Intel® Xeon® 6 Processor BIOS Numa Tuning Guide: Enhancing Microsoft* SQL Server (2016-2022) Performance

Technical Whitepaper

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Revision History

Revision Number	Description	Revision Date
1.0	• Initial Release	February 2025

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1 Introduction

This whitepaper aims to provide comprehensive tuning guidance for Intel customers on BIOS NUMA (Non-Uniform Memory Access) options and configuration recommendations to enhance the performance of Microsoft* SQL Server (versions 2016 through 2022) when running on Intel® Xeon® 6 generation processors.

Intel® Xeon® 6 Generation Processors:

Intel® Xeon® 6500/6700/6900 series with P-cores and E-cores

Microsoft* SQL Server Versions:

- SQL Server 2016 to 2022

Windows* Server Operating Systems:

- Windows* Server 2016 to 2025

Linux* Server Operating Systems:

- Red Hat Enterprise Linux* (RHEL) 8.x, 9.x, SUSE Linux*, Centos

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2 Terminology

Terminology	Description	Availability
Hex and Quad	These are UMA-based clustering options recommended for non-NUMA workloads. They provide a unified memory architecture that simplifies memory access patterns.	Intel® Xeon® 6500/6700/6900 series with P-cores and E-cores
SNC2 and SNC3	SNC2 partitions the Last Level Cache (LLC) into two clusters and SNC3 partitions the Last Level Cache (LLC) into three clusters known as NUMA domains or nodes. Each cluster contains an equal number of cores, LLC slices near the cores, an equal amount of socket address space, and is bound to a subset of the memory controllers within the cluster. This configuration enhances memory locality and performance for NUMA-aware applications.	SNC2: Intel® Xeon® 6500/6700 with P-cores, Intel® Xeon® 6900 series with E-cores SNC3: Intel® Xeon® 6900 series with P-cores.
VirtualNuma	VirtualNUMA is a BIOS mode that creates multiple VirtualNUMA domains within a single physical NUMA node, without altering memory interleaving and LLC grouping of original UMA or NUMA clustering. This feature is particularly beneficial for Windows* and Linux* applications, such as SQL Server (2016-2022), that do not support more than 64 logical processors per NUMA node. VirtualNUMA is not a standalone performance BIOS setting; it should be enabled in conjunction with your preferred UMA or NUMA configuration.	Intel® Xeon® 6500/6700/6900 series with P-cores and E-cores

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3 Background

Windows* server OS has a concept called GROUP and AFFINITY MASK through processor group (K-GROUP) to address up to 64 logical processors with processor atomic operations in an OS scheduling domain. However, this K-group concept did not support more than 64 logical processors (32 physical cores with Hyperthreading enabled) in a single proximity domain.

With limitation of K-group **Windows* server (2019 RTM and below OS versions)** did not support more than 64 logical processors in a single proximity domain, leading to the creation of unbalanced NUMA nodes configurations with memory less Numa nodes. With the release of **Windows* server 2022 RTM (20348 Fe [Iron] version)**, Microsoft* changed this behavior and supported more than 64 logical processors per NUMA node and provides information about the modifications that software might require to support this expanded number of processors.

Database application like **Microsoft* SQL Server (versions 2016 through 2022)** limits the number of logical processors per NUMA node to 64 and has not modified to support this expanded number of processors. SQL will shut down gracefully with not supported HW configuration message on both Windows* and Linux* SQL supported OS versions with system configured for > 64LP/Numa.

If you are using Intel® Xeon® 6 generation based processors and Microsoft* SQL Server (version 2016 through 2022) that is configured with more than 64 logical processor per Numa node, then set VirtualNuma=ON in BIOS/Firmware to reduce the number of logical processors per NUMA node to below 64.

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4 Intel® Xeon® 6 BIOS Numa Recommendation: Microsoft* SQL Server (2016-2022)

To optimize the performance of Microsoft* SQL Server on Intel® Xeon® 6 based processor systems, it is crucial to configure the BIOS/Firmware NUMA settings appropriately.

Intel Sub NUMA Clustering (SNC)

By default, Intel Sub NUMA Clustering (SNC) should be enabled in the BIOS/Firmware settings. SNC divides the cores and memory of each CPU socket into separate clusters. This configuration allows fewer than 64 logical threads per NUMA node and moreover this configuration enhances memory locality and performance for NUMA-aware applications like SQL server.

Intel Sub NUMA Clustering (SNC) and Intel Virtual NUMA

In modern CPU architectures, such as Intel® Xeon® 6 generation (Intel® Xeon® 6700/6900 series), core counts have increased significantly. Even with SNC2 or SNC3 configuration enabled, certain high core count CPU SKUs may still have number of logical processors per NUMA node exceeding 64. This can lead to Microsoft* SQL Server (versions 2016 through 2022) application shutdown due to non-supported hardware configurations.

