Lenovo

Optimizing Memory Performance of Lenovo ThinkSystem Servers

Introduces the Intel Xeon Processor Scalable Family series of processors

Introduces the CPU and memory architecture of the Lenovo ThinkSystem servers that use these processors

Analyzes the effects memory speed and memory DIMM ranks have on performance

Provides best practices to maximize memory performance

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Abstract

This paper examines the architecture and memory performance of the Lenovo® ThinkSystem™ servers based on the Intel Xeon Processor Scalable family. The performance analysis in this paper covers memory latency, bandwidth, and application performance. In addition, the paper describes performance issues that are related to memory speed and memory DIMM ranks. Finally, the paper recommends best practices for configuring the memory subsystem for optimal performance on Lenovo ThinkSystem servers.

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Introduction

The Intel Xeon Processor Scalable family represents an entirely new CPU architecture from its predecessors, the Intel Xeon E5 v4 and E7 v4 series. The Scalable family series contains processors that are grouped in Platinum, Gold, Silver, and Bronze shelves. Table 1 lists the attributes of the top Platinum processors compared to the top processors in the E5 and E7 v4 series.

Table 1 Intel Xeon Processor family attributes and comparison

Feature	E5-2699A v4	E7-8894 v4	Platinum 8180
Process technology	14 nm	14 nm	14 nm
Thermal Design Power (TDP)	145 W	165 W	205 W
Base frequency	2.4 GHz	2.4 GHz	2.5 GHz
Maximum memory speed	2400 MHz	1600 MHz Independent 1866 MHz Lockstep	2666 MHz
Cores / Threads	22 cores 44 threads	24 cores 48 threads	28 cores 56 threads
Intel QPI/UPI speed	9.6 MT/s	9.6 MT/s	10.4 MT/s
PCIe lanes	40 lanes	32 lanes	48 lanes

Both the E5 and E7 series processors implemented a ring interconnect to facilitate cache coherency and communication between cores. The Scalable family introduces a mesh interconnect with bi-directional channels. Changes to caching architecture, reduced traffic on mesh interconnects, snoop optimizations, and a faster memory speed yield lower latencies and greater peak memory bandwidth for Scalable family-based Lenovo servers.

In addition, another important difference between the E5 and E7 v4 processor and the Scalable family of processors is the number of memory channels supported by each integrated memory controller (IMC). There are two IMCs per processor, each supporting three DDR4 memory channels for a total of six DDR4 memory channels per processor. By comparison, the E5 v4 series supported a total of four DDR4 memory channels. This architectural difference is significant when configuring Scalable family-based Lenovo servers for optimal memory performance.

Processors and memory in ThinkSystem servers

The Intel Xeon Processor Scalable family provides a common building block across the following Lenovo ThinkSystem servers:

- ThinkSystem ST550, a 2P Mainstream tower server
- ThinkSystem SD530, a dense 2P server node
- ThinkSystem SR530, a 1U Value 2P rack server
- ThinkSystem SR550, a 2U Value 2P rack server
- ThinkSystem SR630, a 1U Mainstream 2P rack server
- ThinkSystem SR650, a 2U Mainstream 2P rack server
- ThinkSystem SN550, a 2P Mainstream blade
- ThinkSystem SN850, a 4P Mainstream blade
- ThinkSystem SR850, a 2U Value 4P rack server
- ThinkSystem SR950, a 4U 4P rack server scalable to 8P

Figure 1 illustrates CPU and memory architecture block diagrams for Lenovo ThinkSystem two- and four-socket servers based on Scalable family processors. Some system architectures may differ from what is shown in Figure 1, so always refer to platform specific documentation for precise system details.

