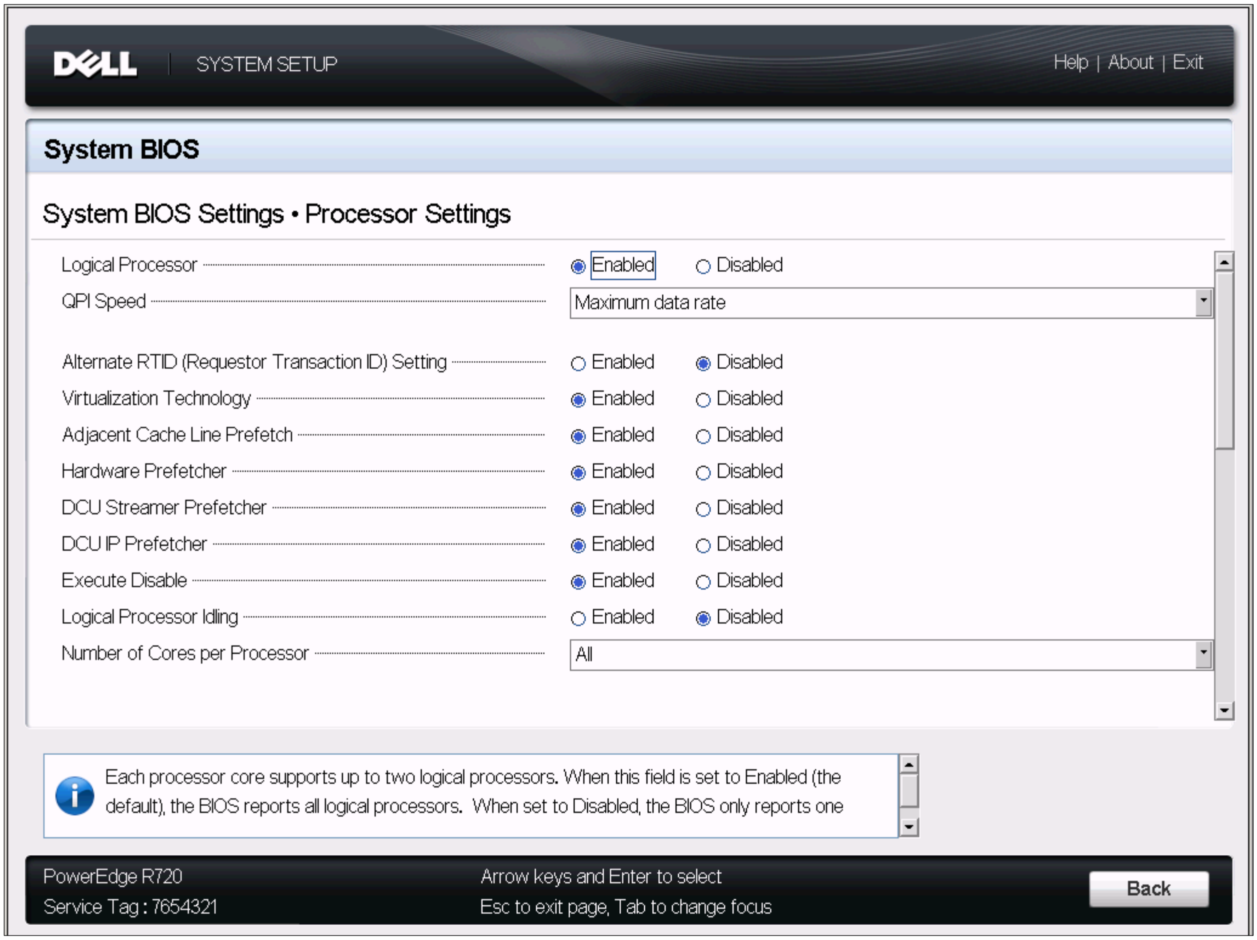
Figure 8. Node interleave disabled vs. enabled



Processor Settings Section

The Processor Settings section of the BIOS setup opens up numerous options to tweak for maximum performance tuning or power efficiency improvement. It is critical to have a basic understanding of these options prior to modifying any of these settings from default, as significant performance penalties may be encountered if options are incorrectly set. The default options, shown in Figure 9, are already optimized for optimal general performance, but under certain circumstances, the user may wish to modify some of these settings. These processor options are explored in detail below.

Figure 9. System BIOS Settings – Processor Settings screen



System BIOS

System BIOS Settings • Processor Settings

Logical Processor	● Enabled	○ Disabled
QPI Speed	Maximum data rate	
Alternate RTID (Requestor Transaction ID) Setting	○ Enabled	● Disabled
Virtualization Technology	● Enabled	○ Disabled
Adjacent Cache Line Prefetch	● Enabled	○ Disabled
Hardware Prefetcher	● Enabled	○ Disabled
DCU Streamer Prefetcher	● Enabled	○ Disabled
DCU IP Prefetcher	● Enabled	○ Disabled
Execute Disable	● Enabled	○ Disabled
Logical Processor Idling	○ Enabled	● Disabled
Number of Cores per Processor	All	

Each processor core supports up to two logical processors. When this field is set to Enabled (the default), the BIOS reports all logical processors. When set to Disabled, the BIOS only reports one

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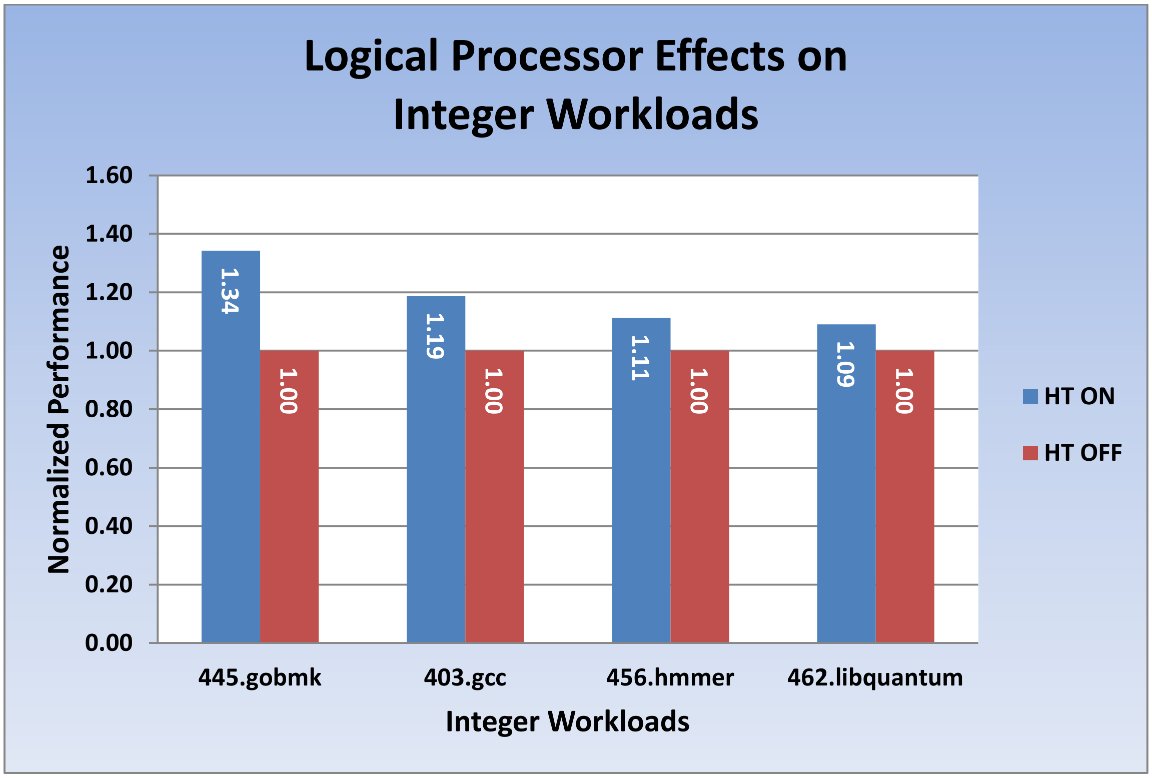
Logical Processor

The Logical Processor option controls whether or not Intel Hyper-Threading (HT) Technology is Enabled or Disabled for the server processors. With Logical Processors enabled, a 16-core, dual-socket system presents 32 logical processors to the operating system. Each physical core is presented to the operating system as two logical processors, which are known to increase the performance of most partially, and fully multithreaded workloads (with the exception of a handful of floating point/scientific workloads, including HPC workloads like Linpack). However, these are outliers and the recommendation for general performance tuning is to leave HT on (the default). Finally, customers running extremely low-latency environments may prefer to disable Logical Processors for the system latency improvement offered, but again this is a special case and is not recommended for most computing environments.

