Red Hat Enterprise Linux 7 Performance Tuning Guide

Optimizing subsystem throughput in Red Hat Enterprise Linux 7

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Abstract

The Red Hat Enterprise Linux 7 Performance Tuning Guide explains how to optimize Red Hat Enterprise Linux 7 performance. It also documents performance-related upgrades in Red Hat Enterprise Linux 7. The Performance Tuning Guide presents only field-tested and proven procedures. Nonetheless, all prospective configurations should be set up and tested in a testing environment before being applied to a production system. Backing up all data and configuration settings prior to tuning is also recommended.

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Chapter 1. Performance Features in Red Hat Enterprise Linux 7

Read this section for a brief overview of the performance-related changes included in Red Hat Enterprise Linux 7.

1.1. New in 7.1

- The kernel idle balance mechanism is now less likely to delay recently queued tasks on the same CPU, reducing processing latency when idle balancing is in use.
- The **swapon** command has a new ***--discard*** parameter. This allows administrators to select which discard policy to use when swapping, providing greater flexibility, and allowing improved performance on solid-state disks. By default, the ***--discard*** parameter discards the entire swap area when **swapon** is run, and discards free swap pages before reuse while swapping. For further information, see the **swapon** manual page: **man swapon**.
- **tuned** profiles can now be configured to alter kernel command line parameters by specifying the ***cmdline*** parameter and a list of kernel parameters in the tuned profile. Any kernel parameters specified with ***cmdline*** take effect after reboot.

1.2. New in 7.0

- This guide has been completely rewritten and restructured for Red Hat Enterprise Linux 7.
- **deadline** replaces **cfq** as the default I/O scheduler for all block devices, except for SATA disks, in Red Hat Enterprise Linux 7. This change provides better performance for most common use cases.
- The XFS file system replaces ext4 as the default file system, and is now supported to a maximum file system size of 500 TB, and a maximum file offset of 8 EB (sparse files). Tuning recommendations for XFS have been updated to assist with clarity.
- The ext4 file system is now supported to a maximum file system size of 50 TB and a maximum file size of 16 TB. Tuning recommendations have been updated accordingly. Additionally, support for the ext2 and ext3 file systems is now provided by the ext4 driver.
- The btrfs file system is now provided as a Technology Preview.
- Red Hat Enterprise Linux 7 includes some minor performance improvements for GFS2.
- **Tuna** has been updated to include support for configuration files, and adding and saving **tuned** profiles. This updated version uses event-based sampling to consume fewer processor resources. The graphical version has also been updated to allow realtime monitoring. **Tuna** is now documented in Section 2.4, “Tuna”, Section 3.3.8, “Configuring CPU, thread, and interrupt affinity with Tuna”, and Section A.2, “Tuna”.
- The default profile for **tuned** is now **throughput-performance**. This replaces the now removed **enterprise-storage** profile. Several new profiles for networking and virtualization have been added. Additionally, **tuned** now provides shell script callout and ***includes*** functionality.
- The **tuned-adm** tool now provides the **recommend** sub-command, which recommends an appropriate tuning profile for your system. This also sets the default profile for your system at install time, so can be used to return to the default profile.

- Red Hat Enterprise Linux 7 provides support for automatic NUMA balancing. The kernel now automatically detects which memory pages process threads are actively using, and groups the threads and their memory into or across NUMA nodes. The kernel reschedules threads and migrates memory to balance the system for optimal NUMA alignment and performance.
- The performance penalty to enabling file system barriers is now negligible (less than 3%). As such, **tuned** profiles no longer disable file system barriers.
- OProfile adds support for profiling based on the Linux Performance Events subsystem with the new **operf** tool. This new tool can be used to collect data in place of the **opcontrol** daemon.
- Control groups remain available as a method of allocating resources to certain groups of processes on your system. For detailed information about implementation in Red Hat Enterprise Linux 7, see the *Red Hat Enterprise Linux 7 Resource Management Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

Chapter 2. Performance Monitoring Tools

This chapter briefly describes some of the performance monitoring and configuration tools available for Red Hat Enterprise Linux 7. Where possible, this chapter directs readers to further information about how to use the tool, and examples of real life situations that the tool can be used to resolve.

The following knowledge base article provides a more comprehensive list of performance monitoring tools suitable for use with Red Hat Enterprise Linux: https://access.redhat.com/site/solutions/173863.

2.1. /proc

The **/proc** "file system" is a directory that contains a hierarchy of files that represent the current state of the Linux kernel. It allows users and applications to see the kernel's view of the system.

The **/proc** directory also contains information about system hardware and any currently running processes. Most files in the **/proc** file system are read-only, but some files (primarily those in /proc/sys) can be manipulated by users and applications to communicate configuration changes to the kernel.

For further information about viewing and editing files in the **/proc** directory, refer to the Red Hat Enterprise Linux 7 System Administrator's Reference Guide, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

2.2. GNOME System Monitor

The GNOME desktop environment includes a graphical tool, System Monitor, to assist you in monitoring and modifying the behavior of your system. System Monitor displays basic system information and allows you to monitor system processes and resource or file system usage.

System Monitor has four tabs, each of which displays different information about the system.

System

This tab displays basic information about the system's hardware and software.

Processes

This tab displays detailed information about active processes and the relationships between those processes. The processes displayed can be filtered to make certain processes easier to find. This tab also lets you perform some actions on the processes displayed, such as start, stop, kill, and change priority.

Resources

This tab displays the current CPU time usage, memory and swap space usage, and network usage.

File Systems

This tab lists all mounted file systems, and provides some basic information about each, such as the file system type, mount point, and memory usage.

To start System Monitor, press the Super key to enter the Activities Overview, type *System Monitor*, and then press Enter.

For more information about System Monitor, see either the Help menu in the application, or the Red Hat Enterprise Linux 7 *System Administrator's Guide*, available from

http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

2.3. Performance Co-Pilot (PCP)

Red Hat Enterprise Linux 7 introduces support for **Performance Co-Pilot** (**PCP**), a suite of tools, services, and libraries for acquiring, storing, and analyzing system-level performance measurements. Its light-weight distributed architecture makes it particularly well-suited for centralized analysis of complex systems. Performance metrics can be added using the Python, Perl, C++, and C interfaces. Analysis tools can use the client APIs (Python, C++, C) directly, and rich web applications can explore all available performance data using a JSON interface.

The Performance Co-Pilot Collection Daemon (**pmcd**) is responsible for collecting performance data on the host system, and various client tools, such as **pminfo** or **pmstat**, can be used to retrieve, display, archive, and process this data on the same host or over the network. The *pcp* package provides the command-line tools and underlying functionality. The graphical tool also requires the *pcp-gui* package.

For a list of system services and tools that are distributed with PCP, see Table A.1, “System Services Distributed with Performance Co-Pilot in Red Hat Enterprise Linux 7” and Table A.2, “Tools Distributed with Performance Co-Pilot in Red Hat Enterprise Linux 7”.

Resources

- For information on PCP, see the Index of Performance Co-Pilot (PCP) articles, solutions, tutorials and white papers on the Red Hat Customer Portal.
- The manual page named **PCPIntro** serves as an introduction to Performance Co-Pilot. It provides a list of available tools as well as a description of available configuration options and a list of related manual pages. By default, comprehensive documentation is installed in the **/usr/share/doc/pcp-doc/** directory, notably the *Performance Co-Pilot User's and Administrator's Guide* and *Performance Co-Pilot Programmer's Guide*.
- See the official PCP documentation for an in-depth description of the Performance Co-Pilot and its usage. If you want to start using PCP on Red Hat Enterprise Linux quickly, see the PCP Quick Reference Guide. The official PCP website also contains a list of frequently asked questions.

2.4. Tuna

Tuna adjusts configuration details such as scheduler policy, thread priority, and CPU and interrupt affinity. The *tuna* package provides a command line tool and a graphical interface with equivalent functionality.

Section 3.3.8, “Configuring CPU, thread, and interrupt affinity with Tuna” describes how to configure your system with Tuna on the command line. For details about how to use Tuna, see Section A.2, “Tuna” or the man page:

```
$ man tuna
```

2.5. Built in command line tools

Red Hat Enterprise Linux 7 provides several tools that can be used to monitor your system from the command line, allowing you to monitor your system outside run level 5. This chapter discusses each tool briefly and provides links to further information about where each tool should be used, and how to use them.

2.5.1. top

The top tool, provided by the *procps-ng* package, gives a dynamic view of the processes in a running system. It can display a variety of information, including a system summary and a list of tasks currently being managed by the Linux kernel. It also has a limited ability to manipulate processes, and to make configuration changes persistent across system restarts.

By default, the processes displayed are ordered according to the percentage of CPU usage, so that you can easily see the processes consuming the most resources. Both the information top displays and its operation are highly configurable to allow you to concentrate on different usage statistics as required.

For detailed information about using top, see the man page:

```
$ man top
```

2.5.2. ps

The ps tool, provided by the *procps-ng* package, takes a snapshot of a select group of active processes. By default, the group examined is limited to processes that are owned by the current user and associated with the terminal in which ps is run.

ps can provide more detailed information about processes than top, but by default it provides a single snapshot of this data, ordered by process identifier.

For detailed information about using ps, see the man page:

```
$ man ps
```

2.5.3. Virtual Memory Statistics (vmstat)

The Virtual Memory Statistics tool, vmstat, provides instant reports on your system's processes, memory, paging, block input/output, interrupts, and CPU activity. Vmstat lets you set a sampling interval so that you can observe system activity in near-real time.

vmstat is provided by the *procps-ng* package. For detailed information about using vmstat, see the man page:

```
$ man vmstat
```

2.5.4. System Activity Reporter (sar)

The System Activity Reporter, sar, collects and reports information about system activity that has occurred so far on the current day. The default output displays the current day's CPU usage at 10 minute intervals from the beginning of the day (00:00:00 according to your system clock).

You can also use the **-i** option to set the interval time in seconds, for example, **sar -i 60** tells sar to check CPU usage every minute.

sar is a useful alternative to manually creating periodic reports on system activity with top. It is provided by the *sysstat* package. For detailed information about using sar, see the man page:

```
$ man sar
```

2.6. tuned and tuned-adm

The **tuned** tuning service can adapt the operating system to perform better under certain workloads by setting a tuning profile. The **tuned-adm** command-line tool allows users to switch between different tuning profiles.

tuned Profiles Overview

Several pre-defined profiles are included for common use cases, but **tuned-adm** also enables you to define custom profiles, which can be either based on one of the pre-defined profiles, or defined from scratch. In Red Hat Enterprise Linux 7, the default profile is **throughput-performance**.

The profiles provided with **tuned-adm** are divided into two categories: power-saving profiles, and performance-boosting profiles. The performance-boosting profiles include profiles focus on the following aspects:

- low latency for storage and network
- high throughput for storage and network
- virtual machine performance
- virtualization host performance

tuned Boot Loader plug-in

You can use the **tuned Bootloader plug-in** to add parameters to the kernel (boot or dracut) command line. Note that only the GRUB 2 boot loader is supported and a reboot is required to apply profile changes. For example, to add the ***quiet*** parameter to a **tuned** profile, include the following lines in the **tuned.conf** file:

```
[bootloader]
cmdline=quiet
```

Switching to another profile removes the additional parameters. If you stop **tuned**, the parameters persist in the **grub.cfg** file.

Environment Variables and Expanding tuned Built-In Functions

If you run **tuned-adm profile *profile_name*** and then **grub2-mkconfig -o *profile_path*** after updating GRUB 2 configuration, you can use Bash environment variables, which are expanded after running **grub2-mkconfig**. For example, the following environment variable is expanded to **nfsroot=/root**:

```
[bootloader]
cmdline="nfsroot=$HOME"
```

You can use **tuned** variables as an alternative to environment variables. In the following example, **${isolated_cores}** expands to **1,2**, so the kernel boots with the **isolcpus=1,2** parameter:

```
[variables]
isolated_cores=1,2

[bootloader]
cmdline=isolcpus=${isolated_cores}
```

In the following example, **${non_isolated_cores}** expands to **0,3-5**, and the **cpulist_invert** built-in function is called with the **0,3-5** arguments:

```
[variables]
non_isolated_cores=0,3-5

[bootloader]
cmdline=isolcpus=${f:cpulist_invert:${non_isolated_cores}}
```

The **cpulist_invert** function inverts the list of CPUs. For a 6-CPU machine, the inversion is **1,2**, and the kernel boots with the **isolcpus=1,2** command-line parameter.

Using **tuned** environment variables reduces the amount of necessary typing. You can also use various built-in functions together with **tuned** variables. If the built-in functions do not satisfy your needs, you can create custom functions in Python and add them to **tuned** in the form of plug-ins. Variables and built-in functions are expanded at run time when the tuned profile is activated.

The variables can be specified in a separate file. You can, for example, add the following lines to **tuned.conf**:

```
[variables]
include=/etc/tuned/my-variables.conf

[bootloader]
cmdline=isolcpus=${isolated_cores}
```

If you add **isolated_cores=1,2** to the **/etc/tuned/*my-variables.conf*** file, the kernel boots with the **isolcpus=1,2** parameter.

Modifying Default System tuned Profiles

There are two ways of modifying the default system **tuned** profiles. You can either create a new **tuned** profile directory, or copy the directory of a system profile and edit the profile as needed.

Procedure 2.1. Creating a new tuned Profile Directory

1. In **/etc/tuned/**, create a new directory named the same as the profile you want to create: **/etc/tuned/*my_profile_name*/**.
2. In the new directory, create a file named **tuned.conf**, and include the following lines at the top:

   ```
   [main]
   include=profile_name
   ```

3. Include your profile modifications. For example, to use the settings from the **throughput-performance** profile with the value of **vm.swappiness** set to 5, instead of default 10, include the following lines:

```
[main]
include=throughput-performance

[sysctl]
vm.swappiness=5
```

4. To activate the profile, run:

```
# tuned-adm profile my_profile_name
```

Creating a directory with a new **tuned.conf** file enables you to keep all your profile modifications after system **tuned** profiles are updated.

Alternatively, copy the directory with a system profile from **/user/lib/tuned/** to **/etc/tuned/**. For example:

```
# cp -r /usr/lib/tuned/throughput-performance /etc/tuned
```

Then, edit the profile in **/etc/tuned** according to your needs. Note that if there are two profiles of the same name, the profile located in **/etc/tuned/** is loaded. The disadvantage of this approach is that if a system profile is updated after a **tuned** upgrade, the changes will not be reflected in the now-outdated modified version.

Resources

For more information, see Section A.5, “tuned” and Section A.6, “tuned-adm”.

For detailed information on **tuned** and power-saving profiles provided with **tuned-adm**, see section 2.5. Tuned in the *Red Hat Enterprise Linux 7 Power Management Guide*.

For detailed information on using **tuned** and **tuned-adm**, see the tuned(8) and tuned-adm(1) manual pages.

2.7. perf

The perf tool uses hardware performance counters and kernel tracepoints to track the impact of other commands and applications on your system. Various perf subcommands display and record statistics for common performance events, and analyze and report on the data recorded.

For detailed information about perf and its subcommands, see Section A.7, “perf”.

Alternatively, more information is available in the Red Hat Enterprise Linux 7 *Developer Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

2.8. turbostat

Turbostat is provided by the *kernel-tools* package. It reports on processor topology, frequency, idle power-state statistics, temperature, and power usage on Intel® 64 processors.

Turbostat is useful for identifying servers that are inefficient in terms of power usage or idle time. It also helps to identify the rate of system management interrupts (SMIs) occurring on the system. It can also be used to verify the effects of power management tuning.

Turbostat requires root privileges to run. It also requires processor support for the following:

- invariant time stamp counters
- APERF model-specific registers
- MPERF model-specific registers

For more details about turbostat output and how to read it, see Section A.11, “turbostat”.

For more information about turbostat, see the man page:

```
$ man turbostat
```

2.9. iostat

The **iostat** tool is provided by the *sysstat* package. It monitors and reports on system input/output device loading to help administrators make decisions about how to balance input/output load between physical disks. It reports on processor or device utilization since iostat was last run, or since boot. You can focus the output of these reports on specific devices by using the parameters defined in the iostat man page:

```
$ man iostat
```

2.10. irqbalance

irqbalance is a command line tool that distributes hardware interrupts across processors to improve system performance. For details about **irqbalance**, see Section A.1, “irqbalance” or the man page:

```
$ man irqbalance
```

2.11. ss

ss is a command-line utility that prints statistical information about sockets, allowing administrators to assess device performance over time. By default, ss lists open non-listening TCP sockets that have established connections, but a number of useful options are provided to help administrators filter out statistics about specific sockets.

Red Hat recommends using ss over netstat in Red Hat Enterprise Linux 7.

One common usage is **`ss -tmpie`** which displays detailed information (including internal information) about TCP sockets, memory usage, and processes using the socket.

ss is provided by the *iproute* package. For more information, see the man page:

```
$ man ss
```

2.12. numastat

The **numastat** tool displays memory statistics for processes and the operating system on a per-NUMA-node basis.

By default, **numastat** displays per-node NUMA hit an miss system statistics from the kernel memory allocator. Optimal performance is indicated by high **numa_hit** values and low **numa_miss** values. **Numastat** also provides a number of command line options, which can show how system and process memory is distributed across NUMA nodes in the system.

It can be useful to cross-reference per-node **numastat** output with per-CPU **top** output to verify that process threads are running on the same node to which memory is allocated.