To mitigate this issue, it is recommended to enable Intel "VirtualNUMA" in addition to SNC2 or SNC3 in the BIOS/Firmware settings. VirtualNUMA helps reduce the number of logical processors to fewer than 64 per NUMA node. This adjustment allows the Windows* operating system to create GROUP objects with fewer than 64 logical threads per NUMA node, ensuring compatibility and stability for Microsoft* SQL Server (2016-2022) application.

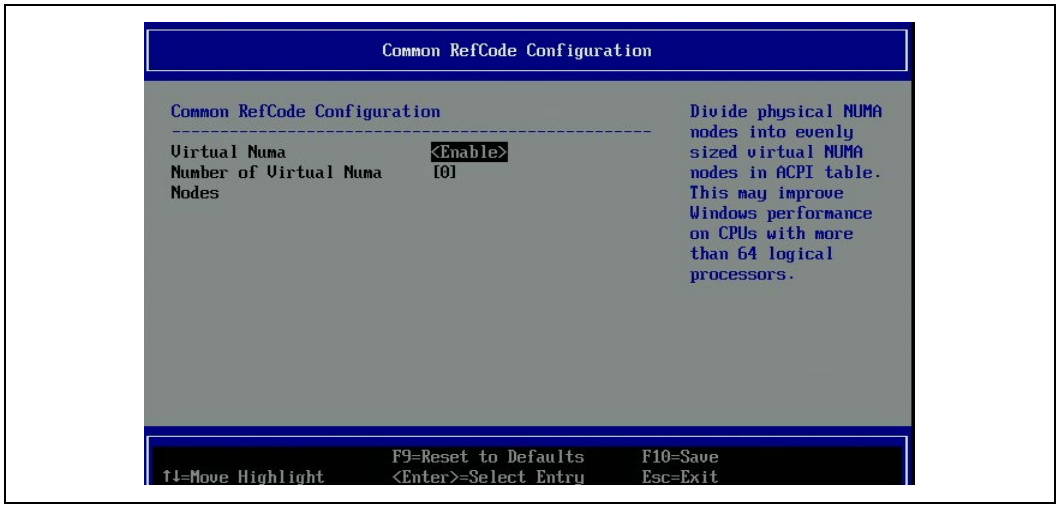
Table 4-1: Summarizes Intel® Recommended Numa BIOS Options for Microsoft* SQL Server (2016-2022) Based on The Processor Type and Core Count

Intel® Xeon® 6 Processor Types	Physical Cores/Socket	Recommended BIOS Numa Option: Microsoft* SQL Server (2016-2022)
Intel® Xeon® 6700 series with P-cores	≤ 64 cores	SNC2
Intel® Xeon® 6700 series with P-cores	> 64 cores	SNC2 + VirtualNuma
Intel® Xeon® 6700 series with E-cores	144 cores	Hex + VirtualNuma
Intel® Xeon® 6900 series with P-cores	≤ 96 cores	SNC3
Intel® Xeon® 6900 series with P-cores	> 96 cores	SNC3 + VirtualNuma
Intel® Xeon® 6900 series with E-cores	288 cores	SNC2 + VirtualNuma

4.1 Intel® VirtualNuma Enablement Steps

By default, VirtualNuma is disabled:

1. Access BIOS/Firmware Settings:
   a. Reboot the server and enter the BIOS/Firmware setup utility.
2. Enable Sub NUMA Clustering (SNC):
   a. Find the SNC option within the EDKII Menu->Socket Configuration->Uncore Configuration->Uncore General Configuration->SNC (Sub NUMA) and enable.
   b. Choose between SNC2 or SNC3 based on your specific hardware
3. Enable Intel® Virtual NUMA:
   a. Find the Virtual NUMA option within the EDKII Menu -> Socket Setup -> Common Reference Code -> VirtualNUMA and enable.
   b. Number of Virtual Numa nodes section will get visible:
      i. 0 means BIOS Firmware automatically adjust or sets the number of virtual NUMA nodes (< 64LP) based on system configuration. [Recommended]
      ii. N - User configurable to N VirtualNuma nodes.



4. Save and Exit:
   a. Save the changes and exit the BIOS/Firmware setup utility.
   b. Reboot the server to apply the new settings.

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5 Intel® VirtualNuma Description

Intel® VirtualNuma is a BIOS Knob feature introduced with 3rd Gen Intel® Xeon® processors to address the applications limitation associated with handling more than 64 processors per NUMA node. By creating multiple VirtualNuma proximity domains within a single physical NUMA node, it effectively manages < 64 processors per Numa and maintains high memory bandwidth without altering memory interleaving or LLC grouping of original on-die UMA or Numa clustering that is enabled.