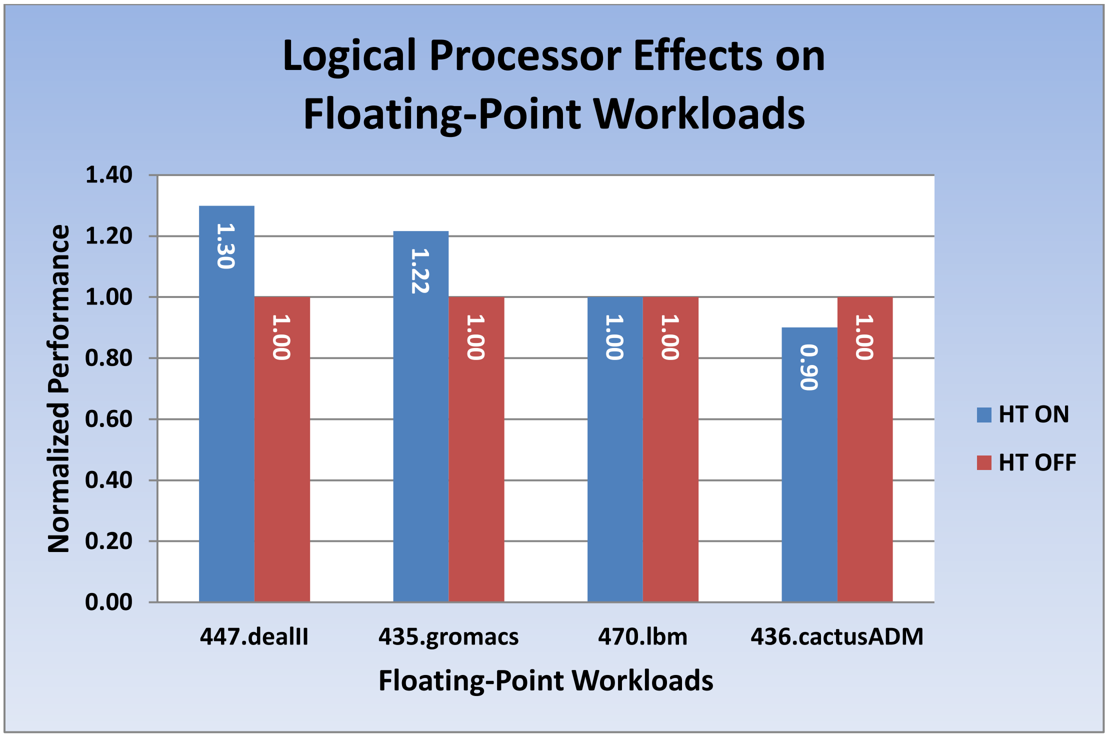
In Figure 10, we see that for a range of integer workloads, which is a subset of server workloads contained in the SPECint_rate_base2006 benchmark, enabling Logical Processors provides an uplift of between 9% and 34%. The most impacted benchmark by far is 445.gobmk (an Artificial Intelligence workload based on the game Go) at 34%. For 403.gcc (a GNU C Compiler workload), the uplift for HT mode was measured at 19%. For 456.hmmer (a Gene Sequencing workload) and 462.libquantum (a quantum cryptography/prime factorization benchmark), the differences were between 11% and 9% in favor of HT on.

Figure 10. Logical Processor performance on integer workloads



In Figure 11, the impact of Hyper-Threading is contrasted across several floating-point workloads that are part SPECfp_rate_base2006. The impacts are quite varied depending on the workload executed. The workloads measured with the largest positive impact for Hyper-Threading was 447.dealII (a Finite Analysis workload). Similarly, 435.gromacs (a Biochemistry/Molecular Dynamics workload) saw a 22% performance gain with HT enabled. For 470.lbm (a Computational Fluid Dynamics workload), no discernable difference was detected between HT on and off. For 436.cactusADM (a Computational Electromagnetics workload), a 10% decline in performance was measured with HT on compared to HT off. Caution should be shown when considering disabling of HT unless the workloads planned to be run on the system are known to benefit from HT off, as the vast majority of tested workloads show benefit from enabling this option.

Figure 11. Logical processor performance on floating-point workloads



QPI Speed

The Intel QuickPath Interconnect (QPI) Speed option in the Processor section governs the frequency of the QPI links between the populated processors. Depending on the platform and processor type, the number of QPI links can differ between systems, but the maximum link frequency across all E5-2400, E5-2600, and E5-4600 processors tops out at 8.0 GT/sec, depending on the processor. The user should be aware that standard and basic bin Intel processors of this architecture support slower QPI link speeds than the advanced parts provide.

There can be up to four available selections for this BIOS option. Maximum Data Rate is the default, which indicates that the BIOS will run the QPI links at the maximum frequency supported by the processor. For processors that support a maximum of 8.0 GT/sec, three other options are presented: 8.0 GT/s, 7.2 GT/s, and 6.4 GT/s.

For best performance, the QPI link speed should be left at the maximized setting, for any reduction in QPI speed will affect the performance of non-local memory accesses and cache coherency traffic. In addition, access to non-local I/O devices from a particular core can be slowed by the reduction of QPI link speed. However, in some cases it may be advisable to reduce QPI speed where power considerations outweigh the performance cost. For users considering reducing the QPI link speeds, memory and I/O accesses should be localized to the nearest NUMA node to minimize the performance impact.

Alternate RTID setting

This setting manipulates Requestor Transaction IDs, which are QPI resources. This option is disabled by default, and generally should be left at this setting, as no workloads have been identified as benefitting from the manipulation of this option.

NOTE: Enabling this option almost always results in negative impacts to overall system performance, and that few similarities exist between this option previous-generation architectures.

Virtualization technology

When this option is enabled, the BIOS will enable processor Virtualization features and provide the virtualization support to the OS through the DMAR table. In general, only virtualized environments such as VMware® ESX™, Microsoft Hyper-V®, Red Hat® KVM, and other virtualized operating systems will take advantage of these features. Disabling this feature is not known to significantly alter the performance or power characteristics of the system, so leaving this option Enabled is advised for most cases.

Processor prefetchers

All 12th generation Dell PowerEdge systems have several processor prefetching options available under the Processor Settings section of the BIOS setup. The default settings for these options is **Enabled**. Generally, Dell does *not* recommend disabling them, as in most cases they are a net performance enhancement. However, for very random, memory-intensive workloads, the user can try disabling these settings to evaluate whether this may increase performance of virtualized workloads.

The following available options are listed below (not all of which are available across all Xeon E5-series processors):

- Adjacent Cache Line Prefetch
- Hardware Prefetcher
- DCU Streamer Prefetcher
- DCU IP Prefetcher

Execute disable

This is a security feature designed to prevent certain types of buffer overflow attacks by enforcing specific areas of memory that applications can execute code. In general, it is best to leave this option Enabled for the security benefits, as no real performance advantage has been detected by disabling this feature in BIOS.

Number of cores per processor

This BIOS option can control the number of cores presented to the Operating System from each populated processor socket. In general, it is uncommon to artificially reduce the core count for a given system, but under some circumstances, limited performance improvements to Intel Turbo Boost Technology and potentially larger shared caches may benefit some customers. Most computing environments tend to benefit more from larger numbers of processing cores, so disabling cores to gain nominal performance enhancements must be carefully weighed prior to changing this setting from the default.