Numastat is provided by the *numactl* package. For details about how to use numastat, see Section A.12, “numastat”. For further information about numastat, see the man page:

```
$ man numastat
```

2.13. numad

numad is an automatic NUMA affinity management daemon. It monitors NUMA topology and resource usage within a system in order to dynamically improve NUMA resource allocation and management (and therefore system performance). Depending on system workload, numad can provide up to 50 percent improvements in performance benchmarks. It also provides a pre-placement advice service that can be queried by various job management systems to provide assistance with the initial binding of CPU and memory resources for their processes.

numad monitors available system resources on a per-node basis by periodically accessing information in the **/proc** file system. It tries to maintain a specified resource usage level, and rebalances resource allocation when necessary by moving processes between NUMA nodes. numad attempts to achieve optimal NUMA performance by localizing and isolating significant processes on a subset of the system's NUMA nodes.

numad primarily benefits systems with long-running processes that consume significant amounts of resources, and are contained in a subset of the total system resources. It may also benefit applications that consume multiple NUMA nodes' worth of resources; however, the benefits provided by numad decrease as the consumed percentage of system resources increases.

numad is unlikely to improve performance when processes run for only a few minutes, or do not consume many resources. Systems with continuous, unpredictable memory access patterns, such as large in-memory databases, are also unlikely to benefit from using numad.

For further information about using numad, see Section 3.3.5, “Automatic NUMA affinity management with numad” or Section A.14, “numad”, or refer to the man page:

```
$ man numad
```

2.14. SystemTap

SystemTap is a tracing and probing tool that lets you monitor and analyze operating system activities, especially kernel activities, in fine detail. It provides information similar to the output of tools like top, ps, netstat, and iostat, but includes additional options for filtering and analyzing collected data.

SystemTap provides a deeper, more precise analysis of system activities and application behavior to allow you to pinpoint system and application bottlenecks.

For more detailed information about SystemTap, see the Red Hat Enterprise Linux 7 *SystemTap Beginner's Guide* and the Red Hat Enterprise Linux 7 *SystemTap TapSet Reference*. Both books are available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

2.15. OProfile

OProfile is a system-wide performance monitoring tool. It uses the processor's dedicated performance monitoring hardware to retrieve information about the kernel and system executables to determine the frequency of certain events, such as when memory is referenced, the number of second-level cache requests, and the number of hardware requests received. OProfile can also be used to determine processor usage, and to determine which applications and services are used most often.

However, OProfile does have several limitations:

- Performance monitoring samples may not be precise. Because the processor may execute instructions out of order, samples can be recorded from a nearby instruction instead of the instruction that triggered the interrupt.
- OProfile expects processes to start and stop multiple times. As such, samples from multiple runs are allowed to accumulate. You may need to clear the sample data from previous runs.
- OProfile focuses on identifying problems with processes limited by CPU access. It is therefore not useful for identifying processes that are sleeping while they wait for locks on other events.

For more detailed information about OProfile, see Section A.15, “OProfile”, or the *Red Hat Enterprise Linux 7 System Administrator's Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/. Alternatively, refer to the documentation on your system, located in **/usr/share/doc/oprofile-*version***.

2.16. Valgrind

Valgrind provides a number of detection and profiling tools to help improve the performance of your applications. These tools can detect memory and thread-related errors, as well as heap, stack, and array overruns, letting you easily locate and correct errors in your application code. They can also profile the cache, the heap, and branch-prediction to identify factors that may increase application speed and minimize memory usage.

Valgrind analyzes your application by running it on a synthetic CPU and instrumenting existing application code as it is executed. It then prints commentary that clearly identifies each process involved in application execution to a user-specified file, file descriptor, or network socket. Note that executing instrumented code can take between four and fifty times longer than normal execution.

Valgrind can be used on your application as-is, without recompiling. However, because Valgrind uses debugging information to pinpoint issues in your code, if your application and support libraries were not compiled with debugging information enabled, Red Hat recommends recompiling to include this information.

Valgrind also integrates with the GNU Project Debugger (gdb) to improve debugging efficiency.

Valgrind and its subordinate tools are useful for memory profiling. For detailed information about using Valgrind to profile system memory, see Section 4.2.2, “Profiling application memory usage with Valgrind”.

For detailed information about Valgrind, see the Red Hat Enterprise Linux 7 Developer Guide, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

For detailed information about using Valgrind, see the man page:

```
$ man valgrind
```

Accompanying documentation can also be found in **/usr/share/doc/valgrind-*version*** when the valgrind package is installed.

Chapter 3. CPU

This chapter outlines CPU hardware details and configuration options that affect application performance in Red Hat Enterprise Linux 7. Section 3.1, “Considerations” discusses the CPU related factors that affect performance. Section 3.2, “Monitoring and diagnosing performance problems” teaches you how to use Red Hat Enterprise Linux 7 tools to diagnose performance problems related to CPU hardware or configuration details. Section 3.3, “Configuration suggestions” discusses the tools and strategies you can use to solve CPU related performance problems in Red Hat Enterprise Linux 7.

3.1. Considerations

Read this section to gain an understanding of how system and application performance is affected by the following factors:

- How processors are connected to each other and to related resources like memory.
- How processors schedule threads for execution.
- How processors handle interrupts in Red Hat Enterprise Linux 7.

3.1.1. System Topology

In modern computing, the idea of a *central* processing unit is a misleading one, as most modern systems have multiple processors. How these processors are connected to each other and to other system resources — the *topology* of the system — can greatly affect system and application performance, and the tuning considerations for a system.

There are two primary types of topology used in modern computing:

Symmetric Multi-Processor (SMP) topology

SMP topology allows all processors to access memory in the same amount of time. However, because shared and equal memory access inherently forces serialized memory accesses from all the CPUs, SMP system scaling constraints are now generally viewed as unacceptable. For this reason, practically all modern server systems are NUMA machines.

Non-Uniform Memory Access (NUMA) topology

NUMA topology was developed more recently than SMP topology. In a NUMA system, multiple processors are physically grouped on a socket. Each socket has a dedicated area of memory, and processors that have local access to that memory are referred to collectively as a node.

Processors on the same node have high speed access to that node's memory bank, and slower access to memory banks not on their node. Therefore, there is a performance penalty to accessing non-local memory.

Given this performance penalty, performance sensitive applications on a system with NUMA topology should access memory that is on the same node as the processor executing the application, and should avoid accessing remote memory wherever possible.

When tuning application performance on a system with NUMA topology, it is therefore important to consider where the application is being executed, and which memory bank is closest to the point of execution.

In a system with NUMA topology, the **/sys** file system contains information about how

processors, memory, and peripheral devices are connected. The **/sys/devices/system/cpu** directory contains details about how processors in the system are connected to each other. The **/sys/devices/system/node** directory contains information about NUMA nodes in the system, and the relative distances between those nodes.

3.1.1.1. Determining system topology

There are a number of commands that can help you understand the topology of your system. The **numactl --hardware** command gives an overview of your system's topology.

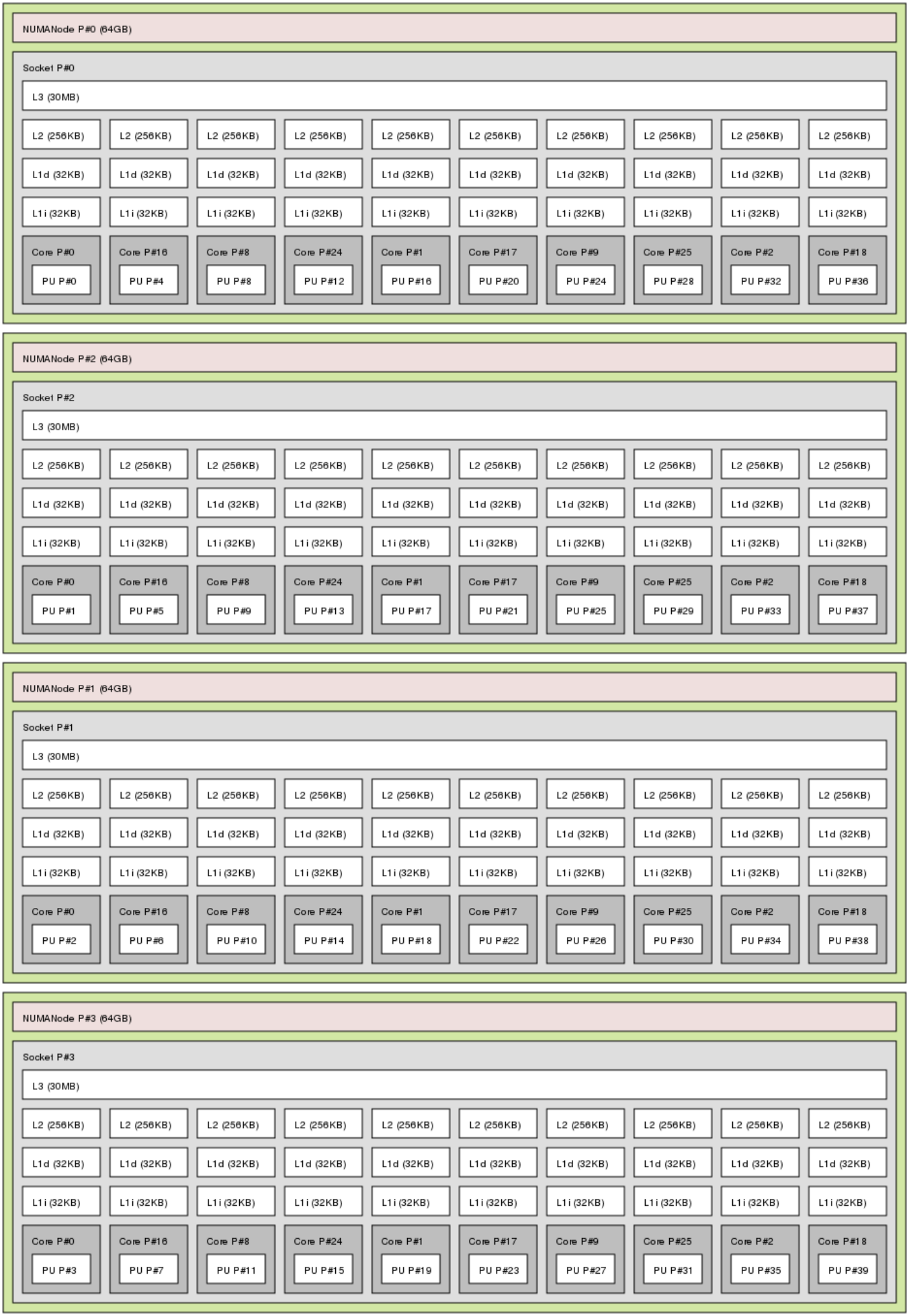
```
$ numactl --hardware
available: 4 nodes (0-3)
node 0 cpus: 0 4 8 12 16 20 24 28 32 36
node 0 size: 65415 MB
node 0 free: 43971 MB
node 1 cpus: 2 6 10 14 18 22 26 30 34 38
node 1 size: 65536 MB
node 1 free: 44321 MB
node 2 cpus: 1 5 9 13 17 21 25 29 33 37
node 2 size: 65536 MB
node 2 free: 44304 MB
node 3 cpus: 3 7 11 15 19 23 27 31 35 39
node 3 size: 65536 MB
node 3 free: 44329 MB
node distances:
node   0   1   2   3
  0:  10  21  21  21
  1:  21  10  21  21
  2:  21  21  10  21
  3:  21  21  21  10
```

The **lscpu** command, provided by the *util-linux* package, gathers information about the CPU architecture, such as the number of CPUs, threads, cores, sockets, and NUMA nodes.

```
$ lscpu
Architecture:          x86_64
CPU op-mode(s):        32-bit, 64-bit
Byte Order:            Little Endian
CPU(s):                40
On-line CPU(s) list:   0-39
Thread(s) per core:    1
Core(s) per socket:    10
Socket(s):             4
NUMA node(s):          4
Vendor ID:             GenuineIntel
CPU family:            6
Model:                 47
Model name:            Intel(R) Xeon(R) CPU E7- 4870  @ 2.40GHz
Stepping:              2
CPU MHz:               2394.204
BogoMIPS:              4787.85
Virtualization:        VT-x
L1d cache:             32K
L1i cache:             32K
```

```
L2 cache:              256K
L3 cache:              30720K
NUMA node0 CPU(s):     0,4,8,12,16,20,24,28,32,36
NUMA node1 CPU(s):     2,6,10,14,18,22,26,30,34,38
NUMA node2 CPU(s):     1,5,9,13,17,21,25,29,33,37
NUMA node3 CPU(s):     3,7,11,15,19,23,27,31,35,39
```

The **lstopo** command, provided by the *hwloc* package, creates a graphical representation of your system. The **lstopo-no-graphics** command provides detailed textual output.



Output of lstopo command

3.1.2. Scheduling

In Red Hat Enterprise Linux, the smallest unit of process execution is called a *thread*. The system scheduler determines which processor runs a thread, and for how long the thread runs. However, because the scheduler's primary concern is to keep the system busy, it may not schedule threads optimally for application performance.

For example, say an application on a NUMA system is running on Node A when a processor on Node B becomes available. To keep the processor on Node B busy, the scheduler moves one of the application's threads to Node B. However, the application thread still requires access to memory on Node A. Because the thread is now running on Node B, and Node A memory is no longer local to the thread, it will take longer to access. It may take longer for the thread to finish running on Node B than it would have taken to wait for a processor on Node A to become available, and to execute the thread on the original node with local memory access.

Performance sensitive applications often benefit from the designer or administrator determining where threads are run. For details about how to ensure threads are scheduled appropriately for the needs of performance sensitive applications, see Section 3.3.6, “Tuning scheduling policy”.

3.1.2.1. Kernel Ticks

In previous versions of Red Hat Enterprise Linux, the Linux kernel interrupted each CPU on a regular basis to check what work needed to be done. It used the results to make decisions about process scheduling and load balancing. This regular interruption was known as a kernel *tick*.

This tick occurred regardless of whether there was work for the core to do. This meant that even idle cores were forced into higher power states on a regular basis (up to 1000 times per second) to respond to the interrupts. This prevented the system from effectively using deep sleep states included in recent generations of x86 processors.

In Red Hat Enterprise Linux 6 and 7, by default, the kernel no longer interrupts idle CPUs, which tend to be in low power states. This behavior is known as the tickless kernel. Where one or fewer tasks are running, periodic interrupts have been replaced with on-demand interrupts, allowing CPUs to remain in an idle or low power state for longer, and reducing power usage.

Red Hat Enterprise Linux 7 offers a dynamic tickless option (**`nohz_full`**) to further improve determinism by reducing kernel interference with user-space tasks. This option can be enabled on specified cores with the ***`nohz_full`*** kernel parameter. When this option is enabled on a core, all timekeeping activities are moved to non-latency-sensitive cores. This can be useful for high performance computing and realtime computing workloads where user-space tasks are particularly sensitive to microsecond-level latencies associated with the kernel timer tick.

For details on how to enable the dynamic tickless behavior in Red Hat Enterprise Linux 7, see Section 3.3.1, “Configuring kernel tick time”.

3.1.3. Interrupt Request (IRQ) Handling

An interrupt request or IRQ is a signal for immediate attention sent from a piece of hardware to a processor. Each device in a system is assigned one or more IRQ numbers to allow it to send unique interrupts. When interrupts are enabled, a processor that receives an interrupt request will immediately pause execution of the current application thread in order to address the interrupt request.

Because they halt normal operation, high interrupt rates can severely degrade system performance. It is possible to reduce the amount of time taken by interrupts by configuring interrupt affinity or by sending a number of lower priority interrupts in a batch (*coalescing* a number of interrupts).

For more information about tuning interrupt requests, see Section 3.3.7, “Setting interrupt affinity” or Section 3.3.8, “Configuring CPU, thread, and interrupt affinity with Tuna”. For information specific to network interrupts, see Chapter 6, *Networking*.

3.2. Monitoring and diagnosing performance problems

Red Hat Enterprise Linux 7 provides a number of tools that are useful for monitoring system performance and diagnosing performance problems related to processors and their configuration. This section outlines the available tools and gives examples of how to use them to monitor and diagnose processor related performance issues.

3.2.1. turbostat

Turbostat prints counter results at specified intervals to help administrators identify unexpected behavior in servers, such as excessive power usage, failure to enter deep sleep states, or system management interrupts (SMIs) being created unnecessarily.

The **turbostat** tool is part of the *kernel-tools* package. It is supported for use on systems with AMD64 and Intel® 64 processors. It requires root privileges to run, and processor support for invariant time stamp counters, and APERF and MPERF model specific registers.

For usage examples, see the man page:

```
$ man turbostat
```

3.2.2. numastat

Important

This tool received substantial updates in the Red Hat Enterprise Linux 6 life cycle. While the default output remains compatible with the original tool written by Andi Kleen, supplying any options or parameters to numastat significantly changes the format of its output.

The **numastat** tool displays per-NUMA node memory statistics for processes and the operating system and shows administrators whether process memory is spread throughout a system or centralized on specific nodes.

Cross reference **numastat** output with per-processor **top** output to confirm that process threads are running on the same node from which process memory is allocated.

Numastat is provided by the *numactl* package. For further information about **numastat** output, see the man page:

```
$ man numastat
```

3.2.3. /proc/interrupts

The **/proc/interrupts** file lists the number of interrupts sent to each processor from a particular I/O device. It displays the interrupt request (IRQ) number, the number of that type of interrupt request handled by each processor in the system, the type of interrupt sent, and a comma-separated list of devices that respond to the listed interrupt request.

If a particular application or device is generating a large number of interrupt requests to be handled by a remote processor, its performance is likely to suffer. In this case, poor performance can be alleviated by having a processor on the same node as the application or device handle the interrupt requests. For details on how to assign interrupt handling to a specific processor, see Section 3.3.7, “Setting interrupt affinity”.

3.3. Configuration suggestions

Red Hat Enterprise Linux provides a number of tools to assist administrators in configuring the system. This section outlines the available tools and provides examples of how they can be used to solve processor related performance problems in Red Hat Enterprise Linux 7.