Key Features and Technical Benefits:

1. **Functionality**: The ACPI (Advanced Configuration and Power Interface) BIOS mode enables the creation of multiple VirtualNuma proximity domains within a single physical NUMA node. This is achieved without altering the existing memory interleaving and Last Level Cache (LLC) grouping, thereby maintaining high memory bandwidth.
2. **OS Processor Group Creation**: The operating system interprets the ACPI tables to create processor groups based on the virtual NUMA domains as defined by the system firmware. This allows for better scalability and resource allocation in high core count environments.
3. **Latency Management**: The System Locality Information Table (SLIT) remains consistent across multiple VirtualNuma domains. This ensures uniform memory access latency, which is crucial for maintaining performance in NUMA architectures. By keeping the SLIT consistent, the system can manage memory access latency effectively, providing a balanced and predictable performance profile across all NUMA nodes.
4. **Memory BW Management**: VirtualNuma inherits memory channel interleaving properties based on the original on-die NUMA clustering that is enabled on system. This applies to any given 2/4/8/16/32 socket platform.
5. **Performance expectations:** It is important to note that Virtual NUMA is not a standalone performance feature. It is an additional feature to address 64LP per Numa limitations that comes with certain applications. It should be enabled in conjunction with your preferred UMA or NUMA configuration hence the performance expectations when enabling Virtual NUMA will align with the underlying original on-die UMA or NUMA settings for a given workload, ensuring that it does not introduce unexpected performance variations.

5.1 Proper Use Of VirtualNuma

VirtualNuma should only be enabled on top of the preferred UMA or NUMA settings for application. Since it is not a standalone BIOS Numa performance Knob, Intel VirtualNuma should not be evaluated by comparing (SNC Disable + VirtualNuma ON) vs (SNC enabled +VirtualNuma ON), such comparisons are misleading to understand and conclude the effectiveness of VirtualNuma. This comparison essentially equates to comparing quad or hex (UMA) configurations with SNC-enabled configurations.

VirtualNuma is an additional feature to address 64LP per Numa limitations that comes with applications. It inherits performance expectations of the original UMA or NUMA clustering for a given workload.

Table 5-1: Summarizes Concise Overview on the Configuration and Behavior of the System Based on the SNC and VirtualNuma Settings

SNC Setting	VirtualNuma Setting	Notes
Disable	Enable	• SRAT reports Multiple Proximity domains (VNUMA nodes) with fewer than 64 logical processors (LPs). • Each VNUMA owns equal memory capacity. • Inherits quad or hex channel interleaving (if all channels are populated). • LLC access routing is uniform via all memory controllers within the socket.
SNC2 Enable	Enable	• SRAT reports Multiple Proximity domains (VNUMA nodes) with fewer than 64 LPs per NUMA node on top of SNC physical NUMA nodes. • Socket = SNC2 NUMA nodes + VNUMA nodes. • Each VNUMA owns equal memory capacity. • Inherits SNC2 channel interleaving (if all channels are populated). • Inherits SNC2 LLC access routing via memory controller split.
SNC3 Enable	Enable	• SRAT reports Multiple Proximity domains (VNUMA nodes) with fewer than 64 LPs per NUMA node on top of SNC3 physical NUMA nodes. • Socket = SNC3 NUMA nodes + VNUMA nodes. • Each VNUMA owns equal memory capacity. • Inherits SNC3 channel interleaving (if all channels are populated). • Inherits SNC3 LLC access routing via memory controller split.

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5.1.1 Intel® Xeon® 6900 series (120core CPU SKU)

SNC OFF (Hex or Quad)					
Socket	**Numa**	**Physical Cores/Numa**	**Logical Cores/Numa**	**Memory Capacity/Numa**	**Memory BW/Numa**
0	0	120	240 [0-239]	Socket 0 Mem	Max socket0 BW
1	1	120	240 [0-239]	Socket 1 Mem	Max socket1 BW

SNC3					
Socket	**Numa**	**Physical Cores/Numa**	**Logical Cores/Numa**	**Memory Capacity/Numa**	**Memory BW/Numa**
0	0	40	80 [0-79]	1/3rd Mem on S0	S0 SNC0 Numa0 BW
	1	40	80 [80-159]	1/3rd Mem on S0	S0 SNC1 Numa1 BW
	2	40	80 [160-239]	1/3rd Mem on S0	S0 SNC2 Numa2 BW
1	0	40	80 [0-79]	1/3rd Mem on S1	S1 SNC0 Numa0 BW
	1	40	80 [80-159]	1/3rd Mem on S1	S1 SNC1 Numa1 BW
	2	40	80 [160-239]	1/3rd Mem on S1	S1 SNC2 Numa2 BW

NOTE: Microsoft* SQL Server (2016-2022) limits the number of logical processors per NUMA node to 64. To prevent potential SQL server application shutdown, users should enable VirtualNUMA on top of SNC3 configuration to ensure number of logical processors per NUMA node remains within supported limits of SQL server.