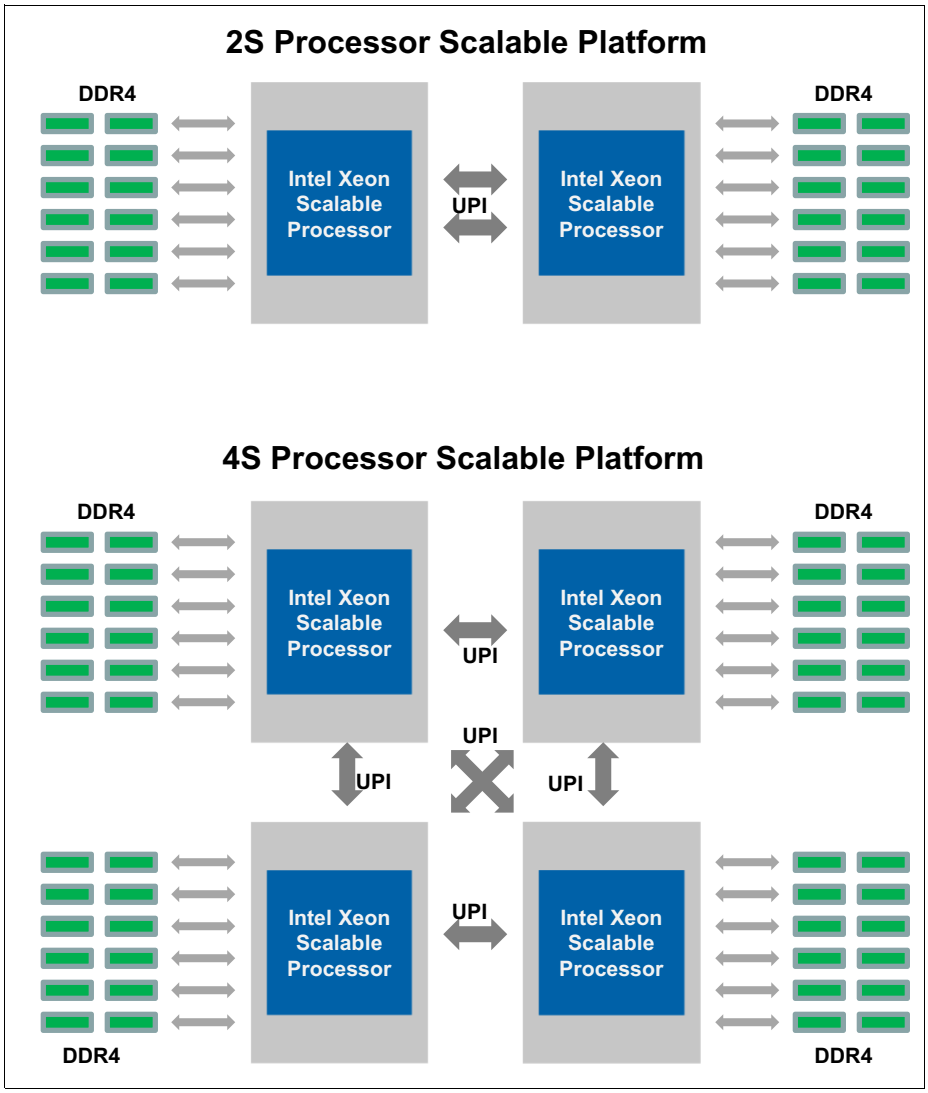

Figure 1 2-socket and 4-socket CPU and memory architecture block diagrams

The 2-socket (2S) block diagram shows two Intel Ultra Path Interconnect (UPI) links between processors, and six channels of memory per processor with two DIMMs maximum per channel for a total of 24 DIMM slots.

The 4-socket (4S) block diagram shows a fully-connected UPI topology between all four processors, also called a mesh topology. Each processor has six channels of memory with two DIMMs maximum per channel for a total of forty-eight DIMM slots.

Not shown in Figure 1 is the CPU and memory block diagrams for the ThinkSystem SR950 8S and the ThinkSystem SR850. The SR850 is a 2U 4-socket server with a ring topology, as opposed to a mesh topology. The SR850 does not have the two UPI links in the middle as shown in Figure 1 for the 4S configuration.