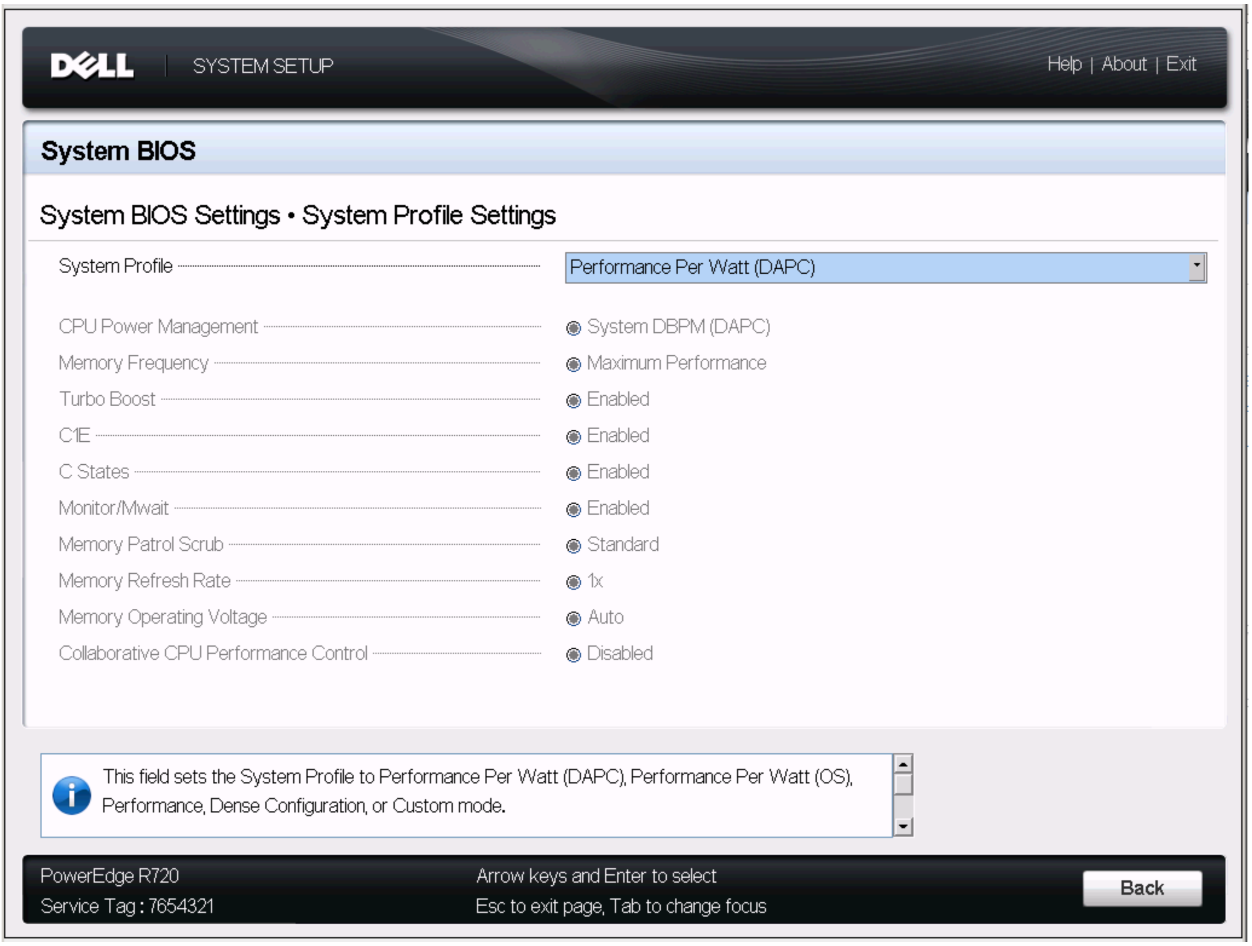
Logical processor idling

This option is related to Power Capping, and should only be enabled if the operating environment supports the LPI interface. At of the time that this whitepaper was written, Windows Server 2012 and some new Linux kernels have support for this feature. Generally, this option should be left at the default of Disabled unless specific power capping support is required. Enabling this feature has been known to cause issues on older Linux kernels.

System Profile Settings section

The System Profile Settings section of the BIOS Setup is the last major area that this white paper explores. Dell PowerEdge 12th generation platforms provide a new class of BIOS settings known as "System Profiles" that govern the values set for multiple sub-options. Table 1 lists the four System Profiles that exist at the time of writing this white paper. Each profile is selected for a particular purpose. As shown in Figure 12 and in the following sections, these four profiles can have a major impact on both power efficiency and performance.

Figure 12. System BIOS Settings – System Profiles Settings screen



System BIOS

System BIOS Settings • System Profile Settings

System Profile: Performance Per Watt (DAPC)

CPU Power Management: ● System DBPM (DAPC)
Memory Frequency: ● Maximum Performance
Turbo Boost: ● Enabled
C1E: ● Enabled
C States: ● Enabled
Monitor/Mwait: ● Enabled
Memory Patrol Scrub: ● Standard
Memory Refresh Rate: ● 1x
Memory Operating Voltage: ● Auto
Collaborative CPU Performance Control: ● Disabled

This field sets the System Profile to Performance Per Watt (DAPC), Performance Per Watt (OS), Performance, Dense Configuration, or Custom mode.

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Arrow keys and Enter to select
Esc to exit page, Tab to change focus

System Profiles comparison

The four system profiles feature the following functional areas, as shown in Table 1:

Performance-per-watt (DAPC) profile is the default, and represents an excellent mix of performance balanced with power consumption reduction. Dell Active Power Control (or DAPC), relies on a BIOS-centric power control mechanism which offers excellent power efficiency advantages with minimal performance impact in most environments, and is the CPU Power Management choice for this overall System Profile.

Performance-per-watt (OS), otherwise known as "OS Control", is similar to the DAPC profile for all sub-options except for the CPU Power Management. The power management scheme used for this profile is called "OS DBPM", which allows the Operating System to manipulate processor frequencies for higher power efficiency. However, the effectiveness of this profile for reducing overall system power consumption is based on how well the Operating System is able to effectively control hardware resources, so the impacts are mixed across all supported Operating Systems.

Performance profile provides potentially increased performance by maximizing processor frequency and the disabling certain power saving features such as C-states and. Although not optimal for all environments, this is an excellent starting point for performance optimization baseline comparisons.

Dense Configuration enhances reliability features and reduces power consumption at the cost of considerable performance. This profile is targeted for operating environments where enhanced reliability is desired and temperatures may exceed the thresholds encountered in less densely-packed data centers.

Table 1. System performance profiles

Profile	DAPC	OS Control	Performance	Dense configuration
CPU power management	System DBPM	OS DBPM	Maximum performance	System DBPM
Memory frequency	Maximum performance	Maximum performance	Maximum performance	Maximum performance
Turbo	Enabled	Enabled	Enabled	Disabled
C1E	Enabled	Enabled	Disabled	Enabled
C-States	Enabled	Enabled	Disabled	Enabled
Monitor/Mwait	Enabled	Enabled	Enabled	Enabled
Memory patrol scrub	Standard	Standard	Standard	Extended
Memory refresh rate	1x	1x	1x	2x
Memory operating voltage	Auto	Auto	Auto	1.5V
Collaborative CPU performance control	Disabled	Disabled	Disabled	Disabled

One additional System Profile is available for configuration. This is the **Custom Profile**, but it is crucial to understand that this option by itself has no defaults for Profile sub-options. The default state of all of the sub-options is based on the last System Profile selected by the user. Thus, it is important to ensure that no inadvertent sub-option selection has taken place by carefully evaluating the state of each setting once the Custom Profile is selected. Another great resource can be found in the Dell PowerEdge 12th Generation Server System Profiles white paper.

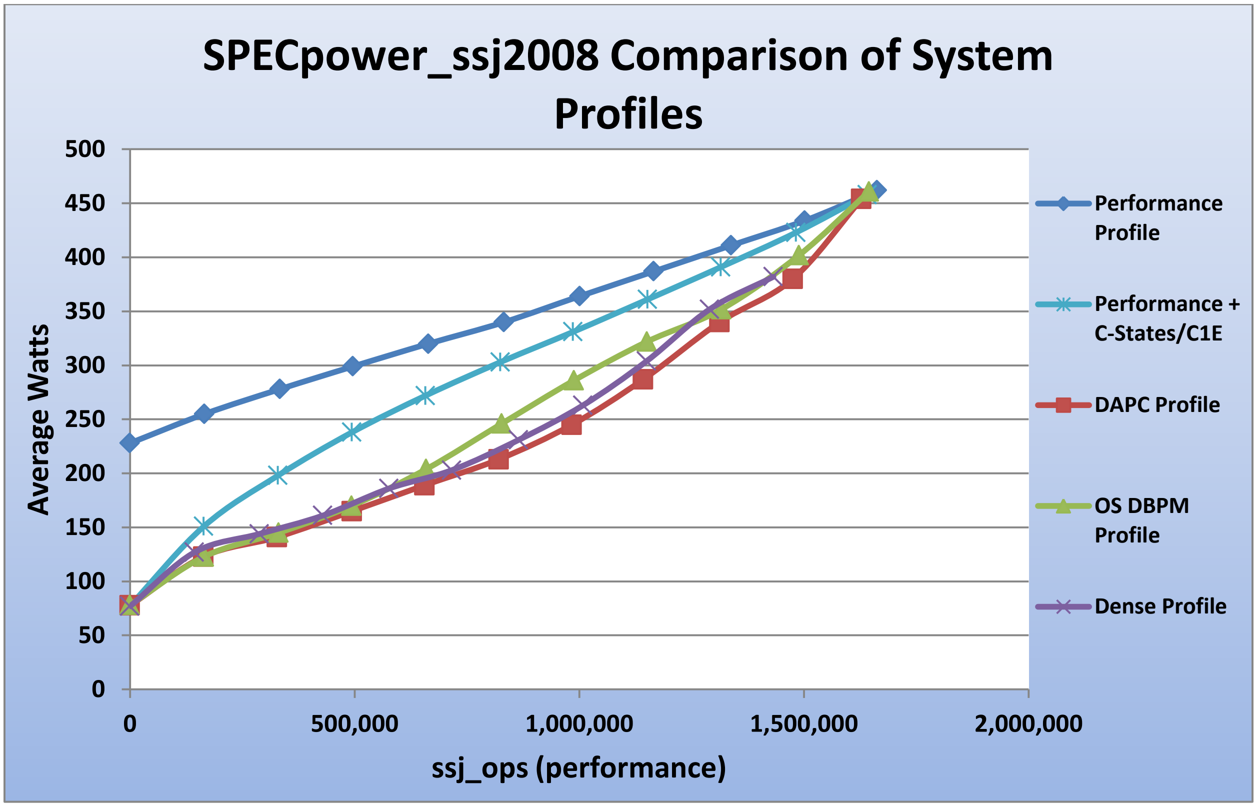
Performance and power comparisons of System Profiles

To evaluate the performance and power impacts of the four available System Profiles, the industry standard SPECpower_ssj2008 performance-per-watt benchmark was used to characterize these options. In addition, one Custom profile was selected for this comparison, and was set by selecting the Performance Profile followed by selecting Custom. The C1E and C-States options were then enabled. This custom profile provides the benefits of locking in maximum processor frequency, while providing for some opportunity to save power at lower workload levels and at idle. In the chart, this is represented as **Performance + C-States/C1E**.

Examining Figure 13, each System Profile was measured and the performance/watt curve displayed on the graph. The points on each line indicate the load level, starting with active idle up to 100% in 10% intervals. The X-axis represents the performance level for each load level, and the Y-axis represents the average watts measured for that load level. For better performance-per-watt configurations, the performance will be as high as possible while consuming a minimum amount of power. **It should be understood that the system hardware configuration chosen to compare these System Profiles is one optimized for maximum performance, not power efficiency, and contained the highest TDP processors and 128GB of 1600MHz memory, so alternate system configurations will offer different performance and power characteristics**. However, the approximate shape of the efficiency curves should be generally accurate regardless of processor and memory configuration.