SNC3 + VirtualNuma						
Socket	**Numa**	**Virtual Numa**	**Physical Cores/Numa**	**Logical Cores/Numa**	**Memory Capacity/Numa**	**Memory BW/Numa**
0	0	0	20	40 [0-39]	1/6th Mem on S0	S0 SNC0 Numa0 BW
		1	20	40 [40-79]	1/6th Mem on S0	
	1	2	20	40 [80-119]	1/6th Mem on S0	S0 SNC1 Numa1 BW
		3	20	40 [120-159]	1/6th Mem on S0	
	2	4	20	40 [160-199]	1/6th Mem on S0	S0 SNC2 Numa2 BW
		5	20	40 [200-239]	1/6th Mem on S0	
1	0	0	20	40 [0-39]	1/6th Mem on S1	S1 SNC0 Numa0 BW
		1	20	40 [40-79]	1/6th Mem on S1	
	1	2	20	40 [80-119]	1/6th Mem on S1	S1 SNC1 Numa1 BW
		3	20	40 [120-159]	1/6th Mem on S1	
	2	4	20	40 [160-199]	1/6th Mem on S1	S1 SNC2 Numa2 BW
		5	20	40 [200-239]	1/6th Mem on S1	

5.1.2 Intel® Xeon® 6700 series (86core CPU SKU)

SNC OFF (Hex or Quad)					
Socket	**Numa**	**Physical Cores/Numa**	**Logical Cores/Numa**	**Memory Capacity/Numa**	**Memory BW/Numa**
0	0	86	172 [0-171]	Socket 0 Mem	Max socket0 BW
1	1	86	172 [0-171]	Socket 1 Mem	Max socket1 BW

SNC2					
Socket	**Numa**	**Physical Cores/Numa**	**Logical Cores/Numa**	**Memory Capacity/Numa**	**Memory BW/Numa**
0	0	43	86 [0-85]	1/2 Mem on S0	S0 SNC0 Numa0 BW
	1	43	86 [86-171]	1/2 Mem on S0	S0 SNC1 Numa1 BW
1	0	43	86 [0-85]	1/2 Mem on S1	S1 SNC0 Numa0 BW
	1	43	86 [86-171]	1/2 Mem on S1	S1 SNC1 Numa1 BW

NOTE: Microsoft* SQL Server (2016 -2022) limits the number of logical processors per NUMA node to 64. To prevent potential SQL server application shutdown, users should enable VirtualNUMA on top of SNC2 configuration to ensure number of logical processors per NUMA node remains within supported limits of SQL server.

SNC2 + VirtualNuma						
Socket	**Numa**	**Virtual Numa**	**Physical Cores/Numa**	**Logical Cores/Numa**	**Memory Capacity/Numa**	**Memory BW/Numa**
0	0	0	22	44 [0-43]	1/4th Mem on S0	S0 SNC0 Numa0 BW
		1	21	42 [44-85]	1/4th Mem on S0	
	1	2	22	44 [86-129]	1/4th Mem on S0	S0 SNC1 Numa1 BW
		3	21	42 [130-171]	1/4th Mem on S0	
1	0	0	22	44 [0-43]	1/4th Mem on S1	S1 SNC0 Numa0 BW
		1	21	42 [44-85]	1/4th Mem on S1	
	1	2	22	44 [86-129]	1/4th Mem on S1	S1 SNC1 Numa1 BW
		3	21	42 [130-171]	1/4th Mem on S1	

6 Conclusion

Microsoft* SQL Server versions from 2016 to 2022 impose a limit of 64 logical processors per NUMA (Non-Uniform Memory Access) node. For high core count CPU SKUs, such as certain Intel® Xeon® 6 generation processors (Intel® Xeon® 6700/6900 series), the existing on-die clustering options like SNC2 (Sub-NUMA Clustering 2) or SNC3 (Sub-NUMA Clustering 3) are insufficient to meet this requirement. Instead, users should enable Virtual NUMA on top of SNC2 or SNC3 configurations. This approach ensures that the number of logical processors per NUMA node remains within supported limits (<64 LP/Numa), thereby preventing potential SQL Server application shutdowns.

By enabling both Intel® Sub-NUMA Clustering (SNC) and Intel® VirtualNUMA in the BIOS/Firmware settings, you can optimize the performance and stability of Microsoft* SQL Server on modern Intel CPU architectures.

It is important to note that Virtual NUMA is not a standalone performance feature. It should be enabled in conjunction with your preferred UMA or NUMA configuration for your workload. The performance expectations when enabling Virtual NUMA will align with the underlying original on-die NUMA settings for a given workload, ensuring that it does not introduce unexpected performance variations.

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7 References

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