Intel Xeon Processors

ThinkSystem servers are based on the Intel Xeon Processor Scalable family, which consists of four different shelves (groups) of processors denoted by the names Platinum, Gold, Silver, and Bronze. Table 2 lists the Scalable family that were supported in ThinkSystem servers at the time of publication.

Table 2 Models of the Intel Xeon Processor Scalable Family used in ThinkSystem servers

Processor	TDP Power	Cores	Core frequency	Memory Capacity per Socket	Maximum Memory Speed
Intel Xeon Platinum Processors					
Intel Xeon Platinum 8160T 24C 150W 2.1GHz Processor	150 W	24	2.1 GHz	768 GB	2666 MHz
Intel Xeon Platinum 8180 28C 205W 2.5GHz Processor	205 W	28	2.5 GHz	768 GB	2666 MHz
Intel Xeon Platinum 8180M 28C 205W 2.5GHz Processor	205 W	28	2.5 GHz	1.5 TB	2666 MHz
Intel Xeon Platinum 8168 24C 205W 2.7GHz Processor	205 W	24	2.7 GHz	768 GB	2666 MHz
Intel Xeon Platinum 8176 28C 165W 2.1GHz Processor	165 W	28	2.1 GHz	768 GB	2666 MHz
Intel Xeon Platinum 8176M 28C 165W 2.1GHz Processor	165 W	28	2.1 GHz	1.5 TB	2666 MHz
Intel Xeon Platinum 8170 26C 165W 2.1GHz Processor	165 W	26	2.1 GHz	768 GB	2666 MHz
Intel Xeon Platinum 8170M 26C 165W 2.1GHz Processor	165 W	26	2.1 GHz	1.5 TB	2666 MHz
Intel Xeon Platinum 8164 26C 150W 2.0GHz Processor	150 W	26	2.0 GHz	768 GB	2666 MHz
Intel Xeon Platinum 8160 24C 150W 2.1GHz Processor	150 W	24	2.1 GHz	768 GB	2666 MHz
Intel Xeon Platinum 8160M 24C 150W 2.1GHz Processor	150 W	24	2.1 GHz	1.5 TB	2666 MHz
Intel Xeon Platinum 8158 12C 150W 3.0GHz Processor	150 W	12	3.0 GHz	768 GB	2666 MHz
Intel Xeon Platinum 8156 4C 105W 3.6GHz Processor	105 W	4	3.6 GHz	768 GB	2666 MHz
Intel Xeon Platinum 8153 16C 125W 2.0GHz Processor	125 W	16	2.0 GHz	768 GB	2666 MHz
Intel Xeon Gold Processor					
Intel Xeon Gold 6138T 20C 125W 2.0GHz Processor	125 W	20	2.0 GHz	768 GB	2666 MHz
Intel Xeon Gold 6130T 16C 125W 2.1GHz Processor	125 W	16	2.1 GHz	768 GB	2666 MHz
Intel Xeon Gold 6126T 12C 125W 2.6GHz Processor	125 W	12	2.6 GHz	768 GB	2666 MHz
Intel Xeon Gold 6154 18C 200W 3.0GHz Processor	200 W	18	3.0 GHz	768 GB	2666 MHz
Intel Xeon Gold 6150 18C 165W 2.7GHz Processor	165 W	18	2.7 GHz	768 GB	2666 MHz
Intel Xeon Gold 6146 12C 165W 3.2GHz Processor	165 W	12	3.2 GHz	768 GB	2666 MHz
Intel Xeon Gold 6148 20C 150W 2.4GHz Processor	150 W	20	2.4 GHz	768 GB	2666 MHz
Intel Xeon Gold 6142 16C 150W 2.6GHz Processor	150 W	16	2.6 GHz	768 GB	2666 MHz
Intel Xeon Gold 6142M 16C 150W 2.6GHz Processor	150 W	16	2.6 GHz	1.5 TB	2666 MHz
Intel Xeon Gold 6136 12C 150W 3.0GHz Processor	150 W	12	3.0 GHz	768 GB	2666 MHz
Intel Xeon Gold 6144 8C 150W 3.5GHz Processor	150 W	8	3.5 GHz	768 GB	2666 MHz