The DAPC System Profile represents the best performance-per-watt combination for this benchmark across all workload intervals, using the least amount of power while offering maximum performance levels within 2% of that provided by the Performance System Profile. The Dense and OS Control profiles vie for second place and the shape of the curves look similar to one another at first glance. However, the Dense Profile achieves only 86% of the 100% workload interval performance that was achieved with the Performance Profile. The Performance System Profile provided the highest performance levels, but at considerable cost to power. This was especially true at idle, but the choice of processors and the large memory configuration are driving a great deal of this high idle, which tend to be more greatly affected by the reduction in power saving modes that this profile utilizes. The Custom Profile, Performance + C-States/C1E is capable of achieving within 1% of the maximum ssj_ops of the Performance System Profile, but the idle power is radically reduced due the two power saving options turned on in this custom profile.

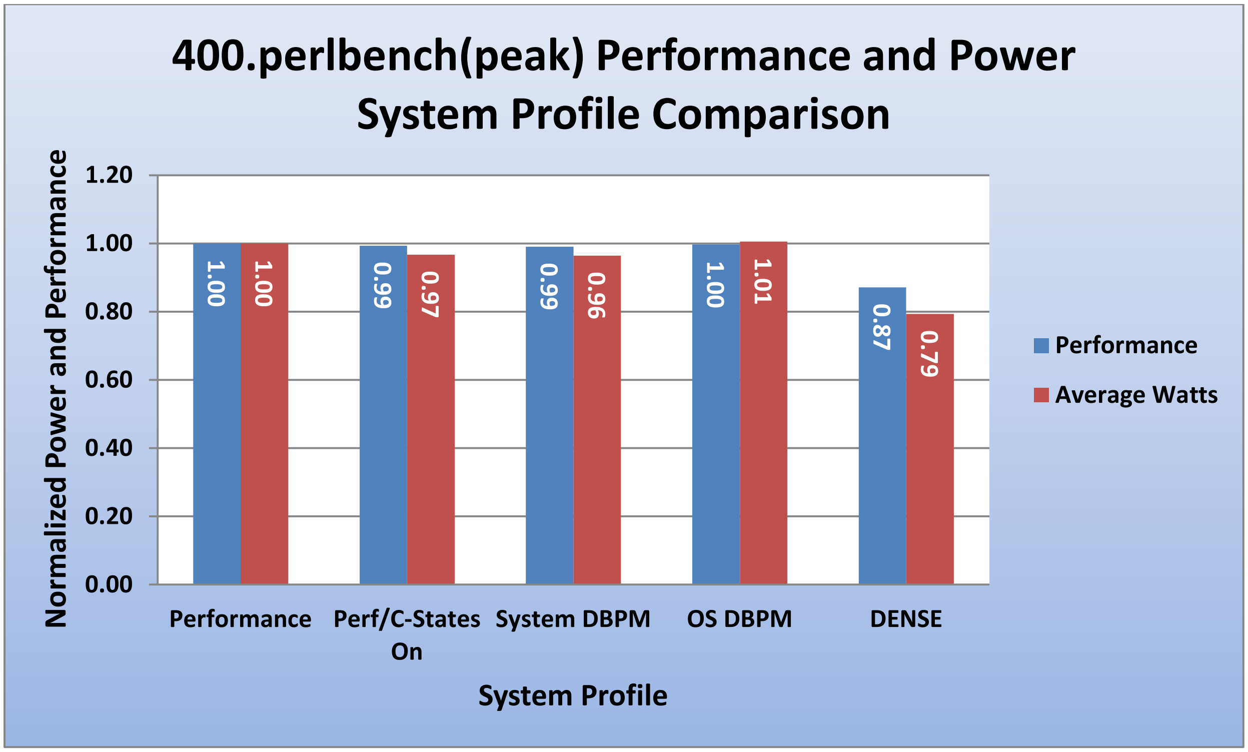
Figure 13. SPECpower_ssJ2008 comparison



In addition, various SPECrate workloads were chosen from the SPEC CPU2006 benchmark suite for additional System Profile performance and power characterization. The four standard System Profiles were used for the CPU2006 comparison, as well as one additional modified profile; the Custom profile (Performance + C-States/C1E) is the same as the profile described in SPECpower comparison in Figure 13.

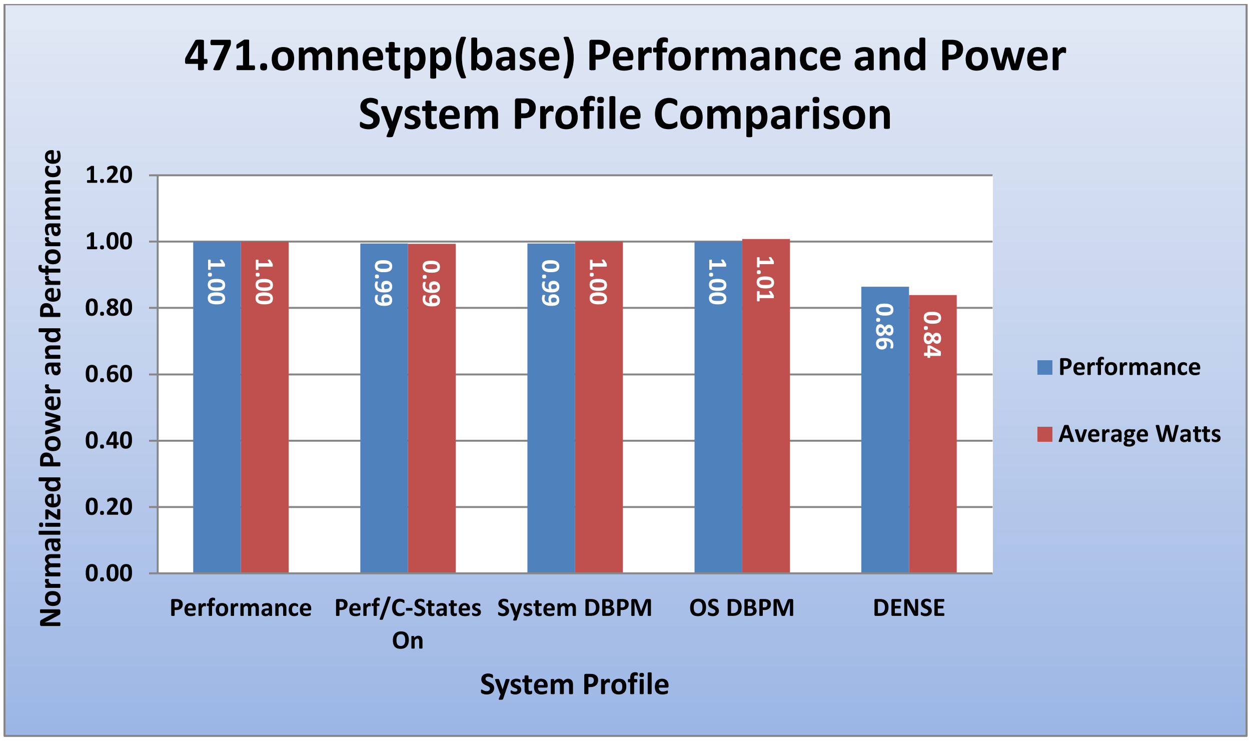
The 400.perlbench workload (a PERL programming language benchmark) in Figure 14 was compared with the four System Profiles (plus Custom Performance + C-States) to chart the impacts to performance and power utilization. This workload, as all CPU2006 rate sub benchmarks, is fully multithreaded such that all logical processors will be fully utilized for the duration of the test. This test type limits the ability for some Profiles to engage in significant power saving at this highest utilization level. For all Profiles excepting Dense, the performance variance was less than 1%. However, some nominal power savings were detected from the Custom profile as well as through System DBPM (DAPC), ranging from 3% to 4% average wattage reduction. The OS DBPM profile performed equivalently with the Performance Profile, at slightly higher power utilization. For the Dense Configuration system profile, there were noticeable impacts to both power and performance. Compared with the baseline Performance profile, the Dense Profile only achieved 87% of the performance, but at 79% of the power.

Figure 14. Performance and power comparison — 400.perlbench(peak)



The 471.omnetpp workload (a Discrete Event Simulation benchmark in Figure 15), was compared with the four System Profiles and the Custom profile described in the beginning of this section. Similar to 400.perlbench, all Profiles except Dense achieved performance levels within 1% of each other. The average power utilization was also within 1% for the first four Profile selections, which sets this workload apart from 400.perlbench. For the Dense Configuration system profile, there were again noticeable impacts to both power and performance. Compared with the baseline Performance profile, the Dense Profile only achieved 86% of the performance, and consumed 84% of the power.

Figure 15. Performance and power comparison — 471.omnetpp(base)



In Figure 16, we see that for the floating-point workload 410.bwaves (a Fluid Dynamics/blast wave simulator workload), performance levels across the first four profile selections was equivalent. Therefore, no significant impact should be taken away from this comparison. The Dense Configuration profile again showed a large performance impact at 85% of that achieved by the Performance profile. The average power utilization was 88% of that measured from the Performance profile.