3.3.1. Configuring kernel tick time

By default, Red Hat Enterprise Linux 7 uses a tickless kernel, which does not interrupt idle CPUs in order to reduce power usage and allow newer processors to take advantage of deep sleep states.

Red Hat Enterprise Linux 7 also offers a dynamic tickless option (disabled by default), which is useful for very latency-sensitive workloads, such as high performance computing or realtime computing.

To enable dynamic tickless behavior in certain cores, specify those cores on the kernel command line with the ***nohz_full*** parameter. On a 16 core system, specifying **nohz_full=1-15** enables dynamic tickless behavior on cores 1 through 15, moving all timekeeping to the only unspecified core (core 0). This behavior can be enabled either temporarily at boot time, or persistently in the **/etc/default/grub** file. For persistent behavior, run the **grub2-mkconfig -o /boot/grub2/grub.cfg** command to save your configuration.

Enabling dynamic tickless behavior does require some manual administration.

- When the system boots, you must manually move rcu threads to the non-latency-sensitive core, in this case core 0.

```
# for i in `pgrep rcu[^c]` ; do taskset -pc 0 $i ; done
```

- Use the ***isolcpus*** parameter on the kernel command line to isolate certain cores from user-space tasks.
- Optionally, set CPU affinity for the kernel's write-back bdi-flush threads to the housekeeping core:

```
echo 1 > /sys/bus/workqueue/devices/writeback/cpumask
```

Verify that the dynamic tickless configuration is working correctly by executing the following command, where *stress* is a program that spins on the CPU for 1 second.

```
# perf stat -C 1 -e irq_vectors:local_timer_entry taskset -c 1 stress -t
1 -c 1
```

One possible replacement for *stress* is a script that runs something like **while :; do d=1; done**. The program available at the following link is another suitable replacement: https://dl.fedoraproject.org/pub/epel/6/x86_64/repoview/stress.html.

The default kernel timer configuration shows 1000 ticks on a busy CPU:

```
# perf stat -C 1 -e irq_vectors:local_timer_entry taskset -c 1 stress -t
1 -c 1
1000 irq_vectors:local_timer_entry
```

With the dynamic tickless kernel configured, you should see 1 tick instead:

```
# perf stat -C 1 -e irq_vectors:local_timer_entry taskset -c 1 stress -t
1 -c 1
1 irq_vectors:local_timer_entry
```

3.3.2. Setting hardware performance policy (x86_energy_perf_policy)

The **x86_energy_perf_policy** tool allows administrators to define the relative importance of performance and energy efficiency. This information can then be used to influence processors that support this feature when they select options that trade off between performance and energy efficiency.

By default, it operates on all processors in **performance** mode. It requires processor support, which is indicated by the presence of **CPUID.06H.ECX.bit3**, and must be run with root privileges.

x86_energy_perf_policy is provided by the *kernel-tools* package. For details of how to use **x86_energy_perf_policy**, see Section A.10, “x86_energy_perf_policy” or refer to the man page:

```
$ man x86_energy_perf_policy
```

3.3.3. Setting process affinity with taskset

The **taskset** tool is provided by the *util-linux* package. **Taskset** allows administrators to retrieve and set the processor affinity of a running process, or launch a process with a specified processor affinity.

Important

taskset does not guarantee local memory allocation. If you require the additional performance benefits of local memory allocation, Red Hat recommends using **numactl** instead of **taskset**.

For more information about **taskset**, see Section A.16, “taskset” or the man page:

```
$ man taskset
```

3.3.4. Managing NUMA affinity with numactl

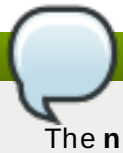
Administrators can use **numactl** to run a process with a specified scheduling or memory placement policy. **Numactl** can also set a persistent policy for shared memory segments or files, and set the processor affinity and memory affinity of a process.

In a system with NUMA topology, a processor's memory access slows as the distance between the processor and the memory bank increases. Therefore, it is important to configure applications that are sensitive to performance so that they allocate memory from the closest possible memory bank. It is best to use memory and CPUs that are in the same NUMA node.

Multi-threaded applications that are sensitive to performance may benefit from being configured to execute on a specific NUMA node rather than a specific processor. Whether this is suitable depends on your system and the requirements of your application. If multiple application threads access the same cached data, then configuring those threads to execute on the same processor may be suitable. However, if multiple threads that access and cache different data execute on the same processor, each thread may evict cached data accessed by a previous thread. This means that each thread 'misses' the cache, and wastes execution time fetching data from disk and replacing it in the cache. You can use the **perf** tool, as documented in Section A.7, “perf”, to check for an excessive number of cache misses.

Numactl provides a number of options to assist you in managing processor and memory affinity. See Section A.12, “numastat” or the man page for details:

```
$ man numactl
```



Note

The **numactl** package includes the **libnuma** library. This library offers a simple programming interface to the NUMA policy supported by the kernel, and can be used for more fine-grained tuning than the **numactl** application. For more information, see the man page:

```
$ man numa
```

3.3.5. Automatic NUMA affinity management with numad

numad is an automatic NUMA affinity management daemon. It monitors NUMA topology and resource usage within a system in order to dynamically improve NUMA resource allocation and management.

numad also provides a pre-placement advice service that can be queried by various job management systems to provide assistance with the initial binding of CPU and memory resources for their processes. This pre-placement advice is available regardless of whether numad is running as an executable or a service.

For details of how to use **numad**, see Section A.14, “numad” or refer to the man page:

```
$ man numad
```

3.3.6. Tuning scheduling policy

The Linux scheduler implements a number of scheduling policies, which determine where and for how long a thread runs. There are two major categories of scheduling policies: normal policies and realtime policies. Normal threads are used for tasks of normal priority. Realtime policies are used for time-sensitive tasks that must complete without interruptions.

Realtime threads are not subject to time slicing. This means they will run until they block, exit, voluntarily yield, or are pre-empted by a higher priority thread. The lowest priority realtime thread is scheduled before any thread with a normal policy.

3.3.6.1. Scheduling policies

3.3.6.1.1. Static priority scheduling with SCHED_FIFO

SCHED_FIFO (also called static priority scheduling) is a realtime policy that defines a fixed priority for each thread. This policy allows administrators to improve event response time and reduce latency, and is recommended for time sensitive tasks that do not run for an extended period of time.

When **SCHED_FIFO** is in use, the scheduler scans the list of all **SCHED_FIFO** threads in priority order and schedules the highest priority thread that is ready to run. The priority level of a **SCHED_FIFO** thread can be any integer from 1 to 99, with 99 treated as the highest priority. Red Hat recommends starting at a low number and increasing priority only when you identify latency issues.

Warning

Because realtime threads are not subject to time slicing, Red Hat does not recommend setting a priority of 99. This places your process at the same priority level as migration and watchdog threads; if your thread goes into a computational loop and these threads are blocked, they will not be able to run. Systems with a single processor will eventually hang in this situation.

Administrators can limit **SCHED_FIFO** bandwidth to prevent realtime application programmers from initiating realtime tasks that monopolize the processor.

/proc/sys/kernel/sched_rt_period_us

This parameter defines the time period in microseconds that is considered to be one hundred percent of processor bandwidth. The default value is **1000000** µs, or 1 second.

/proc/sys/kernel/sched_rt_runtime_us

This parameter defines the time period in microseconds that is devoted to running realtime threads. The default value is **950000** µs, or 0.95 seconds.

3.3.6.1.2. Round robin priority scheduling with SCHED_RR

SCHED_RR is a round-robin variant of **SCHED_FIFO**. This policy is useful when multiple threads need to run at the same priority level.

Like **SCHED_FIFO**, **SCHED_RR** is a realtime policy that defines a fixed priority for each thread. The scheduler scans the list of all **SCHED_RR** threads in priority order and schedules the highest priority thread that is ready to run. However, unlike **SCHED_FIFO**, threads that have the same priority are scheduled round-robin style within a certain time slice.

You can set the value of this time slice in milliseconds with the ***sched_rr_timeslice_ms*** kernel parameter (**/proc/sys/kernel/sched_rr_timeslice_ms**). The lowest value is 1 millisecond.

3.3.6.1.3. Normal scheduling with SCHED_OTHER

SCHED_OTHER is the default scheduling policy in Red Hat Enterprise Linux 7. This policy uses the Completely Fair Scheduler (CFS) to allow fair processor access to all threads scheduled with this policy. This policy is most useful when there are a large number of threads or data throughput is a priority, as it allows more efficient scheduling of threads over time.

When this policy is in use, the scheduler creates a dynamic priority list based partly on the niceness value of each process thread. Administrators can change the niceness value of a process, but cannot change the scheduler's dynamic priority list directly.

For details about changing process niceness, see the *Red Hat Enterprise Linux 7 Deployment Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

3.3.6.2. Isolating CPUs

You can isolate one or more CPUs from the scheduler with the ***isolcpus*** boot parameter. This prevents the scheduler from scheduling any user-space threads on this CPU.

Once a CPU is isolated, you must manually assign processes to the isolated CPU, either with the CPU affinity system calls or the numactl command.

To isolate the third and sixth to eighth CPUs on your system, add the following to the kernel command line:

```
isolcpus=2,5-7
```

You can also use the **Tuna** tool to isolate a CPU. **Tuna** can isolate a CPU at any time, not just at boot time. However, this method of isolation is subtly different from the ***isolcpus*** parameter, and does not currently achieve the performance gains associated with ***isolcpus***. See Section 3.3.8, "Configuring CPU, thread, and interrupt affinity with Tuna" for more details about this tool.

3.3.7. Setting interrupt affinity

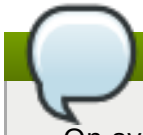
Interrupt requests have an associated affinity property, ***smp_affinity***, that defines the processors that will handle the interrupt request. To improve application performance, assign interrupt affinity and process affinity to the same processor, or processors on the same core. This allows the specified interrupt and application threads to share cache lines.

The interrupt affinity value for a particular interrupt request is stored in the associated **/proc/irq/*irq_number*/smp_affinity** file. ***smp_affinity*** is stored as a hexadecimal bit mask representing all processors in the system. The default value is **f**, meaning that an interrupt request can be handled on any processor in the system. Setting this value to **1** means that only processor 0 can handle the interrupt.

On systems with more than 32 processors, you must delimit ***smp_affinity*** values for discrete 32 bit groups. For example, if you want only the first 32 processors of a 64 processor system to service an interrupt request, you could run:

```
# echo 0xffffffff,00000000 > /proc/irq/IRQ_NUMBER/smp_affinity
```

Alternatively, if the BIOS exports its NUMA topology, the **irqbalance** service can use that information to serve interrupt requests on the node that is local to the hardware requesting service. For details about **irqbalance**, see Section A.1, "irqbalance"



Note

On systems that support interrupt steering, modifying the ***smp_affinity*** of an interrupt request sets up the hardware so that the decision to service an interrupt with a particular processor is made at the hardware level with no intervention from the kernel. For more information about interrupt steering, see Chapter 6, *Networking*.

3.3.8. Configuring CPU, thread, and interrupt affinity with Tuna

Tuna can control CPU, thread, and interrupt affinity, and provides a number of actions for each type of entity it can control. For a full list of **Tuna**'s capabilities, see Section A.2, "Tuna".

To move all threads away from one or more specified CPUs, run the following command, replacing *CPUs* with the number of the CPU you want to isolate.

```
# tuna --cpus CPUs --isolate
```

To include a CPU in the list of CPUs that can run certain threads, run the following command, replacing *CPUs* with the number of the CPU you want to include.

```
# tuna --cpus CPUs --include
```

To move an interrupt request to a specified CPU, run the following command, replacing *CPU* with the number of the CPU, and *IRQs* with the comma-delimited list of interrupt requests you want to move.

```
# tuna --irqs IRQs --cpus CPU --move
```

Alternatively, you can use the following command to find all interrupt requests of the pattern **sfc1***.

```
# tuna -q sfc1* -c7 -m -x
```

To change the policy and priority of a thread, run the following command, replacing *thread* with the thread you want to change, *policy* with the name of the policy you want the thread to operate under, and *level* with an integer from 0 (lowest priority) to 99 (highest priority).

```
# tuna --threads thread --priority policy:level
```

Chapter 4. Memory

This chapter outlines the memory management capabilities of Red Hat Enterprise Linux 7. Section 4.1, “Considerations” discusses memory related factors that affect performance. Section 4.2, “Monitoring and diagnosing performance problems” teaches you how to use Red Hat Enterprise Linux 7 tools to diagnose performance problems related to memory utilization or configuration details. Section 4.5, “Configuring system memory capacity” and Section 4.3, “Configuring HugeTLB huge pages” discuss the tools and strategies you can use to solve memory related performance problems in Red Hat Enterprise Linux 7.

4.1. Considerations

By default, Red Hat Enterprise Linux 7 is optimized for moderate workloads. If your application or workload requires a large amount of memory, changing the way your system manages virtual memory may improve the performance of your application.

4.1.1. Larger Page Size

Physical memory is managed in chunks called pages. On most architectures supported by Red Hat Enterprise Linux 7, the default size of a memory page is 4 KB. This default page size has proved to be suitable for general-purpose operating systems, such as Red Hat Enterprise Linux 7, which support many different kinds of workloads.

However, specific applications can benefit from using larger page sizes in certain cases. For example, an application that works with a large and relatively fixed data set of hundreds of megabytes or even dozens of gigabytes can have performance issues when using 4 KB pages. Such data sets can require hundreds of thousands of 4 KB pages, which can lead to overhead in the operating system and the CPU.

Red Hat Enterprise Linux 7 enables the use of larger page sizes for applications working with big data sets. Using larger page sizes can improve the performance of such applications.

Two different large page features are available in Red Hat Enterprise Linux 7: the **HugeTLB** feature, also called **static huge pages** in this guide, and the **Transparent Huge Page** feature.

4.1.2. Translation Lookaside Buffer size

Reading address mappings from the page table is time-consuming and resource-expensive, so CPUs are built with a cache for recently-used addresses: the Translation Lookaside Buffer (TLB). However, the default TLB can only cache a certain number of address mappings. If a requested address mapping is not in the TLB (that is, the TLB is *missed*), the system still needs to read the page table to determine the physical to virtual address mapping.

Because of the relationship between application memory requirements and the size of pages used to cache address mappings, applications with large memory requirements are more likely to suffer performance degradation from TLB misses than applications with minimal memory requirements. It is therefore important to avoid TLB misses wherever possible.

Both HugeTLB and Transparent Huge Page features allow applications to use pages larger than 4 KB. This allows addresses stored in the TLB to reference more memory, which reduces TLB misses and improves application performance.

4.2. Monitoring and diagnosing performance problems

Red Hat Enterprise Linux 7 provides a number of tools that are useful for monitoring system performance and diagnosing performance problems related to system memory. This section outlines the available tools and gives examples of how to use them to monitor and diagnose memory related performance issues.

4.2.1. Monitoring memory usage with vmstat

Vmstat, provided by the *procps-ng* package, outputs reports on your system's processes, memory, paging, block input/output, interrupts, and CPU activity. It provides an instantaneous report of the average of these events since the machine was last booted, or since the previous report.

The following command displays a table of various event counters and memory statistics.

```
$ vmstat -s
```

For further details of how to use **vmstat**, see Section A.9, “vmstat” or the man page:

```
$ man vmstat
```

4.2.2. Profiling application memory usage with Valgrind

Valgrind is a framework that provides instrumentation to user-space binaries. It ships with a number of tools that can be used to profile and analyze program performance. The **valgrind** tools outlined in this section can help you to detect memory errors such as uninitialized memory use and improper memory allocation or deallocation.

To use **valgrind** or any of its tools, install the *valgrind* package:

```
# yum install valgrind
```

4.2.2.1. Profiling memory usage with Memcheck

Memcheck is the default **valgrind** tool. It detects and reports on a number of memory errors that can be difficult to detect and diagnose, such as:

- Memory access that should not occur
- Undefined or uninitialized value use
- Incorrectly freed heap memory
- Pointer overlap
- Memory leaks

Note

Memcheck can only report these errors; it cannot prevent them from occurring. If your program accesses memory in a way that would normally cause a segmentation fault, the segmentation fault still occurs. However, **memcheck** will log an error message immediately prior to the fault.

Because **memcheck** uses instrumentation, applications executed with **memcheck** run ten to thirty times slower than usual.

To run **memcheck** on an application, execute the following command:

```
# valgrind --tool=memcheck application
```

You can also use the following options to focus **memcheck** output on specific types of problem.

--leak-check

After the application finishes executing, **memcheck** searches for memory leaks. The default value is **--leak-check=summary**, which prints the number of memory leaks found. You can specify **--leak-check=yes** or **--leak-check=full** to output details of each individual leak. To disable, specify **--leak-check=no**.

--undef-value-errors

The default value is **--undef-value-errors=yes**, which reports errors when undefined values are used. You can also specify **--undef-value-errors=no**, which will disable this report and slightly speed up Memcheck.

--ignore-ranges

Specifies one or more ranges that **memcheck** should ignore when checking for memory addressability, for example, **--ignore-ranges=0xPP-0xQQ,0xRR-0xSS**.

For a full list of **memcheck** options, see the documentation included at **/usr/share/doc/valgrind-version/valgrind_manual.pdf**.

4.2.2.2. Profiling cache usage with Cachegrind

Cachegrind simulates application interaction with a system's cache hierarchy and branch predictor. It tracks usage of the simulated first level instruction and data caches to detect poor code interaction with this level of cache. It also tracks the last level of cache (second or third level) in order to track memory access. As such, applications executed with **cachegrind** run twenty to one hundred times slower than usual.

Cachegrind gathers statistics for the duration of application execution and outputs a summary to the console. To run **cachegrind** on an application, execute the following command:

```
# valgrind --tool=cachegrind application
```

You can also use the following options to focus **cachegrind** output on a specific problem.