Processor	TDP Power	Cores	Core frequency	Memory Capacity per Socket	Maximum Memory Speed
Intel Xeon Gold 6152 22C 140W 2.1GHz Processor	140 W	22	2.1 GHz	768 GB	2666 MHz
Intel Xeon Gold 6140 18C 140W 2.3GHz Processor	140 W	18	2.3 GHz	768 GB	2666 MHz
Intel Xeon Gold 6140M 18C 140W 2.3GHz Processor	140 W	18	2.3 GHz	1.5 TB	2666 MHz
Intel Xeon Gold 6132 14C 140W 2.6GHz Processor	140 W	14	2.6 GHz	768 GB	2666 MHz
Intel Xeon Gold 6134 8C 130W 3.2GHz Processor	130 W	8	3.2 GHz	768 GB	2666 MHz
Intel Xeon Gold 6134M 8C 130W 3.2GHz Processor	130 W	8	3.2 GHz	1.5 TB	2666 MHz
Intel Xeon Gold 6138 20C 125W 2.0GHz Processor	125 W	20	2.0 GHz	768 GB	2666 MHz
Intel Xeon Gold 6130 16C 125W 2.1GHz Processor	125 W	16	2.1 GHz	768 GB	2666 MHz
Intel Xeon Gold 6126 12C 125W 2.6GHz Processor	125 W	12	2.6 GHz	768 GB	2666 MHz
Intel Xeon Gold 6128 6C 115W 3.4GHz Processor	115 W	6	3.4 GHz	768 GB	2666 MHz
Intel Xeon Gold 5120T 14C 105W 2.2GHz Processor	105 W	14	2.2 GHz	768 GB	2400 MHz
Intel Xeon Gold 5119T 14C 85W 1.9GHz Processor	85 W	14	1.9 GHz	768 GB	2400 MHz
Intel Xeon Gold 5122 4C 105W 3.6GHz Processor	105 W	4	3.6 GHz	768 GB	2666 MHz
Intel Xeon Gold 5120 14C 105W 2.2GHz Processor	105 W	14	2.2 GHz	768 GB	2400 MHz
Intel Xeon Gold 5118 12C 105W 2.3GHz Processor	105 W	12	2.3 GHz	768 GB	2400 MHz
Intel Xeon Gold 5117 14C 105W 2.0GHz Processor	105 W	14	2.0 GHz	768 GB	2400 MHz
Intel Xeon Gold 5115 10C 85W 2.4GHz Processor	85 W	10	2.4 GHz	768 GB	2400 MHz
Intel Xeon Silver Processor					
Intel Xeon Silver 4116T 12C 85W 2.1GHz Processor	85 W	12	2.1 GHz	768 GB	2400 MHz
Intel Xeon Silver 4114T 10C 85W 2.2GHz Processor	85 W	10	2.2 GHz	768 GB	2400 MHz
Intel Xeon Silver 4109T 8C 70W 2.0GHz Processor	70 W	8	2.0 GHz	768 GB	2400 MHz
Intel Xeon Silver 4116 12C 85W 2.1GHz Processor	85 W	12	2.1 GHz	768 GB	2400 MHz
Intel Xeon Silver 4114 10C 85W 2.2GHz Processor	85 W	10	2.2 GHz	768 GB	2400 MHz
Intel Xeon Silver 4112 4C 85W 2.6GHz Processor	85 W	4	2.6 GHz	768 GB	2400 MHz
Intel Xeon Silver 4110 8C 85W 2.1GHz Processor	85 W	8	2.1 GHz	768 GB	2400 MHz
Intel Xeon Silver 4108 8C 85W 1.8GHz Processor	85 W	8	1.8 GHz	768 GB	2400 MHz
Intel Xeon Bronze Processor					
Intel Xeon Bronze 3106 8C 85W 1.7GHz Processor	85 W	8	1.7 GHz	768 GB	2133 MHz
Intel Xeon Bronze 3104 6C 85W 1.7GHz Processor	85 W	6	1.7 GHz	768 GB	2133 MHz