Figure 16. Performance and power comparison — 410.bwaves(base)

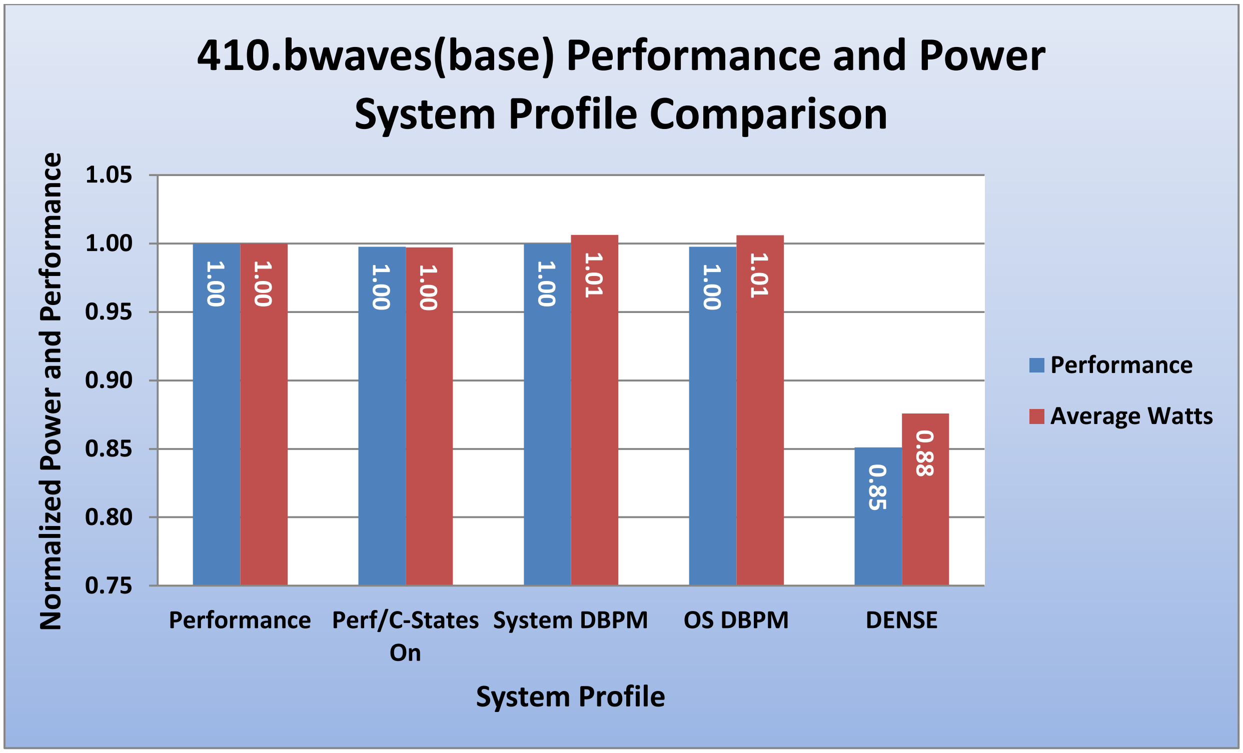
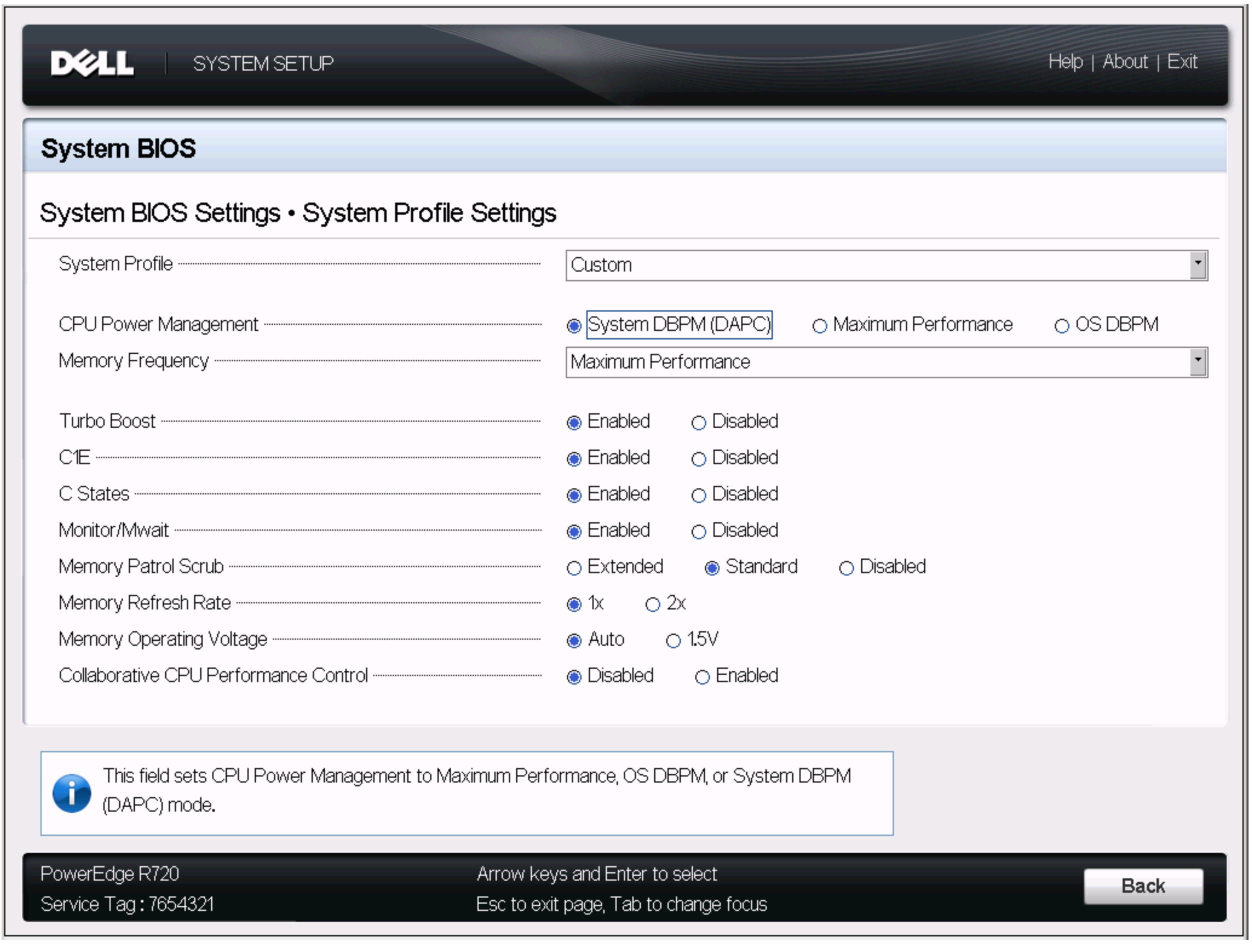


Figure 17. Additional Options Exposed by the Custom System Profile



System BIOS

System BIOS Settings • System Profile Settings

System Profile: Custom

CPU Power Management: ● System DBPM (DAPC) ○ Maximum Performance ○ OS DBPM

Memory Frequency: Maximum Performance

Turbo Boost: ● Enabled ○ Disabled

C1E: ● Enabled ○ Disabled

C States: ● Enabled ○ Disabled

Monitor/Mwait: ● Enabled ○ Disabled

Memory Patrol Scrub: ○ Extended ● Standard ○ Disabled

Memory Refresh Rate: ● 1x ○ 2x

Memory Operating Voltage: ● Auto ○ 1.5V

Collaborative CPU Performance Control: ● Disabled ○ Enabled

This field sets CPU Power Management to Maximum Performance, OS DBPM, or System DBPM (DAPC) mode.

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CPU Power Management modes

There are three available selections for CPU Power Management in the System Profile section of BIOS Setup. Although typically predetermined as part of an overall System Profile selection, these options can be exposed by choosing a Custom Profile. These three options are described here and are shown in Figure 17.

1. **System DBPM (DAPC)** - This is the CPU Power Management mode that utilizes a BIOS-controlled dynamic frequency manipulation scheme to save power across a variety of utilization levels. The power saving features of this option are typically are greatest at mid-to-lower utilization levels.
2. **Maximum Performance** - This specific mode is typically selected for Performance-centric users who are willing to consume additional power to achieve the highest possible performance for their computing environment. This mode drives processor frequency to the maximum across all cores (although idled cores can still be frequency reduced by C-state enforcement through BIOS or OS mechanisms if enabled). This mode also offers the lowest latency of the CPU Power Management Mode options, so is always preferred for latency-sensitive environments.