--I1

Specifies the size, associativity, and line size of the first level instruction cache, like so: **--I1=*size*,*associativity*,*line_size***.

--D1

Specifies the size, associativity, and line size of the first level data cache, like so: **--D1=*size*,*associativity*,*line_size***.

--LL

Specifies the size, associativity, and line size of the last level cache, like so: **--LL=*size*,*associativity*,*line_size***.

--cache-sim

Enables or disables the collection of cache access and miss counts. This is enabled (**--cache-sim=yes**) by default. Disabling both this and **--branch-sim** leaves **cachegrind** with no information to collect.

--branch-sim

Enables or disables the collection of branch instruction and incorrect prediction counts. This is enabled (**--branch-sim=yes**) by default. Disabling both this and **--cache-sim** leaves **cachegrind** with no information to collect.

Cachegrind writes detailed profiling information to a per-process **cachegrind.out.*pid*** file, where *pid* is the process identifier. This detailed information can be further processed by the companion **cg_annotate** tool, like so:

```
# cg_annotate cachegrind.out.pid
```

Cachegrind also provides the cg_diff tool, which makes it easier to chart program performance before and after a code change. To compare output files, execute the following command, replacing first with the initial profile output file, and second with the subsequent profile output file.

```
# cg_diff first second
```

The resulting output file can be viewed in greater detail with the **cg_annotate** tool.

For a full list of **cachegrind** options, see the documentation included at **/usr/share/doc/valgrind-version/valgrind_manual.pdf**.

4.2.2.3. Profiling heap and stack space with Massif

Massif measures the heap space used by a specified application. It measures both useful space and any additional space allocated for bookkeeping and alignment purposes. **massif** helps you understand how you can reduce your application's memory use to increase execution speed and reduce the likelihood that your application will exhaust system swap space. Applications executed with **massif** run about twenty times slower than usual.

To run **massif** on an application, execute the following command:

```
# valgrind --tool=massif application
```

You can also use the following options to focus **massif** output on a specific problem.

--heap

Specifies whether **massif** profiles the heap. The default value is **--heap=yes**. Heap profiling can be disabled by setting this to **--heap=no**.

--heap-admin

Specifies the number of bytes per block to use for administration when heap profiling is enabled. The default value is **8** bytes.

--stacks

Specifies whether **massif** profiles the stack. The default value is **--stack=no**, as stack profiling can greatly slow **massif**. Set this option to **--stack=yes** to enable stack profiling. Note that **massif** assumes that the main stack starts with a size of zero in order to better indicate the changes in stack size that relate to the application being profiled.

--time-unit

Specifies the interval at which **massif** gathers profiling data. The default value is **i** (instructions executed). You can also specify **ms** (milliseconds, or realtime) and **B** (bytes allocated or deallocated on the heap and stack). Examining bytes allocated is useful for short run applications and for testing purposes, as it is most reproducible across different hardware.

Massif outputs profiling data to a **massif.out.*pid*** file, where *pid* is the process identifier of the specified application. The **ms_print** tool graphs this profiling data to show memory consumption over the execution of the application, as well as detailed information about the sites responsible for allocation at points of peak memory allocation. To graph the data from the **massif.out.*pid*** file, execute the following command:

```
# ms_print massif.out.pid
```

For a full list of **Massif** options, see the documentation included at **/usr/share/doc/valgrind-version/valgrind_manual.pdf**.

4.3. Configuring HugeTLB huge pages

Starting with Red Hat Enterprise Linux 7.1, there are two ways of reserving huge pages: at **boot time** and at **run time**. Reserving at boot time increases the possibility of success because the memory has not yet been significantly fragmented. However, on NUMA machines, the number of pages is automatically split among NUMA nodes. The run-time method allows you to reserve huge pages per NUMA node. If the run-time reservation is done as early as possible in the boot process, the probability of memory fragmentation is lower.

4.3.1. Configuring huge pages at boot time

To configure huge pages at boot time, add the following parameters to the kernel boot command line:

hugepages

Defines the number of persistent huge pages configured in the kernel at boot time. The default value is 0. It is only possible to allocate huge pages if there are sufficient physically contiguous free pages in the system. Pages reserved by this parameter cannot be used for other purposes.

This value can be adjusted after boot by changing the value of the **/proc/sys/vm/nr_hugepages** file.

In a NUMA system, huge pages assigned with this parameter are divided equally between nodes. You can assign huge pages to specific nodes at runtime by changing the value of the node's **/sys/devices/system/node/*node_id*/hugepages/hugepages-1048576kB/nr_hugepages** file.

For more information, read the relevant kernel documentation, which is installed in **/usr/share/doc/kernel-doc-kernel_version/Documentation/vm/hugetlbpage.txt** by default.

hugepagesz

Defines the size of persistent huge pages configured in the kernel at boot time. Valid values are 2 MB and 1 GB. The default value is 2 MB.

default_hugepagesz

Defines the default size of persistent huge pages configured in the kernel at boot time. Valid values are 2 MB and 1 GB. The default value is 2 MB.

Procedure 4.1. Reserving 1 GB Pages During Early Boot

The page size the HugeTLB subsystem supports depends on the architecture. On the AMD64 and Intel 64 architecture, 2 MB huge pages and 1 GB gigantic pages are supported.

1. Create a HugeTLB pool for 1 GB pages by appending the following line to the kernel command-line options:

```
default_hugepagesz=1G hugepagesz=1G
```

2. Create a file named **/usr/lib/systemd/system/hugetlb-gigantic-pages.service** with the following content:

```
[Unit]
Description=HugeTLB Gigantic Pages Reservation
DefaultDependencies=no
Before=dev-hugepages.mount
ConditionPathExists=/sys/devices/system/node
ConditionKernelCommandLine=hugepagesz=1G

[Service]
Type=oneshot
RemainAfterExit=yes
ExecStart=/usr/lib/systemd/hugetlb-reserve-pages

[Install]
WantedBy=sysinit.target
```

3. Create a file named **/usr/lib/systemd/hugetlb-reserve-pages** with the following content:

```
nodes_path=/sys/devices/system/node/
if [ ! -d $nodes_path ]; then
 echo "ERROR: $nodes_path does not exist"
 exit 1
fi

reserve_pages()
{
 echo $1 > $nodes_path/$2/hugepages/hugepages-
1048576kB/nr_hugepages
}

# This example reserves 2 1G pages on node0 and 1 1G page on node1.
You
# can modify it to your needs or add more lines to reserve memory
```

```
in
# other nodes. Don't forget to uncomment the lines, otherwise then
won't
# be executed.
# reserve_pages 2 node0
# reserve_pages 1 node1
```

4. Modify **/usr/lib/systemd/hugetlb-reserve-pages** according to the comments in the file.

5. Run the following commands to enable early boot reservation:

```
# chmod +x /usr/lib/systemd/hugetlb-reserve-pages
# systemctl enable hugetlb-gigantic-pages
```

Note

You can try reserving more 1G pages at runtime by writing to **nr_hugepages** at any time. However, such reservations can fail due to memory fragmention. The most reliable way to reserve 1G pages is by doing it at early boot as described in step 4.

4.3.2. Configuring huge pages at run time

Use the following parameters to influence huge page behavior at run time:

/sys/devices/system/node/*node_id*/hugepages/hugepages-*size*/nr_hugepages

Defines the number of huge pages of the specified size assigned to the specified NUMA node. This is supported as of Red Hat Enterprise Linux 7.1. The following example moves adds twenty 2048 kB huge pages to **node2**.

```
# numastat -cm | egrep 'Node|Huge'
                 Node 0 Node 1 Node 2 Node 3  Total add
AnonHugePages         0      2      0      8     10
HugePages_Total       0      0      0      0      0
HugePages_Free        0      0      0      0      0
HugePages_Surp        0      0      0      0      0
# echo 20 > /sys/devices/system/node/node2/hugepages/hugepages-
2048kB/nr_hugepages
# numastat -cm | egrep 'Node|Huge'
                 Node 0 Node 1 Node 2 Node 3  Total
AnonHugePages         0      2      0      8     10
HugePages_Total       0      0     40      0     40
HugePages_Free        0      0     40      0     40
HugePages_Surp        0      0      0      0      0
```

/proc/sys/vm/nr_overcommit_hugepages

Defines the maximum number of additional huge pages that can be created and used by the system through overcommitting memory. Writing any non-zero value into this file indicates that the system obtains that number of huge pages from the kernel's normal page pool if the persistent huge page pool is exhausted. As these surplus huge pages become unused, they are then freed and returned to the kernel's normal page pool.

4.4. Configuring Transparent Huge Pages

Transparent Huge Pages (THP) is an alternative solution to HugeTLB. With THP, the kernel automatically assigns huge pages to processes, so huge pages do not need to be reserved manually.

The THP feature has two modes of operation: system-wide and per-process. When THP is enabled system-wide, the kernel tries to assign huge pages to any process when it is possible to allocate huge pages and the process is using a large contiguous virtual memory area. If THP is enabled per-process, the kernel only assigns huge pages to individual processes' memory areas specified with the **madvise()** system call.

Note that the THP feature only supports 2-MB pages. Transparent huge pages are enabled by default. To check the current status, run:

```
# cat /sys/kernel/mm/transparent_hugepage/enabled
```

To enable transparent huge pages, run:

```
# echo always > /sys/kernel/mm/transparent_hugepage/enabled
```

To prevent applications from allocating more memory resources than necessary, you can disable huge pages system-wide and only enable them inside MADV_HUGEPAGE madvise regions by running:

```
# echo madvise > /sys/kernel/mm/transparent_hugepage/enabled
```

To disable transparent huge pages, run:

```
# echo never > /sys/kernel/mm/transparent_hugepage/enabled
```

Sometimes, providing low latency to short-lived allocations has higher priority than immediately achieving the best performance with long-lived allocations. In such cases, **direct compaction** can be *disabled* while leaving THP enabled.

Direct compaction is a synchronous memory compaction during the huge page allocation. Disabling direct compaction provides no guarantee of saving memory, but can decrease the risk of higher latencies during frequent page faults. Note that if the workload benefits significantly from THP, the performance decreases. To disable direct compaction, run:

```
# echo madvise > /sys/kernel/mm/transparent_hugepage/defrag
```

For comprehensive information on transparent huge pages, see the **/usr/share/doc/kernel-doc-*kernel_version*/Documentation/vm/transhuge.txt** file, which is available after installing the *kernel-doc* package.

4.5. Configuring system memory capacity

This section discusses memory-related kernel parameters that may be useful in improving memory utilization on your system. These parameters can be temporarily set for testing purposes by altering the value of the corresponding file in the **/proc** file system. Once you have determined the values that produce optimal performance for your use case, you can set them permanently by using the **sysctl** command.

Memory usage is typically configured by setting the value of one or more kernel parameters. These parameters can be set temporarily by altering the contents of files in the /proc file system, or they can be set persistently with the sysctl tool, which is provided by the *procps-ng* package.

For example, to set the overcommit_memory parameter to 1 temporarily, run the following command:

```
# echo 1 > /proc/sys/vm/overcommit_memory
```

To set this value persistently, add sysctl vm.overcommit_memory=1 in **/etc/sysctl.conf** then run the following command:

```
# sysctl -p
```

Setting a parameter temporarily is useful for determining the effect the parameter has on your system. You can then set the parameter persistently when you are sure that the parameter's value has the desired effect.

Note

To expand your expertise, you might also be interested in the Red Hat Enterprise Linux Performance Tuning (RH442) training course.

4.5.1. Virtual Memory parameters

The parameters listed in this section are located in **/proc/sys/vm** unless otherwise indicated.

dirty_ratio

A percentage value. When this percentage of total system memory is modified, the system begins writing the modifications to disk with the **pdflush** operation. The default value is **20** percent.

dirty_background_ratio

A percentage value. When this percentage of total system memory is modified, the system begins writing the modifications to disk in the background. The default value is **10** percent.

overcommit_memory

Defines the conditions that determine whether a large memory request is accepted or denied.

The default value is **0**. By default, the kernel performs heuristic memory overcommit handling by estimating the amount of memory available and failing requests that are too large. However, since memory is allocated using a heuristic rather than a precise algorithm, overloading memory is possible with this setting.

When this parameter is set to **1**, the kernel performs no memory overcommit handling. This increases the possibility of memory overload, but improves performance for memory-intensive tasks.

When this parameter is set to **2**, the kernel denies requests for memory equal to or larger than the sum of total available swap space and the percentage of physical RAM specified in ***overcommit_ratio***. This reduces the risk of overcommitting memory, but is recommended only for systems with swap areas larger than their physical memory.

overcommit_ratio

Specifies the percentage o f physical RAM considered when ***overcommit_memory*** is set to **2**. The default value is **50**.

max_map_count

Defines the maximum number of memory map areas that a process can use. The default value (**65530**) is appropriate for most cases. Increase this value if your application needs to map more than this number of files.

min_free_kbytes

Specifies the minimum number of kilobytes to keep free across the system. This is used to determine an appropriate value for each low memory zone, each of which is assigned a number of reserved free pages in proportion to their size.

Warning

Extreme values can damage your system. Setting ***min_free_kbytes*** to an extremely low value prevents the system from reclaiming memory, which can result in system hangs and OOM-killing processes. However, setting ***min_free_kbytes*** too high (for example, to 5–10% of total system memory) causes the system to enter an out-of-memory state immediately, resulting in the system spending too much time reclaiming memory.

oom_adj

In the event that the system runs out of memory and the ***panic_on_oom*** parameter is set to **0**, the **oom_killer** function kills processes until the system can recover, starting from the process with the highest **oom_score**.

The ***oom_adj*** parameter helps determine the ***oom_score*** of a process. This parameter is set per process identifier. A value of **-17** disables the **oom_killer** for that process. Other valid values are from **-16** to **15**.

Note

Processes spawned by an adjusted process inherit that process's **oom_score**.

swappiness

A value from **0** to **100** which controls the degree to which the system favour anonymous memory or the page cache. A high value improves file-system performance, while aggressively swapping less active processes out of RAM. A low value avoids swapping processes out of memory, which usually decrease latency, at the cost of I/O performance. The default value is **60**.

Warning

Setting **swappiness==0** will very aggressively avoids swapping out, which increase the risk of OOM killing under strong memory and I/O pressure.

4.5.2. File system parameters

Parameters listed in this section are located in **/proc/sys/fs** unless otherwise indicated.

aio-max-nr

Defines the maximum allowed number of events in all active asynchronous input/output contexts. The default value is **65536**. Modifying this value does not pre-allocate or resize any kernel data structures.

file-max

Defines the maximum number of file handles allocated by the kernel. The default value matches the value of **files_stat.max_files** in the kernel, which is set to the largest value out of either ***NR_FILE*** (8192 in Red Hat Enterprise Linux), or the result of the following:

```
(mempages * (PAGE_SIZE / 1024)) / 10
```

Raising this value can resolve errors caused by a lack of available file handles.

4.5.3. Kernel parameters

Parameters listed in this section are located under **/proc/sys/kernel** unless otherwise indicated.

msgmax

Defines the maximum allowable size in bytes of any single message in a message queue. This value must not exceed the size of the queue (***msgmnb***). The default value is **8192**.

msgmnb

Defines the maximum size in bytes of a single message queue. The default value is **65536**.

msgmni

Defines the maximum number of message queue identifiers (and therefore the maximum number of queues). The default value on systems with 64-bit architecture is **1985**.

shmall

Defines the total amount of shared memory (in pages or bytes) that can be used on the system at one time. Starting with Red Hat Enterprise Linux 7.1, the default value for ***shmall*** set by the kernel at boot time is **18014398442373116** pages. In Red Hat Enterprise Linux 7.1, this value was overwritten by the ***kernel.shmall sysctl*** parameter set in the **/usr/lib/sysctl.d/00-system.conf** file. In Red Hat Enterprise Linux 7.2 and later, parameters overriding the kernel default have been removed, so the system-wide default value is set to 18014398442373116 pages. To change the system-wide default value, set ***kernel.shmall*** in **/etc/sysctl.d/01-shm.conf** to the intended value.

shmmax

Defines the maximum size (in bytes) of a single shared memory segment allowed by the kernel. Starting with Red Hat Enterprise Linux 7.1, the default value for ***shmmax*** set by the kernel at boot time is **18446744073692774399** bytes. In Red Hat Enterprise Linux 7.1, this value was overwritten by the ***kernel.shmmax sysctl*** parameter set in the **/usr/lib/sysctl.d/00-system.conf** file. In Red Hat Enterprise Linux 7.2 and later, parameters overriding the kernel default have been removed, so the system-wide default value is set to 18446744073692774399 bytes. To change the system-wide default value, set ***kernel.shmmax*** in **/etc/sysctl.d/01-shm.conf** to the intended value.

shmmni

Defines the system-wide maximum number of shared memory segments. The default value is **4096** on all systems.

threads-max

Defines the system-wide maximum number of threads available to the kernel at one time. The default value is equal to the value of the kernel parameter ***max_threads***, or the result of:

```
mempages / (8 * THREAD_SIZE / PAGE SIZE )
```

The minimum value is **20**.

Chapter 5. Storage and File Systems

This chapter outlines supported file systems and configuration options that affect application performance for both I/O and file systems in Red Hat Enterprise Linux 7. Section 5.1, “Considerations” discusses the I/O and file system related factors that affect performance. Section 5.2, “Monitoring and diagnosing performance problems” teaches you how to use Red Hat Enterprise Linux 7 tools to diagnose performance problems related to I/O or file system configuration details. Section 5.3, “Configuration tools” discusses the tools and strategies you can use to solve I/O and file system related performance problems in Red Hat Enterprise Linux 7.