Memory DIMMs

The Lenovo ThinkSystem servers support a variety of memory DIMM types and capacities:

- ThinkSystem 8GB TruDDR4™ 2666 MHz (1Rx8 1.2V) RDIMM

- ThinkSystem 16GB TruDDR4 2666 MHz (1Rx4 1.2V) RDIMM
- ThinkSystem 16GB TruDDR4 2666 MHz (2Rx8 1.2V) RDIMM
- ThinkSystem 32GB TruDDR4 2666 MHz (2Rx4 1.2V) RDIMM
- ThinkSystem 64GB TruDDR4 2666 MHz (4Rx4 1.2V) LRDIMM
- ThinkSystem 128GB TruDDR4 2666 MHz (8Rx4 1.2V) 3DS RDIMM

Many end users configure server memory based on a capacity requirement. Historically, RDIMMs have been favored for lower capacity requirements and LRDIMMs for higher capacity requirements.

The 128 GB DIMM is a 3DS RDIMM. 3DS is a relatively new technology which stacks DRAM components vertically and allows for greater capacity DIMMs while not increasing the load on the memory bus.

Memory performance

This section covers the measurement environment details used to produce the data in this document, and some of the factors which can affect memory performance such as processor SKU, memory speed, and ranks per channel (RPC).

Measurement environment

The configuration details used for the performance measurements executed to yield the data required for this paper are:

- Lenovo ThinkSystem SR630
- 2x Intel Xeon Platinum 8180 (28C 205W 2.5GHz)
- Memory
  - 8GB TruDDR4 2666 MHz (1Rx8 1.2V) RDIMM
  - 16GB TruDDR4 2666 MHz (1Rx4 1.2V) RDIMM
  - 16GB TruDDR4 2666 MHz (2Rx8 1.2V) RDIMM
  - 32GB TruDDR4 2666 MHz (2Rx4 1.2V) RDIMM
- UEFI Settings
  - Operating Mode: Maximum Performance Mode / Custom
  - P-States, C-states, C1E, Monitor MWAIT Disabled
- Red Hat Enterprise Linux 7.3 Server x64 Edition

To measure low-level memory performance metrics, the Intel Memory Latency Checker (MLC) v3.3 was used to accurately measure memory bandwidth and memory latency. In addition, the industry standard STREAM benchmark[1] was used to measure peak memory bandwidth performance.

The STREAM benchmark consists of four different memory workloads; however, the data in this paper corresponds to the Triad component. The Triad component of STREAM consists of two read operations and one write operation from the application's perspective.

[1] McCalpin, John D., 1995: "Memory Bandwidth and Machine Balance in Current High Performance Computers", IEEE Computer Society Technical Committee on Computer Architecture (TCCA) Newsletter, December 1995

Memory speed

Memory speed is a critical factor which affects memory performance. It is important to understand the performance characteristics when memory speed is changed, and the factors which control memory speed in ThinkSystem servers. Memory speed is controlled by the following factors:

- Processor model
- System settings

With ThinkSystem servers, memory speed is not affected by DIMM configuration.

Processor model

As stated earlier, the Intel Xeon Processor Scalable family consists of four different shelves (groups) of processors denoted by the names Platinum, Gold, Silver, and Bronze. Within the Platinum and Gold shelves there is further differentiation between processor models with respect to Intel Omni-Path Architecture (OPA) fabric support, total memory capacity per socket, and Tcase/Reliability support.

Some other characteristics which can vary from shelf-to-shelf and processor model-to-model are:

- Number of sockets supported
- Base frequency
- Thermal design point (TDP)
- Number of cores / threads
- Maximum memory speed
- Number of UPI links
- Maximum UPI link speed
- Intel HT Technology
- Intel Turbo Boost Technology
- RAS features

The processors are listed in Table 2 on page 5

System settings

The XClarity Provisioning Manager application embedded in the Unified Extensible Firmware Interface (UEFI) of the ThinkSystem servers can force memory to a speed lower than the maximum speed determined by the processor and the memory subsystem. Memory speed might be set lower to save energy in environments with little memory performance sensitivity.