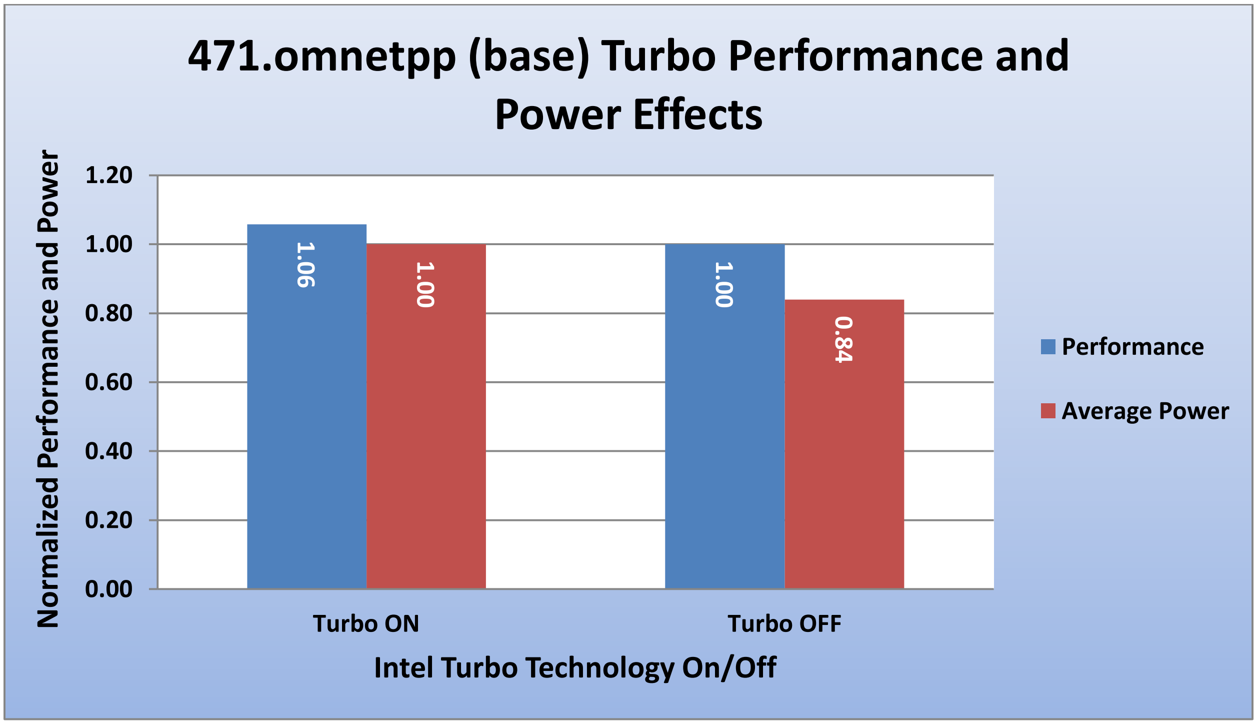
3. **OS DBPM** – This CPU Power Management mode is another performance-per-watt option that relies on the operating system to dynamically control individual core frequency dynamically. Both Windows® and Linux can take advantage of this mode to reduce frequency of idled or under-utilized cores in order to save power.

Turbo Boost

The Turbo Boost option governs the Intel Turbo Boost Technology feature of the Intel Xeon processor. This feature allows the processor cores to be automatically clocked up in frequency beyond the advertised processor speed. The amount of increased frequency (or "turbo upside") one can expect from a Xeon processor depends on the processor model, thermal limitations of the operating environment, and in some cases power consumption. In general terms, the fewer cores being exercised with work the higher the potential turbo upside. The potential drawbacks for Turbo Boost are mainly centered on increased power consumption and possible frequency jitter than can affect a small minority of latency-sensitive environments.

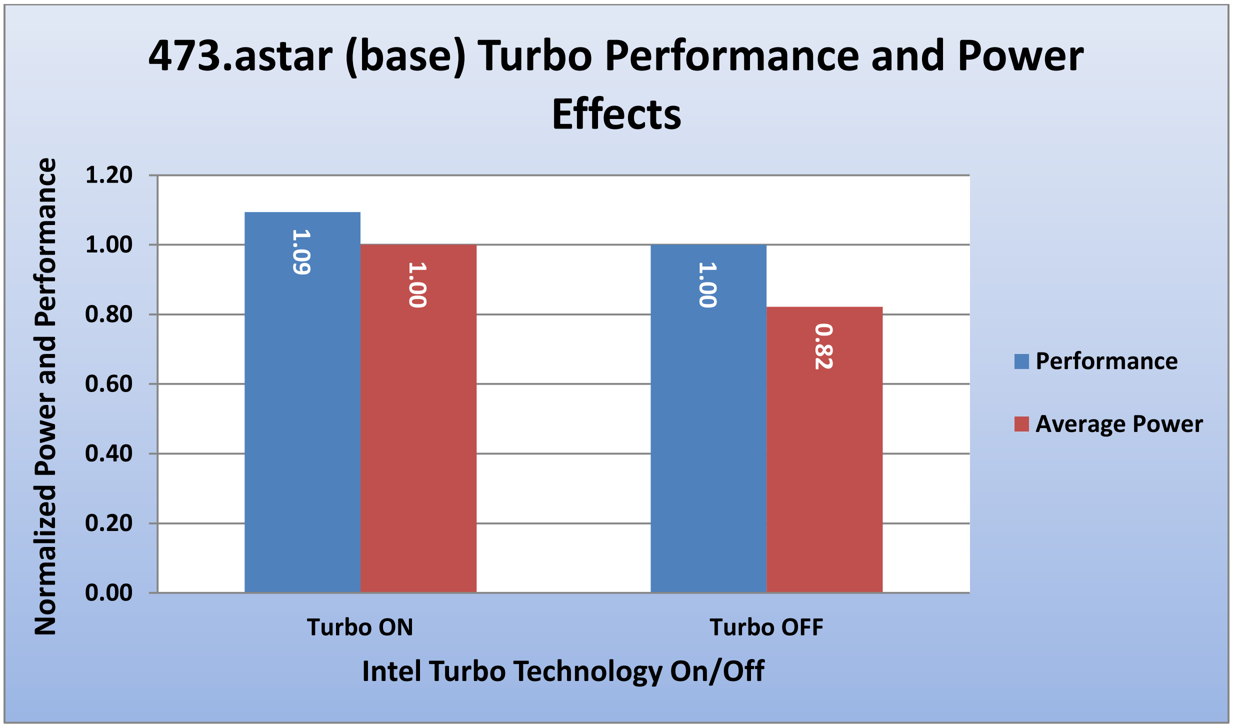
Examining Figure 18, we see that for the integer workload 471.omnetpp, Turbo Boost enabled provides increased performance of 6% compared to the normalized performance achieved with the same processor with Turbo Boost disabled. Comparing the measured average power for both Turbo Boost modes, we see that Turbo Boost disabled consumes only 84% of the power that Turbo Boost enabled does. However, not all workloads behave the same in terms of either performance or power, as we will see with subsequent charts.

Figure 18. Performance and power results — 471.omnetpp(base)



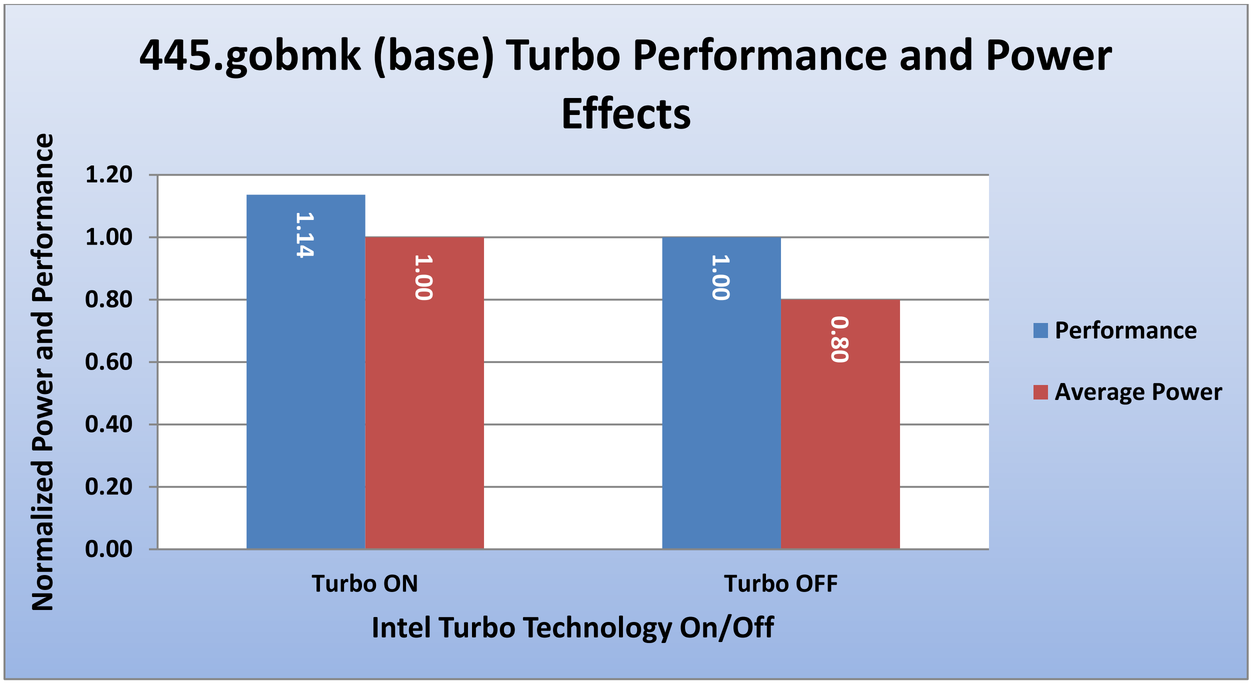
In Figure 19, we see that another integer workload, 473.astar (a Path-Finding Algorithm benchmark) measures a 9% performance boost with Turbo Boost enabled, as compared to Turbo Boost disabled. Comparing the measured average power collected during this test, we see that Turbo Boost disabled consumes only 82% of the power that Turbo Boost enabled configuration consumed.