5.1. Considerations

The appropriate settings for storage and file system performance are highly dependent on the purpose of the storage. I/O and file system performance can be affected by any of the following factors:

- Data write or read patterns
- Data alignment with underlying geometry
- Block size
- File system size
- Journal size and location
- Recording access times
- Ensuring data reliability
- Pre-fetching data
- Pre-allocating disk space
- File fragmentation
- Resource contention

Read this chapter to gain an understanding of the formatting and mount options that affect file system throughput, scalability, responsiveness, resource usage, and availability.

5.1.1. Solid-State Disks

Solid-state disks (SSD) use NAND flash chips rather than rotating magnetic platters to store persistent data. They provide a constant access time for data across their full Logical Block Address range, and do not incur measurable seek costs like their rotating counterparts. They are more expensive per gigabyte of storage space and have a lesser storage density, but they also have lower latency and greater throughput than HDDs.

Performance generally degrades as the used blocks on an SSD approach the capacity of the disk. The degree of degradation varies by vendor, but all devices experience degradation in this circumstance. Enabling discard behavior can help to alleviate this degradation; see Section 5.1.4.3, “Maintenance” for details.

The default I/O scheduler and virtual memory options are suitable for use with SSDs.

5.1.2. I/O Schedulers

The I/O scheduler determines when and for how long I/O operations run on a storage device. It is also known as the I/O elevator.

Red Hat Enterprise Linux 7 provides three I/O schedulers.

deadline

The default I/O scheduler for all block devices, except for SATA disks. **Deadline** attempts to provide a guaranteed latency for requests from the point at which requests reach the I/O scheduler. This scheduler is suitable for most use cases, but particularly those in which read operations occur more often than write operations.

Queued I/O requests are sorted into a read or write batch and then scheduled for execution in increasing LBA order. Read batches take precedence over write batches by default, as applications are more likely to block on read I/O. After a batch is processed, **deadline** checks how long write operations have been starved of processor time and schedules the next read or write batch as appropriate. The number of requests to handle per batch, the number of read batches to issue per write batch, and the amount of time before requests expire are all configurable; see Section 5.3.4, “Tuning the deadline scheduler” for details.

cfq

The default scheduler only for devices identified as SATA disks. The Completely Fair Queueing scheduler, **cfq**, divides processes into three separate classes: real time, best effort, and idle. Processes in the real time class are always performed before processes in the best effort class, which are always performed before processes in the idle class. This means that processes in the real time class can starve both best effort and idle processes of processor time. Processes are assigned to the best effort class by default.

Cfq uses historical data to anticipate whether an application will issue more I/O requests in the near future. If more I/O is expected, **cfq** idles to wait for the new I/O, even if I/O from other processes is waiting to be processed.

Because of this tendency to idle, the cfq scheduler should not be used in conjunction with hardware that does not incur a large seek penalty unless it is tuned for this purpose. It should also not be used in conjunction with other non-work-conserving schedulers, such as a host-based hardware RAID controller, as stacking these schedulers tends to cause a large amount of latency.

Cfq behavior is highly configurable; see Section 5.3.5, “Tuning the cfq scheduler” for details.

noop

The **noop** I/O scheduler implements a simple FIFO (first-in first-out) scheduling algorithm. Requests are merged at the generic block layer through a simple last-hit cache. This can be the best scheduler for CPU-bound systems using fast storage.

For details on setting a different default I/O scheduler, or specifying a different scheduler for a particular device, see Section 5.3, “Configuration tools”.

5.1.3. File systems

Read this section for details about supported file systems in Red Hat Enterprise Linux 7, their recommended use cases, and the format and mount options available to file systems in general. Detailed tuning recommendations for these file systems are available in Section 5.3.7, “Configuring file systems for performance”.

5.1.3.1. XFS

XFS is a robust and highly scalable 64-bit file system. It is the default file system in Red Hat Enterprise Linux 7. XFS uses extent-based allocation, and features a number of allocation schemes, including pre-allocation and delayed allocation, both of which reduce fragmentation and aid performance. It also supports metadata journaling, which can facilitate crash recovery. XFS can be defragmented and enlarged while mounted and active, and Red Hat Enterprise Linux 7 supports several XFS-specific backup and restore utilities.

As of Red Hat Enterprise Linux 7.0 GA, XFS is supported to a maximum file system size of 500 TB, and a maximum file offset of 8 EB (sparse files). For details about administering XFS, see the *Red Hat Enterprise Linux 7 Storage Administration Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/. For assistance tuning XFS for a specific purpose, see Section 5.3.7.1, “Tuning XFS”.

5.1.3.2. Ext4

Ext4 is a scalable extension of the ext3 file system. Its default behavior is optimal for most work loads. However, it is supported only to a maximum file system size of 50 TB, and a maximum file size of 16 TB. For details about administering ext4, see the *Red Hat Enterprise Linux 7 Storage Administration Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/. For assistance tuning ext4 for a specific purpose, see Section 5.3.7.2, “Tuning ext4”.

5.1.3.3. Btrfs (Technology Preview)

The default file system for Red Hat Enterprise Linux 7 is XFS. Btrfs (B-tree file system), a relatively new copy-on-write (COW) file system, is shipped as a Technology Preview. Some of the unique Btrfs features include:

- The ability to take snapshots of specific files, volumes or sub-volumes rather than the whole file system;
- supporting several versions of redundant array of inexpensive disks (RAID);
- back referencing map I/O errors to file system objects;
- transparent compression (all files on the partition are automatically compressed);
- checksums on data and meta-data.

Although Btrfs is considered a stable file system, it is under constant development, so some functionality, such as the repair tools, are basic compared to more mature file systems.

Currently, selecting Btrfs is suitable when advanced features (such as snapshots, compression, and file data checksums) are required, but performance is relatively unimportant. If advanced features are not required, the risk of failure and comparably weak performance over time make other file systems preferable. Another drawback, compared to other file systems, is the maximum supported file system size of 50 TB.

For more information, see Section 5.3.7.3, “Tuning Btrfs”, and the chapter on Btrfs in the Red Hat Enterprise Linux 7 Storage Administration Guide.

5.1.3.4. GFS2

GFS2 is part of the High Availability Add-On, which provides clustered file system support to Red Hat Enterprise Linux 7. GFS2 provides a consistent file system image across all servers in a cluster, allowing servers to read from and write to a single shared file system.

GFS2 is supported to a maximum file system size of 100 TB.

For details about administering GFS2, see the *Red Hat Enterprise Linux 7 Storage Administration Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/. For assistance tuning GFS2 for a specific purpose, see Section 5.3.7.4, “Tuning GFS2”.

5.1.4. Generic tuning considerations for file systems

This section covers tuning considerations common to all file systems. For tuning recommendations specific to your file system, see Section 5.3.7, “Configuring file systems for performance”.

5.1.4.1. Considerations at format time

Some file system configuration decisions cannot be changed after the device is formatted. This section covers the options available to you for decisions that must be made before you format your storage device.

Size

Create an appropriately-sized file system for your workload. Smaller file systems have proportionally shorter backup times and require less time and memory for file system checks. However, if your file system is too small, its performance will suffer from high fragmentation.

Block size

The block is the unit of work for the file system. The block size determines how much data can be stored in a single block, and therefore the smallest amount of data that is written or read at one time.

The default block size is appropriate for most use cases. However, your file system will perform better and store data more efficiently if the block size (or the size of multiple blocks) is the same as or slightly larger than amount of data that is typically read or written at one time. A small file will still use an entire block. Files can be spread across multiple blocks, but this can create additional runtime overhead. Additionally, some file systems are limited to a certain number of blocks, which in turn limits the maximum size of the file system.

Block size is specified as part of the file system options when formatting a device with the **mkfs** command. The parameter that specifies the block size varies with the file system; see the **mkfs** man page for your file system for details. For example, to see the options available when formatting an XFS file system, execute the following command.

```
$ man mkfs.xfs
```

Geometry

File system geometry is concerned with the distribution of data across a file system. If your system uses striped storage, like RAID, you can improve performance by aligning data and metadata with the underlying storage geometry when you format the device.

Many devices export recommended geometry, which is then set automatically when the devices are formatted with a particular file system. If your device does not export these recommendations, or you want to change the recommended settings, you must specify geometry manually when you format the device with **mkfs**.

The parameters that specify file system geometry vary with the file system; see the **mkfs** man page for your file system for details. For example, to see the options available when formatting an ext4 file system, execute the following command.

```
$ man mkfs.ext4
```

External journals

Journaling file systems document the changes that will be made during a write operation in a journal file prior to the operation being executed. This reduces the likelihood that a storage device will become corrupted in the event of a system crash or power failure, and speeds up the recovery process.

Metadata-intensive workloads involve very frequent updates to the journal. A larger journal uses more memory, but reduces the frequency of write operations. Additionally, you can improve the seek time of a device with a metadata-intensive workload by placing its journal on dedicated storage that is as fast as, or faster than, the primary storage.

Warning

Ensure that external journals are reliable. Losing an external journal device will cause file system corruption.

External journals must be created at format time, with journal devices being specified at mount time. For details, see the **mkfs** and **mount** man pages.

```
$ man mkfs
```

```
$ man mount
```

5.1.4.2. Considerations at mount time

This section covers tuning decisions that apply to most file systems and can be specified as the device is mounted.

Barriers

File system barriers ensure that file system metadata is correctly written and ordered on persistent storage, and that data transmitted with **fsync** persists across a power outage. On previous versions of Red Hat Enterprise Linux, enabling file system barriers could significantly slow applications that relied heavily on **fsync**, or created and deleted many small files.

In Red Hat Enterprise Linux 7, file system barrier performance has been improved such that the performance effects of disabling file system barriers are negligible (less than 3%).

For further information, see the *Red Hat Enterprise Linux 7 Storage Administration Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

Access Time

Every time a file is read, its metadata is updated with the time at which access occurred (**atime**). This involves additional write I/O. In most cases, this overhead is minimal, as by default Red Hat Enterprise Linux 7 updates the **atime** field only when the previous access time was older than the times of last modification (**mtime**) or status change (**ctime**).

However, if updating this metadata is time consuming, and if accurate access time data is not required, you can mount the file system with the **noatime** mount option. This disables updates to metadata when a file is read. It also enables **nodiratime** behavior, which disables updates to metadata when a directory is read.

Read-ahead

Read-ahead behavior speeds up file access by pre-fetching data that is likely to be needed soon and loading it into the page cache, where it can be retrieved more quickly than if it were on disk. The higher the read-ahead value, the further ahead the system pre-fetches data.

Red Hat Enterprise Linux attempts to set an appropriate read-ahead value based on what it detects about your file system. However, accurate detection is not always possible. For example, if a storage array presents itself to the system as a single LUN, the system detects the single LUN, and does not set the appropriate read-ahead value for an array.

Workloads that involve heavy streaming of sequential I/O often benefit from high read-ahead values. The storage-related tuned profiles provided with Red Hat Enterprise Linux 7 raise the read-ahead value, as does using LVM striping, but these adjustments are not always sufficient for all workloads.

The parameters that define read-ahead behavior vary with the file system; see the mount man page for details.

```
$ man mount
```

5.1.4.3. Maintenance

Regularly discarding blocks that are not in use by the file system is a recommended practice for both solid-state disks and thinly-provisioned storage. There are two methods of discarding unused blocks: batch discard and online discard.

Batch discard

This type of discard is part of the **fstrim** command. It discards all unused blocks in a file system that match criteria specified by the administrator.

Red Hat Enterprise Linux 7 supports batch discard on XFS and ext4 formatted devices that support physical discard operations (that is, on HDD devices where the value of **/sys/block/*devname*/queue/discard_max_bytes** is not zero, and SSD devices where the value of **/sys/block/*devname*/queue/discard_granularity** is not **0**).

Online discard

This type of discard operation is configured at mount time with the **discard** option, and runs in real time without user intervention. However, online discard only discards blocks that are transitioning from used to free. Red Hat Enterprise Linux 7 supports online discard on XFS and ext4 formatted devices.

Red Hat recommends batch discard except where online discard is required to maintain performance, or where batch discard is not feasible for the system's workload.

Pre-allocation

Pre-allocation marks disk space as being allocated to a file without writing any data into that space. This can be useful in limiting data fragmentation and poor read performance. Red Hat Enterprise Linux 7 supports pre-allocating space on XFS, ext4, and GFS2 devices at mount time; see the **mount** man page for the appropriate parameter for your file system. Applications can also benefit from pre-allocating space by using the **fallocate(2) glibc** call.

5.2. Monitoring and diagnosing performance problems

Red Hat Enterprise Linux 7 provides a number of tools that are useful for monitoring system performance and diagnosing performance problems related to I/O and file systems and their configuration. This section outlines the available tools and gives examples of how to use them to monitor and diagnose I/O and file system related performance issues.

5.2.1. Monitoring system performance with vmstat

Vmstat reports on processes, memory, paging, block I/O, interrupts, and CPU activity across the entire system. It can help administrators determine whether the I/O subsystem is responsible for any performance issues.

The information most relevant to I/O performance is in the following columns:

si

Swap in, or reads from swap space, in KB.

so

Swap out, or writes to swap space, in KB.

bi

Block in, or block write operations, in KB.

bo

Block out, or block read operations, in KB.

wa

The portion of the queue that is waiting for I/O operations to complete.

Swap in and swap out are particularly useful when your swap space and your data are on the same device, and as indicators of memory usage.

Additionally, the free, buff, and cache columns can help identify write-back frequency. A sudden drop in cache values and an increase in free values indicates that write-back and page cache invalidation has begun.

If analysis with **vmstat** shows that the I/O subsystem is responsible for reduced performance, administrators can use **iostat** to determine the responsible I/O device.

vmstat is provided by the *procps-ng* package. For detailed information about using **vmstat**, see the man page:

```
$ man vmstat
```

5.2.2. Monitoring I/O performance with iostat

Iostat is provided by the *sysstat* package. It reports on I/O device load in your system. If analysis with **vmstat** shows that the I/O subsystem is responsible for reduced performance, you can use **iostat** to determine the I/O device responsible.

You can focus the output of **iostat** reports on a specific device by using the parameters defined in the **iostat** man page:

```
$ man iostat
```

5.2.2.1. Detailed I/O analysis with blktrace

Blktrace provides detailed information about how time is spent in the I/O subsystem. The companion utility **blkparse** reads the raw output from **blktrace** and produces a human readable summary of input and output operations recorded by **blktrace**.

For more detailed information about this tool, see the man page:

```
$ man blktrace
```

```
$ man blkparse
```

5.2.2.2. Analyzing blktrace output with btt

Btt is provided as part of the *blktrace* package. It analyzes **blktrace** output and displays the amount of time that data spends in each area of the I/O stack, making it easier to spot bottlenecks in the I/O subsystem.

For example, if **btt** shows that the time between requests being sent to the block layer (**Q2Q**) is larger than the total time that requests spent in the block layer (**Q2C**), the I/O subsystem may not be responsible for performance issues. If the device takes a long time to service a request (**D2C**), the device may be overloaded, or the workload sent to the device may be sub-optimal. If block I/O is queued for a long time before being assigned a request (**Q2G**), it may indicate that the storage in use is unable to serve the I/O load.

For more detailed information about this tool, see the man page:

```
$ man btt
```

5.2.2.3. Analyzing blktrace output with seekwatcher

The **seekwatcher** tool can use **blktrace** output to graph I/O over time. It focuses on the Logical Block Address (LBA) of disk I/O, throughput in megabytes per second, the number of seeks per second, and I/O operations per second. This can help you to identify when you are hitting the operations-per-second limit of a device.

For more detailed information about this tool, see the man page:

```
$ man seekwatcher
```

5.2.3. Storage monitoring with SystemTap

The *Red Hat Enterprise Linux 7 SystemTap Beginner's Guide* includes several sample scripts that are useful for profiling and monitoring storage performance.

The following **SystemTap** example scripts relate to storage performance and may be useful in diagnosing storage or file system performance problems. By default they are installed to the **/usr/share/doc/systemtap-client/examples/io** directory.

disktop.stp

Checks the status of reading/writing disk every 5 seconds and outputs the top ten entries during that period.

iotime.stp

Prints the amount of time spent on read and write operations, and the number of bytes read and written.

traceio.stp

Prints the top ten executables based on cumulative I/O traffic observed, every second.

traceio2.stp

Prints the executable name and process identifier as reads and writes to the specified device occur.

inodewatch.stp

Prints the executable name and process identifier each time a read or write occurs to the specified inode on the specified major/minor device.

inodewatch2.stp

Prints the executable name, process identifier, and attributes each time the attributes are changed on the specified inode on the specified major/minor device.

The *Red Hat Enterprise Linux 7 SystemTap Beginner's Guide* is available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

5.3. Configuration tools

Red Hat Enterprise Linux provides a number of tools to assist administrators in configuring the storage and file systems. This section outlines the available tools and provides examples of how they can be used to solve I/O and file system related performance problems in Red Hat Enterprise Linux 7.

5.3.1. Configuring tuning profiles for storage performance

Tuned and **tuned-adm** provide a number of profiles designed to improve performance for specific use cases. The following profiles are particularly useful for improving storage performance.

- latency-performance
- throughput-performance (the default)

To configure a profile on your system, run the following command, replacing *name* with the name of the profile you want to use.

```
$ tuned-adm profile name
```

The **tuned-adm recommend** command recommends an appropriate profile for your system. This also sets the default profile for your system at install time, so can be used to return to the default profile.

For further details about these profiles or additional configuration options, see Section A.6, “tuned-adm”.

5.3.2. Setting the default I/O scheduler

The default I/O scheduler is the scheduler that is used if no scheduler is specified in a device's mount options.