The functions to control memory speed are in the **System Settings** → **Memory** as shown in Figure 2 on page 9.

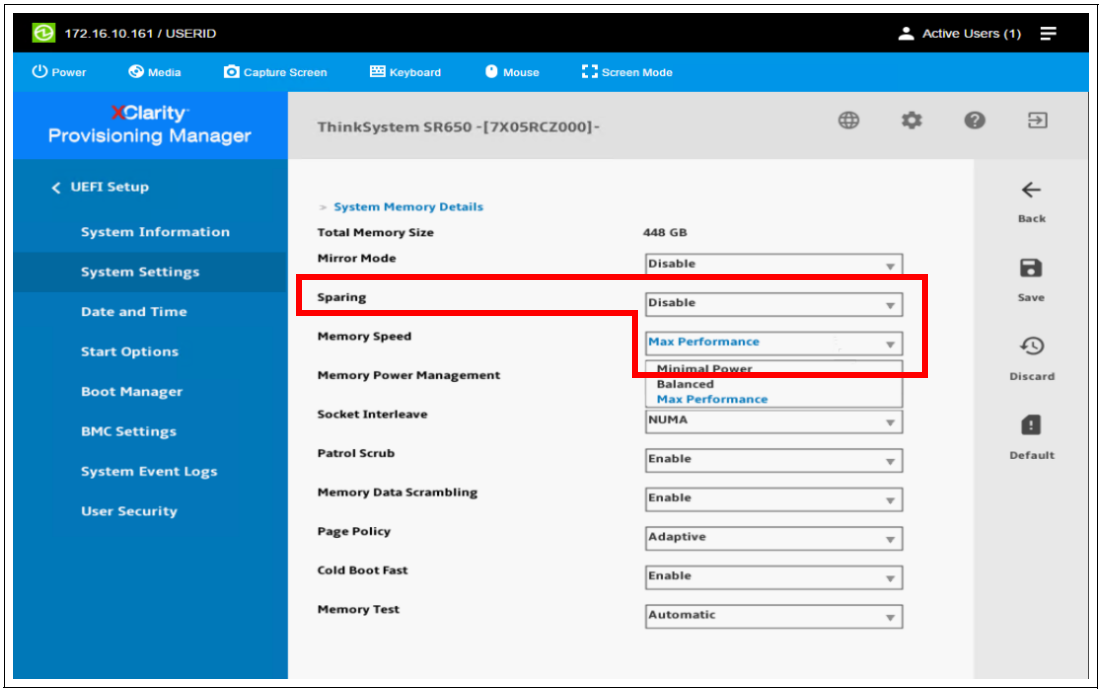

Figure 2 UEFI option to control memory speed

The memory speed options are as follows:

- Maximum Performance (default): Memory runs at the maximum supported speed determined by processor model and memory subsystem.
- Balanced: Memory runs at one step lower than the maximum speed.
- Minimal Power: Memory runs at the lowest speed supported by the architecture. For the ThinkSystem servers running the Scalable family processors, 1866 MHz is the lowest speed supported.

The effects of memory speed on memory latency and peak bandwidth performance are illustrated in Figure 3 on page 10.

About the charts: The charts throughout this paper show the relative performance between two or more parameters, such as memory latency, memory bandwidth, benchmark score, etc. Therefore, the scales on the axes do not have units associated with them. For memory latency axes, lower is better. For memory bandwidth axes, higher is better.