Figure 19. Performance and power results — 473.astar(base)



For the 445.gobmk workload in Figure 20 (an Artificial Intelligence benchmark based on the game Go), perhaps the most striking example of Turbo Boost upside is shown. For this workload, the performance gain from Turbo Boost is a full 14% higher than Turbo Boost disabled. Logically, we see that the power delta between the two Turbo Boost modes is also at the apex of the compared workloads, as Turbo Boost disabled measured only 80% of the power that Turbo Boost Enabled was measured.

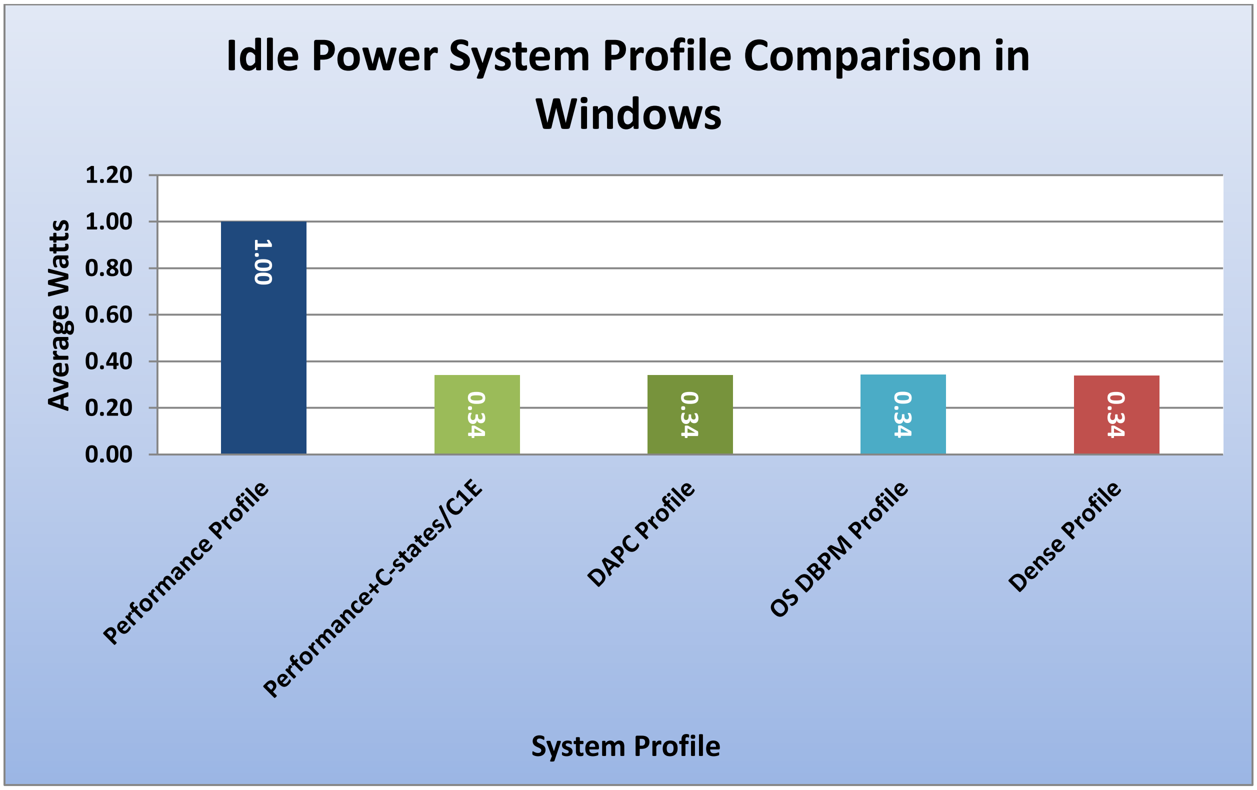
Figure 20. Performance and power results — 445.gomk(base)



C-States and C1E options

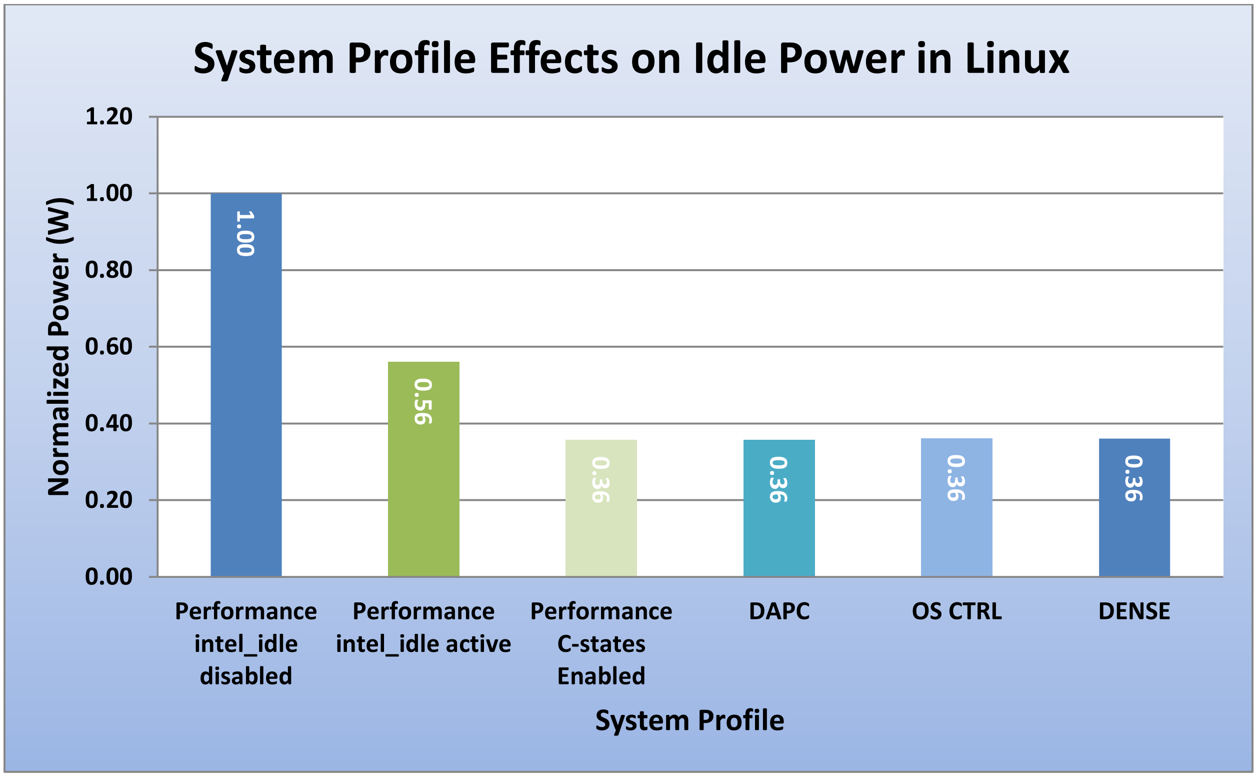
The C-States and C1E options are both processor power-saving features that can apply at a variety of system load levels, and are crucial for environments that need some level of power efficiency. In Figure 21, we compare the four standard System Profiles and include the Custom profile of Performance/C-States (described above) for idle power utilizations under Windows. With the inclusion of this manual profile setting, we can see that C-States + C1E have a major hand in reducing idle power for all System Profiles that enable these options. By disabling C-States in the Performance System Profile, the idle power is increased by 66% compared to all other profiles which have these options enabled.

Figure 21. Windows system profile comparison



A similar idle power measurement was conducted under Linux using the same four base System Profiles and Custom (Performance + C-States/C1E). The overall results are largely the same as what was seen in Windows with one special exception. With recent Linux distributions, a power saving driver called "intel_idle" is started by default, and can enforce some C-states even in systems which have disabled them. We see these effects comparing the two leftmost columns in Figure 22, both using the same Performance System Profile. The leftmost column represents a system where intel_idle has been deliberately disabled, and the column directly to the right shows the same profile with the intel_idle driver active (default for most Linux distributions). For all System Profiles that turn on C-states and C1E, we see that the idle power is identical across the board.

Figure 22. Linux system profile comparison



Enabling C1E and/or C-States is known to be detrimental for memory latency and frequency jitter, which can impact some latency-sensitive workloads outside of the scope normally classified as latency sensitive workloads operated by High Frequency Traders. Thus, if you are willing to trade increased power consumption for potentially better performance in some cases, disabling C-states in a Custom System Profile may be appropriate. Since such workloads are commonly run under Linux, one must also consider disabling the intel_idle driver to truly disable all C-states on the system.

Monitor/Mwait

This option enables or disables specific thread synchronization processor features of Intel Xeon processors. The Monitor/Mwait feature, enabled by default, generally should only be disabled in conjunction with disabling logical processors in the process section of the BIOS unless all workloads avoid the use of spinlocks. Disabling this feature can reduce jitter in latency-sensitive Linux environments by removing the mechanism used by some default kernel power management drives such as intel_idle that will enforce limited C-state use, even if C-states and C1E are manually disabled in BIOS. Disabling the Monitor/Mwait option will automatically prevent the intel_idle driver from starting.