To set the default I/O scheduler, specify the scheduler you want to use by appending the elevator parameter to the kernel command line, either at boot time or by editing the **/etc/grub2.conf** file.

```
elevator=scheduler_name
```

5.3.3. Configuring the I/O scheduler for a device

To set the scheduler or scheduler preference order for a particular storage device, edit the **/sys/block/*devname*/queue/scheduler** file, where *devname* is the name of the device you want to configure.

```
# echo cfq > /sys/block/hda/queue/scheduler
```

5.3.4. Tuning the deadline scheduler

When **deadline** is in use, queued I/O requests are sorted into a read or write batch and then scheduled for execution in increasing LBA order. Read batches take precedence over write batches by default, as applications are more likely to block on read I/O. After a batch is processed, **deadline** checks how long write operations have been starved of processor time and schedules the next read or write batch as appropriate.

The following parameters affect the behavior of the **deadline** scheduler.

fifo_batch

The number of read or write operations to issue in a single batch. The default value is **16**. A higher value can increase throughput, but will also increase latency.

front_merges

If your workload will never generate front merges, this tunable can be set to **0**. However, unless you have measured the overhead of this check, Red Hat recommends the default value of **1**.

read_expire

The number of milliseconds in which a read request should be scheduled for service. The default value is **500** (0.5 seconds).

write_expire

The number of milliseconds in which a write request should be scheduled for service. The default value is **5000** (5 seconds).

writes_starved

The number of read batches that can be processed before processing a write batch. The higher this value is set, the greater the preference given to read batches.

5.3.5. Tuning the cfq scheduler

When **cfq** is in use, processes are placed into three classes: real time, best effort, and idle. All real time processes are scheduled before any best effort processes, which are scheduled before any idle processes. By default, processes are classed as best effort. You can manually adjust the class of a process with the **ionice** command.

You can further adjust the behavior of the **cfq** scheduler with the following parameters. These parameters are set on a per-device basis by altering the specified files under the **/sys/block/*devname*/queue/iosched** directory.

back_seek_max

The maximum distance in kilobytes that **cfq** will perform a backward seek. The default value is **16** KB. Backward seeks typically damage performance, so large values are not recommended.

back_seek_penalty

The multiplier applied to backward seeks when the disk head is deciding whether to move forward or backward. The default value is **2**. If the disk head position is at 1024 KB, and there are equidistant requests in the system (1008 KB and 1040 KB, for example), the ***back_seek_penalty*** is applied to backward seek distances and the disk moves forward.

fifo_expire_async

The length of time in milliseconds that an asynchronous (buffered write) request can remain unserviced. After this amount of time expires, a single starved asynchronous request is moved to the dispatch list. The default value is **250** milliseconds.

fifo_expire_sync

The length of time in milliseconds that a synchronous (read or **O_DIRECT** write) request can remain unserviced. After this amount of time expires, a single starved synchronous request is moved to the dispatch list. The default value is **125** milliseconds.

group_idle

This parameter is set to **0** (disabled) by default. When set to **1** (enabled), the **cfq** scheduler idles on the last process that is issuing I/O in a control group. This is useful when using proportional weight I/O control groups and when ***slice_idle*** is set to **0** (on fast storage).

group_isolation

This parameter is set to **0** (disabled) by default. When set to **1** (enabled), it provides stronger isolation between groups, but reduces throughput, as fairness is applied to both random and sequential workloads. When ***group_isolation*** is disabled (set to **0**), fairness is provided to sequential workloads only. For more information, see the installed documentation in **/usr/share/doc/kernel-doc-version/Documentation/cgroups/blkio-controller.txt**.

low_latency

This parameter is set to **1** (enabled) by default. When enabled, **cfq** favors fairness over throughput by providing a maximum wait time of **300** ms for each process issuing I/O on a device. When this parameter is set to **0** (disabled), target latency is ignored and each process receives a full time slice.

quantum

This parameter defines the number of I/O requests that **cfq** sends to one device at one time, essentially limiting queue depth. The default value is **8** requests. The device being used may support greater queue depth, but increasing the value of quantum will also increase latency, especially for large sequential write work loads.

slice_async

This parameter defines the length of the time slice (in milliseconds) allotted to each process issuing asynchronous I/O requests. The default value is **40** milliseconds.

slice_idle

This parameter specifies the length of time in milliseconds that cfq idles while waiting for further requests. The default value is **0** (no idling at the queue or service tree level). The default value is ideal for throughput on external RAID storage, but can degrade throughput on internal non-RAID storage as it increases the overall number of seek operations.

slice_sync

This parameter defines the length of the time slice (in milliseconds) allotted to each process issuing synchronous I/O requests. The default value is **100** ms.

5.3.5.1. Tuning cfq for fast storage

The **cfq** scheduler is not recommended for hardware that does not suffer a large seek penalty, such as fast external storage arrays or solid-state disks. If your use case requires **cfq** to be used on this storage, you will need to edit the following configuration files:

- Set **/sys/block/*devname*/queue/ionice/slice_idle** to **0**
- Set **/sys/block/*devname*/queue/ionice/quantum** to **64**
- Set **/sys/block/*devname*/queue/ionice/group_idle** to **1**

5.3.6. Tuning the noop scheduler

The **noop** I/O scheduler is primarily useful for CPU-bound systems using fast storage. Requests are merged at the block layer, so **noop** behavior is modified by editing block layer parameters in the files under the **/sys/block/sdX/queue/** directory.

add_random

Some I/O events contribute to the entropy pool for **/dev/random**. This parameter can be set to **0** if the overhead of these contributions becomes measurable.

max_sectors_kb

Specifies the maximum size of an I/O request in kilobytes. The default value is **512** KB. The minimum value for this parameter is determined by the logical block size of the storage device. The maximum value for this parameter is determined by the value of ***max_hw_sectors_kb***.

Some solid-state disks perform poorly when I/O requests are larger than the internal erase block size. In these cases, Red Hat recommends reducing ***max_hw_sectors_kb*** to the internal erase block size.

nomerges

Most workloads benefit from request merging. However, disabling merges can be useful for debugging purposes. Set this parameter to **0** to disable merging. It is enabled (set to **1**) by default.

nr_requests

Specifies the maximum number of read and write requests that can be queued at one time. The default value is **128**; that is, 128 read requests and 128 write requests can be queued before the next process to request a read or write is put to sleep.

For latency-senstitive applications, lower the value of this parameter and limit the command queue depth on the storage so that write-back I/O cannot fill the device queue with write requests. When the device queue fills, other processes attempting to perform I/O operations are put to sleep until queue space becomes available. Requests are then allocated in a round-robin fashion, preventing one process from continuously consuming all spots in the queue.

optimal_io_size

Some storage devices report an optimal I/O size through this parameter. If this value is reported, Red Hat recommends that applications issue I/O aligned to and in multiples of the optimal I/O size wherever possible.

read_ahead_kb

Defines the number of kilobytes that the operating system will read ahead during a sequential read operation in order to store information likely to be needed soon in the page cache. Device mappers often benefit from a high ***read_ahead_kb*** value; 128 KB for each device to be mapped is a good starting point.

rotational

Some solid-state disks do not correctly advertise their solid-state status, and are mounted as traditional rotational disks. If your solid-state device does does not set this to **0** automatically, set it manually to disable unnecessary seek-reducing logic in the scheduler.

rq_affinity

By default, I/O completions can be processed on a different processor than the processor that issued the I/O request. Set ***rq_affinity*** to **1** to disable this ability and perform completions only on the processor that issued the I/O request. This can improve the effectiveness of processor data caching.

5.3.7. Configuring file systems for performance

This section covers the tuning parameters specific to each file system supported in Red Hat Enterprise Linux 7. Parameters are divided according to whether their values should be configured when you format the storage device, or when you mount the formatted device.

Where loss in performance is caused by file fragmentation or resource contention, performance can generally be improved by reconfiguring the file system. However, in some cases the application may need to be altered. In this case, Red Hat recommends contacting Customer Support for assistance.

5.3.7.1. Tuning XFS

This section covers some of the tuning parameters available to XFS file systems at format and at mount time.

The default formatting and mount settings for XFS are suitable for most workloads. Red Hat recommends changing them only if specific configuration changes are expected to benefit your workload.

5.3.7.1.1. Formatting options

For further details about any of these formatting options, see the man page:

```
$ man mkfs.xfs
```

Directory block size

The directory block size affects the amount of directory information that can be retrieved or modified per I/O operation. The minimum value for directory block size is the file system block size (4 KB by default). The maximum value for directory block size is **64** KB.

At a given directory block size, a larger directory requires more I/O than a smaller directory. A system with a larger directory block size also consumes more processing power per I/O operation than a system with a smaller directory block size. It is therefore recommended to have as small a directory and directory block size as possible for your workload.

Red Hat recommends the directory block sizes listed in Table 5.1, "Recommended maximum directory entries for directory block sizes" for file systems with no more than the listed number of entries for write-heavy and read-heavy workloads.

Table 5.1. Recommended maximum directory entries for directory block sizes

Directory block size	Max. entries (read-heavy)	Max. entries (write-heavy)
4 KB	100000–200000	1000000–2000000
16 KB	100000–1000000	1000000–10000000
64 KB	>1000000	>10000000

For detailed information about the effect of directory block size on read and write workloads in file systems of different sizes, see the XFS documentation.

To configure directory block size, use the **`mkfs.xfs -l`** option. See the **`mkfs.xfs`** man page for details.

Allocation groups

An allocation group is an independent structure that indexes free space and allocated inodes across a section of the file system. Each allocation group can be modified independently, allowing XFS to perform allocation and deallocation operations concurrently as long as concurrent operations affect different allocation groups. The number of concurrent operations that can be performed in the file system is therefore equal to the number of allocation groups. However, since the ability to perform concurrent operations is also limited by the number of processors able to perform the operations, Red Hat recommends that the number of allocation groups be greater than or equal to the number of processors in the system.

A single directory cannot be modified by multiple allocation groups simultaneously. Therefore, Red Hat recommends that applications that create and remove large numbers of files do not store all files in a single directory.

To configure allocation groups, use the **mkfs.xfs -d** option. See the **mkfs.xfs** man page for details.

Growth constraints

If you may need to increase the size of your file system after formatting time (either by adding more hardware or through thin-provisioning), you must carefully consider initial file layout, as allocation group size cannot be changed after formatting is complete.

Allocation groups must be sized according to the eventual capacity of the file system, not the initial capacity. The number of allocation groups in the fully-grown file system should not exceed several hundred, unless allocation groups are at their maximum size (1 TB). Therefore for most file systems, the recommended maximum growth to allow for a file system is ten times the initial size.

Additional care must be taken when growing a file system on a RAID array, as the device size must be aligned to an exact multiple of the allocation group size so that new allocation group headers are correctly aligned on the newly added storage. The new storage must also have the same geometry as the existing storage, since geometry cannot be changed after formatting time, and therefore cannot be optimized for storage of a different geometry on the same block device.

Inode size and inline attributes

If the inode has sufficient space available, XFS can write attribute names and values directly into the inode. These inline attributes can be retrieved and modified up to an order of magnitude faster than retrieving separate attribute blocks, as additional I/O is not required.

The default inode size is 256 bytes. Only around 100 bytes of this is available for attribute storage, depending on the number of data extent pointers stored in the inode. Increasing inode size when you format the file system can increase the amount of space available for storing attributes.

Both attribute names and attribute values are limited to a maximum size of 254 bytes. If either name or value exceeds 254 bytes in length, the attribute is pushed to a separate attribute block instead of being stored inline.

To configure inode parameters, use the **mkfs.xfs -i** option. See the **mkfs.xfs** man page for details.

RAID

If software RAID is in use, **mkfs.xfs** automatically configures the underlying hardware with an appropriate stripe unit and width. However, stripe unit and width may need to be manually configured if hardware RAID is in use, as not all hardware RAID devices export this information. To configure stripe unit and width, use the **mkfs.xfs -d** option. See the **mkfs.xfs** man page for details.

Log size

Pending changes are aggregated in memory until a synchronization event is triggered, at which point they are written to the log. The size of the log determines the number of concurrent modifications that can be in-progress at one time. It also determines the maximum amount of change that can be aggregated in memory, and therefore how often

logged data is written to disk. A smaller log forces data to be written back to disk more frequently than a larger log. However, a larger log uses more memory to record pending modifications, so a system with limited memory will not benefit from a larger log.

Logs perform better when they are aligned to the underlying stripe unit; that is, they start and end at stripe unit boundaries. To align logs to the stripe unit, use the **mkfs.xfs -d** option. See the **mkfs.xfs** man page for details.

To configure the log size, use the following **mkfs.xfs** option, replacing *logsize* with the size of the log:

```
# mkfs.xfs -l size=logsize
```

For further details, see the **mkfs.xfs** man page:

```
$ man mkfs.xfs
```

Log stripe unit

Log writes on storage devices that use RAID5 or RAID6 layouts may perform better when they start and end at stripe unit boundaries (are aligned to the underlying stripe unit). **mkfs.xfs** attempts to set an appropriate log stripe unit automatically, but this depends on the RAID device exporting this information.

Setting a large log stripe unit can harm performance if your workload triggers synchronization events very frequently, because smaller writes need to be padded to the size of the log stripe unit, which can increase latency. If your workload is bound by log write latency, Red Hat recommends setting the log stripe unit to 1 block so that unaligned log writes are triggered as possible.

The maximum supported log stripe unit is the size of the maximum log buffer size (256 KB). It is therefore possible that the underlying storage may have a larger stripe unit than can be configured on the log. In this case, **mkfs.xfs** issues a warning and sets a log stripe unit of 32 KB.

To configure the log stripe unit, use one of the following options, where *N* is the number of blocks to use as the stripe unit, and *size* is the size of the stripe unit in KB.

```
mkfs.xfs -l sunit=Nb
mkfs.xfs -l su=size
```

For further details, see the **mkfs.xfs** man page:

```
$ man mkfs.xfs
```

5.3.7.1.2. Mount options

Inode allocation

- compress=zlib - Better compression ratio. It's the default and safe for older kernels. (default).
- compress=lzo - Faster compression but does not compress as much as zlib.
- compress=no - Disables compression.
- compress-force=method - Enable compression even for files that don't compress well,

like videos and dd images of disks. The options are compress-force=zlib and compress-force=lzo.

Highly recommended for file systems greater than 1 TB in size. The ***inode64*** parameter configures XFS to allocate inodes and data across the entire file system. This ensures that inodes are not allocated largely at the beginning of the file system, and data is not largely allocated at the end of the file system, improving performance on large file systems.

Log buffer size and number

The larger the log buffer, the fewer I/O operations it takes to write all changes to the log. A larger log buffer can improve performance on systems with I/O-intensive workloads that do not have a non-volatile write cache.

The log buffer size is configured with the ***logbsize*** mount option, and defines the maximum amount of information that can be stored in the log buffer; if a log stripe unit is not set, buffer writes can be shorter than the maximum, and therefore there is no need to reduce the log buffer size for synchronization-heavy workloads. The default size of the log buffer is 32 KB. The maximum size is 256 KB and other supported sizes are 64 KB, 128 KB or power of 2 multiples of the log stripe unit between 32 KB and 256 KB.

The number of log buffers is defined by the ***logbufs*** mount option. The default value is 8 log buffers (the maximum), but as few as two log buffers can be configured. It is usually not necessary to reduce the number of log buffers, except on memory-bound systems that cannot afford to allocate memory to additional log buffers. Reducing the number of log buffers tends to reduce log performance, especially on workloads sensitive to log I/O latency.

Delay change logging

XFS has the option to aggregate changes in memory before writing them to the log. The ***delaylog*** parameter allows frequently modified metadata to be written to the log periodically instead of every time it changes. This option increases the potential number of operations lost in a crash and increases the amount of memory used to track metadata. However, it can also increase metadata modification speed and scalability by an order of magnitude, and does not reduce data or metadata integrity when **fsync**, **fdatasync**, or **sync** are used to ensure data and metadata is written to disk.

5.3.7.2. Tuning ext4

This section covers some of the tuning parameters available to ext4 file systems at format and at mount time.

5.3.7.2.1. Formatting options

Inode table initialization

Initializing all inodes in the file system can take a very long time on very large file systems. By default, the initialization process is deferred (lazy inode table initialization is enabled). However, if your system does not have an ext4 driver, lazy inode table initialization is disabled by default. It can be enabled by setting **lazy_itable_init** to 1). In this case, kernel processes continue to initialize the file system after it is mounted.

This section describes only some of the options available at format time. For further formatting parameters, see the **mkfs.ext4** man page:

```
$ man mkfs.ext4
```

5.3.7.2.2. Mount options

Inode table initialization rate

When lazy inode table initialization is enabled, you can control the rate at which initialization occurs by specifying a value for the ***init_itable*** parameter. The amount of time spent performing background initialization is approximately equal to 1 divided by the value of this parameter. The default value is **10**.

Automatic file synchronization

Some applications do not correctly perform an **fsync** after renaming an existing file, or after truncating and rewriting. By default, ext4 automatically synchronizes files after each of these operations. However, this can be time consuming.

If this level of synchronization is not required, you can disable this behavior by specifying the **noauto_da_alloc** option at mount time. If **noauto_da_alloc** is set, applications must explicitly use fsync to ensure data persistence.

Journal I/O priority

By default, journal I/O has a priority of **3**, which is slightly higher than the priority of normal I/O. You can control the priority of journal I/O with the ***journal_ioprio*** parameter at mount time. Valid values for ***journal_ioprio*** range from **0** to **7**, with **0** being the highest priority I/O.

This section describes only some of the options available at mount time. For further mount options, see the **mount** man page:

```
$ man mount
```

5.3.7.3. Tuning Btrfs

Starting with Red Hat Enterprise Linux 7.0, Btrfs is provided as a Technology Preview. Tuning should always be done to optimize the system based on its current workload. For information on creation and mounting options, see the chapter on Btrfs in the Red Hat Enterprise Linux 7 Storage Administration Guide. For information on how Btrfs can be used to optimize the use of solid-state disks, see the SSD Optimization section in the same chapter.