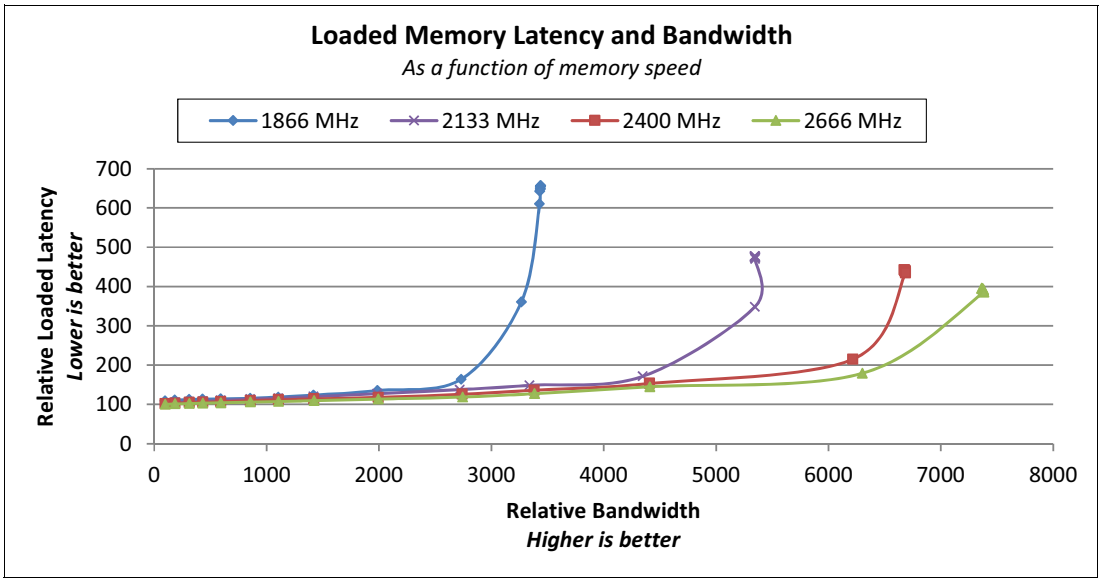

Figure 3 Loaded latency and bandwidth as a function of memory speed

In Figure 3, looking from left-to-right, the load on the CPU and memory subsystem is increasing.

- When the memory speed is set to the lowest supported by the architecture, the peak memory bandwidth is limited to approximately half of the achievable peak bandwidth at 2666 MHz.
- When memory speed is dropped by only one bin to 2400 MHz, the peak sustainable bandwidth is approximately 90% of the peak bandwidth at 2666 MHz.
- Finally, when the memory speed is 2133 MHz, the peak sustainable bandwidth is approximately 72% of the peak bandwidth at 2666 MHz.

Guidance: Pay attention to the details of each processor as listed in Table 2 on page 5, particularly the maximum memory speed supported, in order to maximize memory performance.

Memory DIMM Ranks

This section investigates the effects of the number of memory ranks on peak memory bandwidth. A memory rank is a segment of memory that is addressed by a specific set of address bits. More parallelism at the memory controller is achieved with more ranks. Typically, better performance is achieved with more parallelism. However, sometimes more ranks per channel (RPC) do not translate into better performance.

Figure 4 on page 11 illustrates peak STREAM Triad bandwidth for different memory DIMM configurations with various ranks per channel.