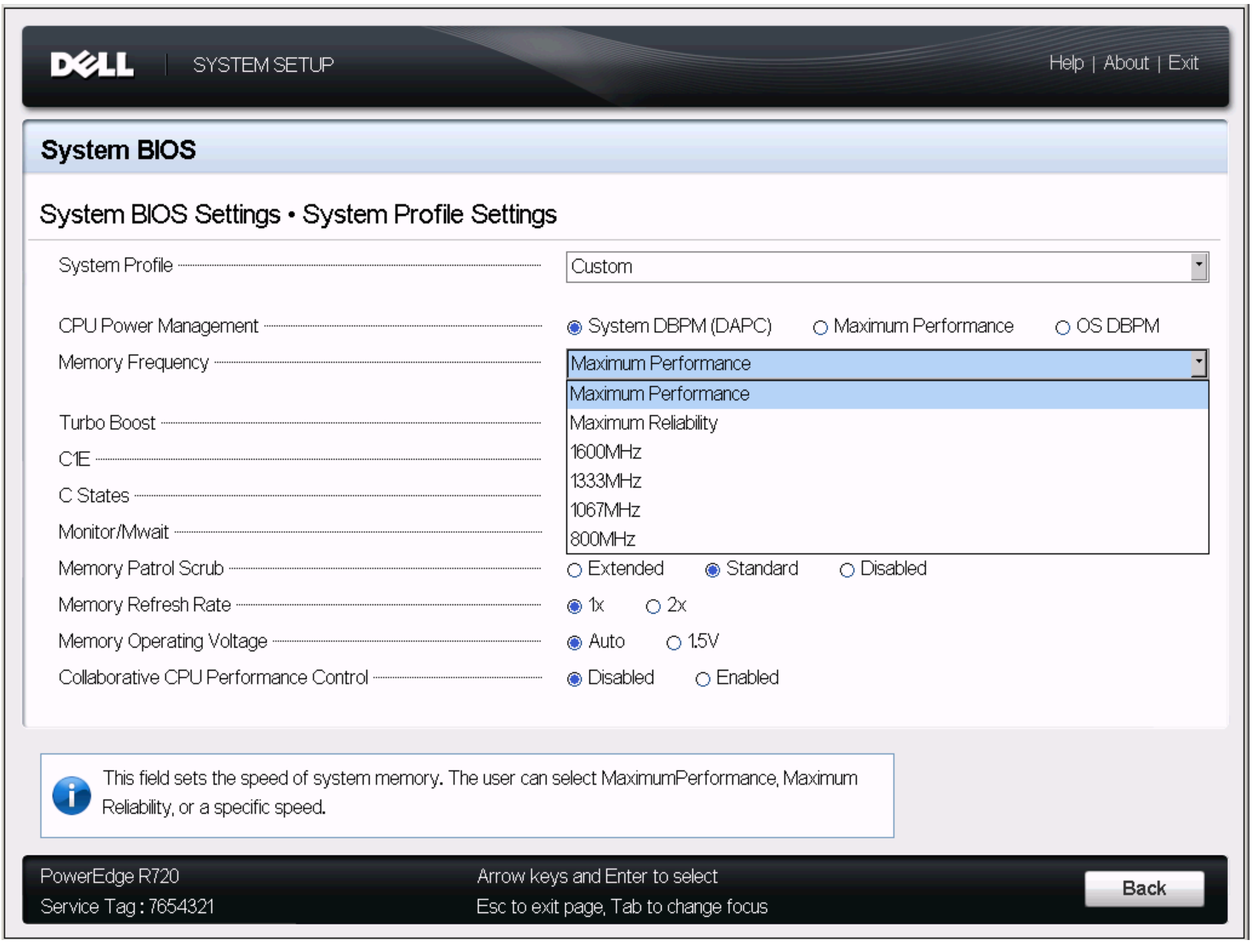
Collaborative CPU Performance Control

This BIOS switch allows for interaction between the BIOS and the operating system to dynamically control processor frequency for optimal power efficiency. This option is targeted primarily for Windows Server 2012, so it can be safely left disabled. Furthermore, this option is only compatible with the System DBPM CPU Power Management (DAPC) mode.

Memory Management section

There are several other System Profile sub-options that can have an impact on overall system performance by manipulating additional memory settings. Although normally optimal for most configurations, it may be necessary under limited circumstances to modify these settings if a specific memory frequency is required, or power savings are desired.

Figure 23. System BIOS Settings options



System BIOS

System BIOS Settings • System Profile Settings

System Profile: Custom

CPU Power Management: ● System DBPM (DAPC) ○ Maximum Performance ○ OS DBPM

Memory Frequency: Maximum Performance

- Maximum Performance
- Maximum Reliability
- 1600MHz
- 1333MHz
- 1067MHz
- 800MHz

Turbo Boost

C1E

C States

Monitor/Mwait

Memory Patrol Scrub: ○ Extended ● Standard ○ Disabled

Memory Refresh Rate: ● 1x ○ 2x

Memory Operating Voltage: ● Auto ○ 1.5V

Collaborative CPU Performance Control: ● Disabled ○ Enabled

This field sets the speed of system memory. The user can select MaximumPerformance, Maximum Reliability, or a specific speed.

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Esc to exit page, Tab to change focus

Some other memory-specific options which control features such as memory frequency, memory voltage, patrol scrub, and memory refresh rate. These features, left in the defaults provided by the

Performance System Profile, are typically optimal for performance. In cases where additional power savings is desired or where higher than default memory frequencies are needed for certain 3 DIMM per channel memory configurations, two options in particular should be noted for possible manipulation. Memory Patrol Scrub and Memory Refresh rates are not normally modified from defaults for performance tuning. Increasing the Memory Refresh rates may increase memory reliability but with a negative impact on memory subsystem performance under some circumstances.

Memory frequency

This option governs the BIOS memory frequency. The variables that govern maximum memory frequency include the maximum rated frequency of the DIMMs, the DIMMs per channel population, the processor choice, and this BIOS option. For cases where 3 DIMMs per channel are utilized and 1333MT/s frequency is needed, the system may not default to this memory frequency automatically. In that situation, manual selection of 1333MT/s may be necessary, along with a memory voltage adjustment.

In cases where additional power savings is required, and the customer is willing to trade some performance for this result, the memory frequency can be reduced for power savings. Reference the Memory Performance Guidelines for Dell PowerEdge 12th Generation Servers for additional resources to help guide decision making.

Memory operating voltage

The Memory Operating Voltage selection determines what voltage is used for the populated DIMMs in a given system configuration. The two options are Auto and 1.5V. For Low Voltage memory, the default selection of Auto will ensure that the DIMMs are running at 1.35V, which will reduce overall power consumption. For some 3 DIMM per channel memory configurations, it may be necessary to manually select 1.5V in conjunction with 1333MT/s in order to achieve this frequency.

Conclusion

Table 2 provides a set of recommended BIOS settings for configuring Dell PowerEdge 12th generation servers for one of three scenarios. The Performance Optimized column represents the recommended options that should be used when tuning a server for optimal performance in most general computing scenarios. The Power Efficient column represents the recommendations for tuning for optimal power efficiency while still retaining high performance characteristics. Finally, the Latency Sensitive column represents BIOS tuning recommendations for customers running in low latency environments that benefit from reduced frequency jitter and consistent, low system latency characteristics.

Table 2. Recommended BIOS settings for Dell PowerEdge 12th generation servers

Profile	Performance Optimized	Power Efficient	Latency Sensitive
Memory Mode	Optimizer	Optimizer	Optimizer
Node Interleave	Disabled	Disabled	Disabled
Logical Processor	Enabled	Enabled	Disabled
QPI Frequency	Maximum Frequency	Maximum Frequency[1]	Maximum Frequency
System Profile	Performance	DAPC	Custom
CPU Power Management	Maximum Performance	System DBPM	Maximum Performance
Turbo Boost	Enabled	Disabled	Disabled[2]
C1E	Disabled	Enabled	Disabled
C-States	Disabled	Enabled	Disabled
Monitor/Mwait	Enabled	Enabled	Disabled
Memory Frequency	Maximum Frequency	Maximum Frequency[3]	Maximum Frequency

[1] In some cases, reducing QPI link speed may provide a favorable performance/watt increase. Evaluate the impact in your environment to determine application performance impact and power efficiency changes.

[2] Intel Turbo Boost Technology may provide some performance uplift at an acceptable latency trade-off for latency-sensitive customers. Customers can evaluate the impact of enabling this option on their own environment to determine whether the processor frequency elevation outweighs the potential increase in latency jitter.

[3] Reducing Memory Frequency may provide an increase in performance/watt in some environments. Evaluate the impact in your environment to determine application performance impact and power efficiency changes. Refer to the Memory Performance Guidelines for Dell PowerEdge 12th Generation Servers white paper for more detailed information.

References

1. Memory Performance Guidelines for Dell PowerEdge 12th Generation Servers white paper
2. Configuring Low-Latency Environments on the Dell PowerEdge 12th Generation Servers white paper
3. HPC Performance on the Dell PowerEdge 12th Generation Servers white paper
4. Dell PowerEdge 12th Generation Servers BIOS Configuration technical brief
5. Dell PowerEdge 12th Generation Server System Profiles white paper