Data Compression

The default compression algorithm is zlib, but a specific workload can give a reason to change the compression algorithm. For example, if you have a single thread with heavy file I/O, using the lzo algorithm can be more preferable. Options at mount time are:

- **compress=zlib** – the default option with a high compression ratio, safe for older kernels.
- **compress=lzo** – compression faster, but lower, than zlib.
- **compress=no** – disables compression.
- **compress-force=*method*** – enables compression even for files that do not compress well, such as videos and disk images. The available methods are **zlib** and **lzo**.

Only files created or changed after the mount option is added will be compressed. To compress existing files, run:

```
$ btrfs filesystem defragment -cmethod
```

Use either the **zlib** or the **lzo**.

To re-compress the file using **lzo**, run:

```
$ btrfs filesystem defragment -r -v -clzo /
```

5.3.7.4. Tuning GFS2

This section covers some of the tuning parameters available to GFS2 file systems at format and at mount time.

Directory spacing

All directories created in the top-level directory of the GFS2 mount point are automatically spaced to reduce fragmentation and increase write speed in those directories. To space another directory like a top-level directory, mark that directory with the ***T*** attribute, as shown, replacing *dirname* with the path to the directory you wish to space:

```
# chattr +T dirname
```

chattr is provided as part of the *e2fsprogs* package.

Reduce contention

GFS2 uses a global locking mechanism that can require communication between the nodes of a cluster. Contention for files and directories between multiple nodes lowers performance. You can minimize the risk of cross-cache invalidation by minimizing the areas of the file system that are shared between multiple nodes.

Chapter 6. Networking

The networking subsystem is comprised of a number of different parts with sensitive connections. Red Hat Enterprise Linux 7 networking is therefore designed to provide optimal performance for most workloads, and to optimize its performance automatically. As such, it is not usually necessary to manually tune network performance. This chapter discusses further optimizations that can be made to functional networking systems.

Network performance problems are sometimes the result of hardware malfunction or faulty infrastructure. Resolving these issues is beyond the scope of this document.

6.1. Considerations

To make good tuning decisions, you need a thorough understanding of packet reception in Red Hat Enterprise Linux. This section explains how network packets are received and processed, and where potential bottlenecks can occur.

A packet sent to a Red Hat Enterprise Linux system is received by the network interface card (NIC) and placed in either an internal hardware buffer or a ring buffer. The NIC then sends a hardware interrupt request, prompting the creation of a software interrupt operation to handle the interrupt request.

As part of the software interrupt operation, the packet is transferred from the buffer to the network stack. Depending on the packet and your network configuration, the packet is then forwarded, discarded, or passed to a socket receive queue for an application and then removed from the network stack. This process continues until either there are no packets left in the NIC hardware buffer, or a certain number of packets (specified in **`/proc/sys/net/core/dev_weight`**) are transferred.

The Red Hat Enterprise Linux Network Performance Tuning Guide available on the Red Hat Customer Portal contains information on packet reception in the Linux kernel, and covers the following areas of NIC tuning: SoftIRQ misses (netdev budget), **`tuned`** tuning daemon, **`numad`** NUMA daemon, CPU power states, interrupt balancing, pause frames, interrupt coalescence, adapter queue (**`netdev`** backlog), adapter RX and TX buffers, adapter TX queue, module parameters, adapter offloading, Jumbo Frames, TCP and UDP protocol tuning, and NUMA locality.

6.1.1. Before you tune

Network performance problems are most often the result of hardware malfunction or faulty infrastructure. Red Hat highly recommends verifying that your hardware and infrastructure are working as expected before beginning to tune the network stack.

6.1.2. Bottlenecks in packet reception

While the network stack is largely self-optimizing, there are a number of points during network packet processing that can become bottlenecks and reduce performance.

The NIC hardware buffer or ring buffer

The hardware buffer might be a bottleneck if a large number of packets are being dropped. For information about monitoring your system for dropped packets, see Section 6.2.4, “ethtool”.

The hardware or software interrupt queues

Interrupts can increase latency and processor contention. For information on how

interrupts are handled by the processor, see Section 3.1.3, “Interrupt Request (IRQ) Handling”. For information on how to monitor interrupt handling in your system, see Section 3.2.3, “/proc/interrupts”. For configuration options that affect interrupt handling, see Section 3.3.7, “Setting interrupt affinity”.

The socket receive queue for the application

A bottleneck in an application's receive queue is indicated by a large number of packets that are not copied to the requesting application, or by an increase in UDP input errors (**InErrors**) in **/proc/net/snmp**. For information about monitoring your system for these errors, see Section 6.2.1, “ss” and Section 6.2.5, “/proc/net/snmp”.

6.2. Monitoring and diagnosing performance problems

Red Hat Enterprise Linux 7 provides a number of tools that are useful for monitoring system performance and diagnosing performance problems related to the networking subsystem. This section outlines the available tools and gives examples of how to use them to monitor and diagnose network related performance issues.

6.2.1. ss

ss is a command-line utility that prints statistical information about sockets, allowing administrators to assess device performance over time. By default, **ss** lists open non-listening TCP sockets that have established connections, but a number of useful options are provided to help administrators filter out statistics about specific sockets.

Red Hat recommends **ss** over **netstat** in Red Hat Enterprise Linux 7.

ss is provided by the *iproute* package. For more information, see the man page:

```
$ man ss
```

6.2.2. ip

The **ip** utility lets administrators manage and monitor routes, devices, routing policies, and tunnels. The **ip monitor** command can continuously monitor the state of devices, addresses, and routes.

ip is provided by the *iproute* package. For details about using ip, see the man page:

```
$ man ip
```

6.2.3. dropwatch

Dropwatch is an interactive tool that monitors and records packets that are dropped by the kernel.

For further information, see the **dropwatch** man page:

```
$ man dropwatch
```

6.2.4. ethtool

The **ethtool** utility allows administrators to view and edit network interface card settings. It is useful for observing the statistics of certain devices, such as the number of packets dropped by that device.

You can view the status of a specified device's counters with **ethtool -S** and the name of the device you want to monitor.

```
$ ethtool -S devname
```

For further information, see the man page:

```
$ man ethtool
```

6.2.5. /proc/net/snmp

The **/proc/net/snmp** file displays data that is used by snmp agents for IP, ICMP, TCP and UDP monitoring and management. Examining this file on a regular basis can help administrators identify unusual values and thereby identify potential performance problems. For example, an increase in UDP input errors (**InErrors**) in **/proc/net/snmp** can indicate a bottleneck in a socket receive queue.

6.2.6. Network monitoring with SystemTap

The *Red Hat Enterprise Linux 7 SystemTap Beginner's Guide* includes several sample scripts that are useful for profiling and monitoring network performance.

The following **SystemTap** example scripts relate to networking and may be useful in diagnosing network performance problems. By default they are installed to the **/usr/share/doc/systemtap-client/examples/network** directory.

nettop.stp

Every 5 seconds, prints a list of processes (process identifier and command) with the number of packets sent and received and the amount of data sent and received by the process during that interval.

socket-trace.stp

Instruments each of the functions in the Linux kernel's **net/socket.c** file, and prints trace data.

dropwatch.stp

Every 5 seconds, prints the number of socket buffers freed at locations in the kernel. Use the **--all-modules** option to see symbolic names.

The **latencytap.stp** script records the effect that different types of latency have on one or more processes. It prints a list of latency types every 30 seconds, sorted in descending order by the total time the process or processes spent waiting. This can be useful for identifying the cause of both storage and network latency. Red Hat recommends using the **--all-modules** option with this script to better enable the mapping of latency events. By default, this script is installed to the **/usr/share/doc/systemtap-client-*version*/examples/profiling** directory.

For further information, see the *Red Hat Enterprise Linux 7 SystemTap Beginner's Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

6.3. Configuration tools

Red Hat Enterprise Linux provides a number of tools to assist administrators in configuring the system. This section outlines the available tools and provides examples of how they can be used to solve network related performance problems in Red Hat Enterprise Linux 7.

However, it is important to keep in mind that network performance problems are sometimes the result of hardware malfunction or faulty infrastructure. Red Hat highly recommends verifying that your hardware and infrastructure are working as expected before using these tools to tune the network stack.

Further, some network performance problems are better resolved by altering the application than by reconfiguring your network subsystem. It is generally a good idea to configure your application to perform frequent posix calls, even if this means queuing data in the application space, as this allows data to be stored flexibly and swapped in or out of memory as required.

6.3.1. Tuned-adm profiles for network performance

tuned-adm provides a number of different profiles to improve performance in a number of specific use cases. The following profiles can be useful for improving networking performance.

- latency-performance
- network-latency
- network-throughput

For more information about these profiles, see Section A.6, “tuned-adm”.

6.3.2. Configuring the hardware buffer

If a large number of packets are being dropped by the hardware buffer, there are a number of potential solutions.

Slow the input traffic

Filter incoming traffic, reduce the number of joined multicast groups, or reduce the amount of broadcast traffic to decrease the rate at which the queue fills. For details of how to filter incoming traffic, see the *Red Hat Enterprise Linux 7 Security Guide*. For details about multicast groups, see the Red Hat Enterprise Linux 7 Clustering documentation. For details about broadcast traffic, see the *Red Hat Enterprise Linux 7 System Administrator's Reference Guide*, or documentation related to the device you want to configure. All Red Hat Enterprise Linux 7 documentation is available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

Resize the hardware buffer queue

Reduce the number of packets being dropped by increasing the size of the queue so that the it does not overflow as easily. You can modify the rx/tx parameters of the network device with the ethtool command:

```
# ethtool --set-ring devname value
```

Change the drain rate of the queue

Device weight refers to the number of packets a device can receive at one time (in a single scheduled processor access). You can increase the rate at which a queue is drained by increasing its device weight, which is controlled by the ***dev_weight*** parameter. This parameter can be temporarily altered by changing the contents of the

/proc/sys/net/core/dev_weight file, or permanently altered with **sysctl**, which is provided by the *procps-ng* package.

Altering the drain rate of a queue is usually the simplest way to mitigate poor network performance. However, increasing the number of packets that a device can receive at one time uses additional processor time, during which no other processes can be scheduled, so this can cause other performance problems.

6.3.3. Configuring interrupt queues

If analysis reveals high latency, your system may benefit from poll-based rather than interrupt-based packet receipt.

6.3.3.1. Configuring busy polling

Busy polling helps reduce latency in the network receive path by allowing socket layer code to poll the receive queue of a network device, and disabling network interrupts. This removes delays caused by the interrupt and the resultant context switch. However, it also increases CPU utilization. Busy polling also prevents the CPU from sleeping, which can incur additional power consumption.

Busy polling is disabled by default. To enable busy polling on specific sockets, do the following.

- Set ***sysctl.net.core.busy_poll*** to a value other than **0**. This parameter controls the number of microseconds to wait for packets on the device queue for socket poll and selects. Red Hat recommends a value of **50**.
- Add the **SO_BUSY_POLL** socket option to the socket.

To enable busy polling globally, you must also set ***sysctl.net.core.busy_read*** to a value other than **0**. This parameter controls the number of microseconds to wait for packets on the device queue for socket reads. It also sets the default value of the **SO_BUSY_POLL** option. Red Hat recommends a value of **50** for a small number of sockets, and a value of **100** for large numbers of sockets. For extremely large numbers of sockets (more than several hundred), use **epoll** instead.

Busy polling behavior is supported by the following drivers. These drivers are also supported on Red Hat Enterprise Linux 7.

- bnx2x
- be2net
- ixgbe
- mlx4
- myri10ge

As of Red Hat Enterprise Linux 7.1, you can also run the following command to check whether a specific device supports busy polling.

```
# ethtool -k device | grep "busy-poll"
```

If this returns **busy-poll: on [fixed]**, busy polling is available on the device.

6.3.4. Configuring socket receive queues

If analysis suggests that packets are being dropped because the drain rate of a socket queue is too slow, there are several ways to alleviate the performance issues that result.

Decrease the speed of incoming traffic

Decrease the rate at which the queue fills by filtering or dropping packets before they reach the queue, or by lowering the weight of the device.

Increase the depth of the application's socket queue

If a socket queue that receives a limited amount of traffic in bursts, increasing the depth of the socket queue to match the size of the bursts of traffic may prevent packets from being dropped.

6.3.4.1. Decrease the speed of incoming traffic

Filter incoming traffic or lower the network interface card's device weight to slow incoming traffic. For details of how to filter incoming traffic, see the *Red Hat Enterprise Linux 7 Security Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

Device weight refers to the number of packets a device can receive at one time (in a single scheduled processor access). Device weight is controlled by the ***dev_weight*** parameter. This parameter can be temporarily altered by changing the contents of the **/proc/sys/net/core/dev_weight** file, or permanently altered with **sysctl**, which is provided by the *procps-ng* package.

6.3.4.2. Increasing queue depth

Increasing the depth of an application socket queue is typically the easiest way to improve the drain rate of a socket queue, but it is unlikely to be a long-term solution.

To increase the depth of a queue, increase the size of the socket receive buffer by making either of the following changes:

Increase the value of /proc/sys/net/core/rmem_default

This parameter controls the default size of the receive buffer used by sockets. This value must be smaller than or equal to the value of **/proc/sys/net/core/rmem_max**.

Use setsockopt to configure a larger SO_RCVBUF value

This parameter controls the maximum size in bytes of a socket's receive buffer. Use the **getsockopt** system call to determine the current value of the buffer. For further information, see the socket(7) manual page.

6.3.5. Configuring Receive-Side Scaling (RSS)

Receive-Side Scaling (RSS), also known as multi-queue receive, distributes network receive processing across several hardware-based receive queues, allowing inbound network traffic to be processed by multiple CPUs. RSS can be used to relieve bottlenecks in receive interrupt processing caused by overloading a single CPU, and to reduce network latency.

To determine whether your network interface card supports RSS, check whether multiple interrupt request queues are associated with the interface in **/proc/interrupts**. For example, if you are interested in the **p1p1** interface:

```
# egrep 'CPU|p1p1' /proc/interrupts
   CPU0    CPU1    CPU2    CPU3    CPU4    CPU5
89:   40187       0       0       0       0       0   IR-PCI-MSI-edge
```

```
p1p1-0
90:         0      790         0         0         0         0   IR-PCI-MSI-edge
p1p1-1
91:         0        0       959         0         0         0   IR-PCI-MSI-edge
p1p1-2
92:         0        0         0      3310         0         0   IR-PCI-MSI-edge
p1p1-3
93:         0        0         0         0       622         0   IR-PCI-MSI-edge
p1p1-4
94:         0        0         0         0         0      2475   IR-PCI-MSI-edge
p1p1-5
```

The preceding output shows that the NIC driver created 6 receive queues for the **p1p1** interface (**p1p1-0** through **p1p1-5**). It also shows how many interrupts were processed by each queue, and which CPU serviced the interrupt. In this case, there are 6 queues because by default, this particular NIC driver creates one queue per CPU, and this system has 6 CPUs. This is a fairly common pattern amongst NIC drivers.

Alternatively, you can check the output of **ls -1 /sys/devices/*/*/*device_pci_address*/msi_irqs** after the network driver is loaded. For example, if you are interested in a device with a PCI address of **0000:01:00.0**, you can list the interrupt request queues of that device with the following command:

```
# ls -1 /sys/devices/*/*/0000:01:00.0/msi_irqs
101
102
103
104
105
106
107
108
109
```

RSS is enabled by default. The number of queues (or the CPUs that should process network activity) for RSS are configured in the appropriate network device driver. For the **bnx2x** driver, it is configured in ***num_queues***. For the **sfc** driver, it is configured in the ***rss_cpus*** parameter. Regardless, it is typically configured in **/sys/class/net/*device*/queues/*rx-queue*/**, where *device* is the name of the network device (such as **eth1**) and *rx-queue* is the name of the appropriate receive queue.

When configuring RSS, Red Hat recommends limiting the number of queues to one per physical CPU core. Hyper-threads are often represented as separate cores in analysis tools, but configuring queues for all cores including logical cores such as hyper-threads has not proven beneficial to network performance.

When enabled, RSS distributes network processing equally between available CPUs based on the amount of processing each CPU has queued. However, you can use the **ethtool *--show-rxfh-indir*** and ***--set-rxfh-indir*** parameters to modify how network activity is distributed, and weight certain types of network activity as more important than others.

The **irqbalance** daemon can be used in conjunction with RSS to reduce the likelihood of cross-node memory transfers and cache line bouncing. This lowers the latency of processing network packets.

6.3.6. Configuring Receive Packet Steering (RPS)

Receive Packet Steering (RPS) is similar to RSS in that it is used to direct packets to specific CPUs for processing. However, RPS is implemented at the software level, and helps to prevent the hardware queue of a single network interface card from becoming a bottleneck in network traffic.

RPS has several advantages over hardware-based RSS:

- RPS can be used with any network interface card.
- It is easy to add software filters to RPS to deal with new protocols.
- RPS does not increase the hardware interrupt rate of the network device. However, it does introduce inter-processor interrupts.

RPS is configured per network device and receive queue, in the **/sys/class/net/*device*/queues/*rx-queue*/rps_cpus** file, where *device* is the name of the network device (such as **eth0**) and *rx-queue* is the name of the appropriate receive queue (such as **rx-0**).

The default value of the **rps_cpus** file is **0**. This disables RPS, so the CPU that handles the network interrupt also processes the packet.

To enable RPS, configure the appropriate **rps_cpus** file with the CPUs that should process packets from the specified network device and receive queue.

The **rps_cpus** files use comma-delimited CPU bitmaps. Therefore, to allow a CPU to handle interrupts for the receive queue on an interface, set the value of their positions in the bitmap to 1. For example, to handle interrupts with CPUs 0, 1, 2, and 3, set the value of **rps_cpus** to **00001111** (1+2+4+8), or **f** (the hexadecimal value for 15).