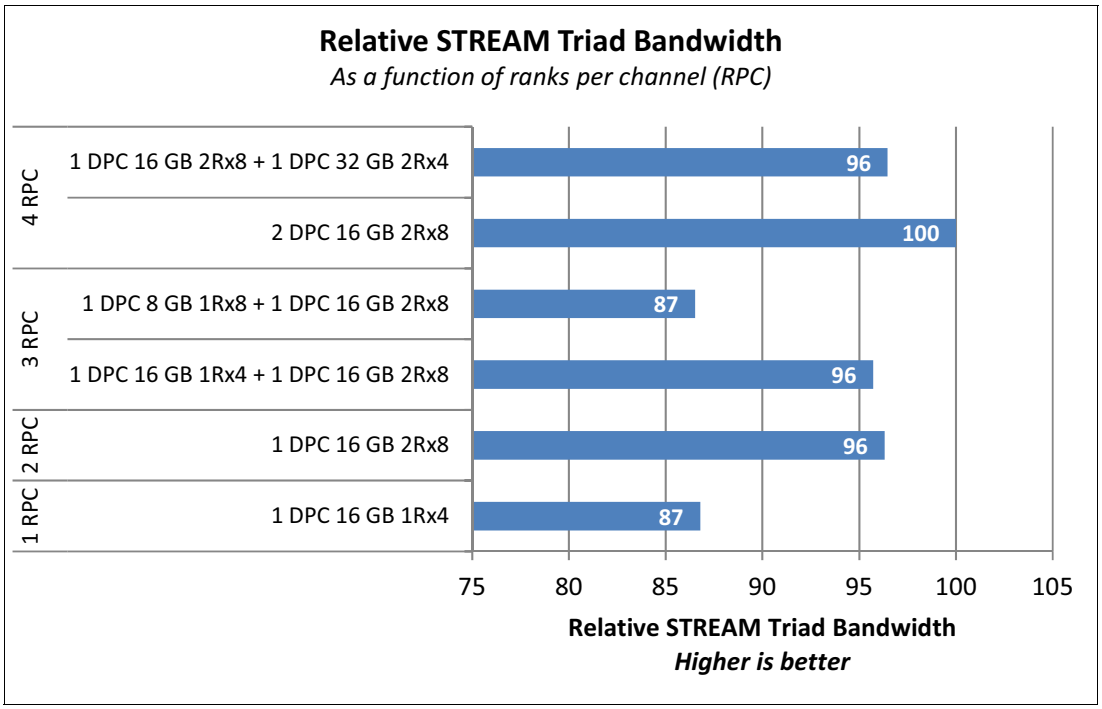

Figure 4 STREAM Triad bandwidth as a function of ranks per channel

First, notice the 10% gain in peak bandwidth from 1 RPC to 2 RPC. This is critical for high performance production environments.

Guidance: Always use a dual rank DIMM whenever possible for optimal memory performance.

Next, notice the gain in peak bandwidth from 2 RPC to 4 RPC is 0% to 4%. As mentioned in the previous section, the optimal number of RPCs for Scalable family processors is two to four. No gain was achieved when the 4 RPC configuration consisted of dual rank DIMMs with different capacities.

There is a small penalty in peak bandwidth performance, because each memory controller has to create multiple interleave sets to accommodate the different capacity DIMMs. However, with two identical dual rank DIMMs per channel, a 4% gain in peak memory bandwidth is achieved from 2 RPC to 4 RPC.

Guidance: Installing two identical dual rank DIMMs per DDR4 channel is the most optimal memory configuration for lowest latency and highest peak bandwidth.

Finally, from 1 RPC to 3 RPC, there is 0% to 10% gain in peak memory bandwidth. In the case of single rank and dual rank 16GB DIMMs combined to make 3 RPC, the IMCs must create multiple interleave sets on the DDR4 channel in order to accommodate the mixing of single and dual ranks. However, in the case of mixing a single rank 8GB DIMM and a dual rank 16GB DIMM on the same channel, the IMCs must create multiple rank interleave sets on the DDR4 channel, and furthermore, the IMCs must create multiple capacity interleave sets. This double penalty yields no gain in peak memory bandwidth from 1 RPC to 3 RPC.

Guidance: Use identical capacity DIMMs if configuring 3 ranks per channel.

Refer to the Lenovo Press paper *Maximizing System Performance with a Balanced Memory Configuration* for more detail on how unbalanced memory configurations affect performance, available from:

https://lenovopress.com/lp0501

Summary of best practices for optimal memory performance

For optimal memory performance on ThinkSystem servers with processors from the Intel Xeon Processor Scalable family, consider the following guidance:

- Always populate processors with equal memory capacity to guarantee a balanced NUMA system.
- Always populate all six DDR4 memory channels on each processor using identical DIMMs. If this is not possible, the next best option is to populate all DDR4 channels with equal memory capacity.
- Use dual-rank RDIMMs whenever possible to configure either 2 or 4 ranks per channel.
- Use identical capacity DIMMs if memory configuration is 3 ranks per channel to minimize peak bandwidth penalty.
- Carefully review the attributes of the different Scalable family processor models.

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