For network devices with single transmit queues, best performance can be achieved by configuring RPS to use CPUs in the same memory domain. On non-NUMA systems, this means that all available CPUs can be used. If the network interrupt rate is extremely high, excluding the CPU that handles network interrupts may also improve performance.

For network devices with multiple queues, there is typically no benefit to configuring both RPS and RSS, as RSS is configured to map a CPU to each receive queue by default. However, RPS may still be beneficial if there are fewer hardware queues than CPUs, and RPS is configured to use CPUs in the same memory domain.

6.3.7. Configuring Receive Flow Steering (RFS)

Receive Flow Steering (RFS) extends RPS behavior to increase the CPU cache hit rate and thereby reduce network latency. Where RPS forwards packets based solely on queue length, RFS uses the RPS backend to calculate the most appropriate CPU, then forwards packets based on the location of the application consuming the packet. This increases CPU cache efficiency.

RFS is disabled by default. To enable RFS, you must edit two files:

/proc/sys/net/core/rps_sock_flow_entries

Set the value of this file to the maximum expected number of concurrently active connections. We recommend a value of **32768** for moderate server loads. All values entered are rounded up to the nearest power of 2 in practice.

/sys/class/net/*device*/queues/*rx-queue*/rps_flow_cnt

Replace *device* with the name of the network device you wish to configure (for example, **eth0**), and *rx-queue* with the receive queue you wish to configure (for example, **rx-0**).

Set the value of this file to the value of **rps_sock_flow_entries** divided by **N**, where **N** is the number of receive queues on a device. For example, if **rps_flow_entries** is set to **32768** and there are 16 configured receive queues, **rps_flow_cnt** should be set to **2048**. For single-queue devices, the value of **rps_flow_cnt** is the same as the value of **rps_sock_flow_entries**.

Data received from a single sender is not sent to more than one CPU. If the amount of data received from a single sender is greater than a single CPU can handle, configure a larger frame size to reduce the number of interrupts and therefore the amount of processing work for the CPU. Alternatively, consider NIC offload options or faster CPUs.

Consider using **numactl** or **taskset** in conjunction with RFS to pin applications to specific cores, sockets, or NUMA nodes. This can help prevent packets from being processed out of order.

6.3.8. Configuring Accelerated RFS

Accelerated RFS boosts the speed of RFS by adding hardware assistance. Like RFS, packets are forwarded based on the location of the application consuming the packet. Unlike traditional RFS, however, packets are sent directly to a CPU that is local to the thread consuming the data: either the CPU that is executing the application, or a CPU local to that CPU in the cache hierarchy.

Accelerated RFS is only available if the following conditions are met:

- Accelerated RFS must be supported by the network interface card. Accelerated RFS is supported by cards that export the **ndo_rx_flow_steer()** **netdevice** function.
- **ntuple** filtering must be enabled.

Once these conditions are met, CPU to queue mapping is deduced automatically based on traditional RFS configuration. That is, CPU to queue mapping is deduced based on the IRQ affinities configured by the driver for each receive queue. Refer to Section 6.3.7, “Configuring Receive Flow Steering (RFS)” for details on configuring traditional RFS.

Red Hat recommends using accelerated RFS wherever using RFS is appropriate and the network interface card supports hardware acceleration.

Appendix A. Tool Reference

This appendix provides a quick reference for the various tools in Red Hat Enterprise Linux 7 that can be used to tweak performance. See the relevant man page for your tool for complete, up-to-date, detailed reference material.

A.1. irqbalance

irqbalance is a command line tool that distributes hardware interrupts across processors to improve system performance. It runs as a daemon by default, but can be run once only with the **--oneshot** option.

The following parameters are useful for improving performance.

--powerthresh

Sets the number of CPUs that can idle before a CPU is placed into powersave mode. If more CPUs than the threshold are more than 1 standard deviation below the average softirq workload and no CPUs are more than one standard deviation above the average, and have more than one irq assigned to them, a CPU is placed into powersave mode. In powersave mode, a CPU is not part of irq balancing so that it is not woken unnecessarily.

--hintpolicy

Determines how irq kernel affinity hinting is handled. Valid values are **exact** (irq affinity hint is always applied), **subset** (irq is balanced, but the assigned object is a subset of the affinity hint), or **ignore** (irq affinity hint is ignored completely).

--policyscript

Defines the location of a script to execute for each interrupt request, with the device path and irq number passed as arguments, and a zero exit code expected by **irqbalance**. The script defined can specify zero or more key value pairs to guide **irqbalance** in managing the passed irq.

The following are recognized as valid key value pairs.

ban

Valid values are **true** (exclude the passed irq from balancing) or **false** (perform balancing on this irq).

balance_level

Allows user override of the balance level of the passed irq. By default the balance level is based on the PCI device class of the device that owns the irq. Valid values are **none**, **package**, **cache**, or **core**.

numa_node

Allows user override of the NUMA node that is considered local to the passed irq. If information about the local node is not specified in ACPI, devices are considered equidistant from all nodes. Valid values are integers (starting from 0) that identify a specific NUMA node, and **-1**, which specifies that an irq should be considered equidistant from all nodes.

--banirq

The interrupt with the specified interrupt request number is added to the list of banned

The interrupt with the specified interrupt request number is added to the list of banned interrupts.

You can also use the ***IRQBALANCE_BANNED_CPUS*** environment variable to specify a mask of CPUs that are ignored by **irqbalance**.

For further details, see the man page:

```
$ man irqbalance
```

A.2. Tuna

Tuna allows you to control processor and scheduling affinity. This section covers the command line interface, but a graphical interface with the same range of functionality is also available. Launch the graphical utility by running **tuna** at the command line.

Tuna accepts a number of command line parameters, which are processed in sequence. The following command distributes load across a four socket system.

```
tuna --socket 0 --isolate \
   --thread my_real_time_app --move \
   --irq serial --socket 1 --move \
   --irq eth* --socket 2 --spread \
   --show_threads --show_irqs
```

--gui

Starts the graphical user interface.

--cpus

Takes a comma-delimited list of CPUs to be controlled by **Tuna**. The list remains in effect until a new list is specified.

--config_file_apply

Takes the name of a profile to apply to the system.

--config_file_list

Lists the pre-loaded profiles.

--cgroup

Used in conjunction with ***--show_threads***. Displays the type of control group that processes displayed with ***--show_threads*** belong to, if control groups are enabled. Requires -P

--affect_children

When specified, **Tuna** affects child threads as well as parent threads.

--filter

Disables the disolay of selected CPUs in --gui. Requires -c

--isolate

Takes a comma-delimited list of CPUs. **Tuna** migrates all threads away from the CPUs

specified. Requires -c or -s

--include

Takes a comma-delimited list of CPUs. Tuna allows all threads to run on the CPUs specified. Requires -c or -s

--no_kthreads

When this parameter is specified, Tuna does not affect kernel threads.

--move

Moves selected entities to CPU-List. Requires -c or -s.

--priority

Specifies the scheduler policy and priority for a thread. Valid scheduler policies are **OTHER**, **FIFO**, **RR**, **BATCH**, or **IDLE**.

When the policy is **FIFO** or **RR**, valid priority values are integers from 1 (lowest) to 99 (highest). The default value is **1**. For example, **tuna --threads 7861 --priority=RR:40** sets a policy of **RR** (round-robin) and a priority of **40** for thread **7861**.

When the policy is **OTHER**, **BATCH**, or **IDLE**, the only valid priority value is **0**, which is also the default. Requires -t.

--show_threads

Show the thread list.

--show_irqs

Show the IRQ list.

--irqs

Takes a comma-delimited list of IRQs that **Tuna** affects. The list remains in effect until a new list is specified. IRQs can be added to the list by using **+** and removed from the list by using **-**.

--save

Saves the kernel threads schedules to the specified file.

--sockets

Takes a comma-delimited list of CPU sockets to be controlled by **Tuna**. This option takes into account the topology of the system, such as the cores that share a single processor cache, and that are on the same physical chip.

--threads

Takes a comma-delimited list of threads to be controlled by **Tuna**. The list remains in effect until a new list is specified. Threads can be added to the list by using **+** and removed from the list by using **-**.

--no_uthreads

Prevents the operation from affecting user threads.

--what_is

To see further help on selected entities. Requires -t

--spread

Distribute the threads specified with **--threads** evenly between the CPUs specified with **--cpus**. Requires -t or -q.

--help

Print a list of options. tuna will exit after this action, ignoring the remainder of the command-line.

--version

Shows version.

A.3. ethtool

The **ethtool** utility allows administrators to view and edit network interface card settings. It is useful for observing the statistics of certain devices, such as the number of packets dropped by that device.

ethtool, its options, and its usage, are comprehensively documented on the man page.

```
$ man ethtool
```

A.4. ss

ss is a command-line utility that prints statistical information about sockets, allowing administrators to assess device performance over time. By default, **ss** lists open non-listening TCP sockets that have established connections, but a number of useful options are provided to help administrators filter out statistics about specific sockets.

One commonly used command is **ss -tmpie**, which displays all TCP sockets (**t**, internal TCP information (**i**), socket memory usage (**m**), processes using the socket (**p**), and detailed socket information (**i**).

Red Hat recommends **ss** over **netstat** in Red Hat Enterprise Linux 7.

ss is provided by the *iproute* package. For more information, see the man page:

```
$ man ss
```

A.5. tuned

Tuned is a tuning daemon that can adapt the operating system to perform better under certain workloads by setting a tuning profile. It can also be configured to react to changes in CPU and network use and adjusts settings to improve performance in active devices and reduce power consumption in inactive devices.

To configure dynamic tuning behavior, edit the ***dynamic_tuning*** parameter in the **/etc/tuned/tuned-main.conf** file. You can also configure the amount of time in seconds between tuned checking usage and updating tuning details with the ***update_interval*** parameter.

For further details about tuned, see the man page:

```
$ man tuned
```

A.6. tuned-adm

tuned-adm is a command line tool that provides a number of different profiles to improve performance in a number of specific use cases. It also provides a sub-command (**tuned-adm recommend**) that assesses your system and outputs a recommended tuning profile. This also sets the default profile for your system at install time, so can be used to return to the default profile.

As of Red Hat Enterprise Linux 7, **tuned-adm** includes the ability to run any command as part of enabling or disabling a tuning profile. This allows you to add environment specific checks that are not available in **tuned-adm**, such as checking whether the system is the master database node before selecting which tuning profile to apply.

Red Hat Enterprise Linux 7 also provides the ***include*** parameter in profile definition files, allowing you to base your own **tuned-adm** profiles on existing profiles.

The following tuning profiles are provided with **tuned-adm** and are supported in Red Hat Enterprise Linux 7.

throughput-performance

A server profile focused on improving throughput. This is the default profile, and is recommended for most systems.

This profile favors performance over power savings by setting **intel_pstate** and **min_perf_pct=100**. It enables transparent huge pages, uses **cpupower** to set the **performance** cpufreq governor, and sets the input/output scheduler to **deadline**. It also sets ***kernel.sched_min_granularity_ns*** to **10** µs, ***kernel.sched_wakeup_granularity_ns*** to **15** µs, and ***vm.dirty_ratio*** to **40**%.

latency-performance

A server profile focused on lowering latency. This profile is recommended for latency-sensitive workloads that benefit from c-state tuning and the increased TLB efficiency of transparent huge pages.

This profile favors performance over power savings by setting **intel_pstate** and **max_perf_pct=100**. It enables transparent huge pages, uses **cpupower** to set the **performance** cpufreq governor, and requests a ***cpu_dma_latency*** value of **1**.

network-latency

A server profile focused on lowering network latency.

This profile favors performance over power savings by setting **intel_pstate** and **min_perf_pct=100**. It disables transparent huge pages, and automatic NUMA balancing. It also uses **cpupower** to set the **performance** cpufreq governor, and requests a ***cpu_dma_latency*** value of **1**. It also sets ***busy_read*** and ***busy_poll*** times to **50** µs, and ***tcp_fastopen*** to **3**.

network-throughput

A server profile focused on improving network throughput.

This profile favors performance over power savings by setting **intel_pstate** and **max_perf_pct=100** and increasing kernel network buffer sizes. It enables transparent huge pages, and uses **cpupower** to set the **performance** cpufreq governor. It also sets

kernel.sched_min_granularity_ns to **10** µs, ***kernel.sched_wakeup_granularity_ns*** to 15 µs, and ***vm.dirty_ratio*** to **40**%.

virtual-guest

A profile focused on optimizing performance in Red Hat Enterprise Linux 7 virtual machines.

This profile favors performance over power savings by setting **intel_pstate** and **max_perf_pct=100**. It also decreases the swappiness of virtual memory. It enables transparent huge pages, and uses **cpupower** to set the **performance** cpufreq governor. It also sets ***kernel.sched_min_granularity_ns*** to **10** µs, ***kernel.sched_wakeup_granularity_ns*** to 15 µs, and ***vm.dirty_ratio*** to **40**%.

virtual-host

A profile focused on optimizing performance in Red Hat Enterprise Linux 7 virtualization hosts.

This profile favors performance over power savings by setting **intel_pstate** and **max_perf_pct=100**. It also decreases the swappiness of virtual memory. This profile enables transparent huge pages and writes dirty pages back to disk more frequently. It uses **cpupower** to set the **performance** cpufreq governor. It also sets ***kernel.sched_min_granularity_ns*** to **10** µs, ***kernel.sched_wakeup_granularity_ns*** to 15 µs, ***kernel.sched_migration_cost*** to **5** µs, and ***vm.dirty_ratio*** to **40**%.

For detailed information about the power saving profiles provided with tuned-adm, see the *Red Hat Enterprise Linux 7 Power Management Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

For detailed information about using **tuned-adm**, see the man page:

```
$ man tuned-adm
```

A.7. perf

The **perf** tool provides a number of useful commands, some of which are listed in this section. For detailed information about **perf**, see the *Red Hat Enterprise Linux 7 Developer Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/, or refer to the man pages.

perf stat

This command provides overall statistics for common performance events, including instructions executed and clock cycles consumed. You can use the option flags to gather statistics on events other than the default measurement events. As of Red Hat Enterprise Linux 6.4, it is possible to use **perf stat** to filter monitoring based on one or more specified control groups (cgroups).

For further information, read the man page:

```
$ man perf-stat
```

perf record

This command records performance data into a file which can be later analyzed using **perf report**. For further details, read the man page:

```
$ man perf-record
```

perf report

This command reads the performance data from a file and analyzes the recorded data. For further details, read the man page:

```
$ man perf-report
```

perf list

This command lists the events available on a particular machine. These events vary based on the performance monitoring hardware and the software configuration of the system. For further information, read the man page:

```
$ man perf-list
```

perf top

This command performs a similar function to the **top** tool. It generates and displays a performance counter profile in realtime. For further information, read the man page:

```
$ man perf-top
```

perf trace

This command performs a similar function to the **strace** tool. It monitors the system calls used by a specified thread or process and all signals received by that application. Additional trace targets are available; refer to the man page for a full list:

```
$ man perf-trace
```

A.8. Performance Co-Pilot (PCP)

Performance Co-Pilot (PCP) provides a large number of command-line tools, graphical tools, and libraries. For more information on these tools, see their respective manual pages.

Table A.1. System Services Distributed with Performance Co-Pilot in Red Hat Enterprise Linux 7

Name	Description
pmcd	The Performance Co-Pilot Collection Daemon (PMCD).
pmie	The Performance Metrics Inference Engine.
pmlogger	The performance metrics logger.
pmmgr	Manages a collection of PCP daemons for a set of discovered local and remote hosts running the Performance Co-Pilot Collection Daemon (PMCD) according to zero or more configuration directories.
pmproxy	The Performance Co-Pilot Collection Daemon (PMCD) proxy server.
pmwebd	Binds a subset of the Performance Co-Pilot client API to RESTful web applications using the HTTP protocol.

Table A.2. Tools Distributed with Performance Co-Pilot in Red Hat Enterprise Linux 7

Name	Description
dbpmda	Provides an interactive debugger for Performance Metrics Domain Agents (PMDAs).
genpmda	Creates new Performance Metrics Domain Agents (PMDAs).
pcp	Displays the current status of a Performance Co-Pilot installation.
pmafm	Examines, manages, and replays a Performance Co-Pilot archive folio.
pmatop	Shows the system-level occupation of the most critical hardware resources from the performance point of view: CPU, memory, disk, and network.
pmchart	Plots performance metrics values available through the facilities of the Performance Co-Pilot.
pmclient	Displays high-level system performance metrics by using the Performance Metrics Application Programming Interface (PMAPI).
pmcollectl	Collects and displays system-level data, either from a live system or from a Performance Co-Pilot archive file.
pmconfig	Displays the values of configuration parameters.
pmdate	Displays the current date and time with an optional offset.
pmdbg	Displays available Performance Co-Pilot debug control flags and their values.
pmdiff	Compares the average values for every metric in either one or two archives, in a given time window, for changes that are likely to be of interest when searching for performance regressions.
pmdumplog	Displays control, metadata, index, and state information from a Performance Co-Pilot archive file.
pmdumptext	Outputs the values of performance metrics collected live or from a Performance Co-Pilot archive.
pmerr	Displays available Performance Co-Pilot error codes and their corresponding error messages.
pmevent	Displays details about event record metrics. The metrics are collected either from a live system, or from a Performance Co-Pilot archive file.
pmgenmap	Generates C declarations and **cpp** macros for custom programs that use the Performance Metrics Programming Interface (PMAPI).
pmie	An inference engine that periodically evaluates a set of arithmetic, logical, and rule expressions. The metrics are collected either from a live system, or from a Performance Co-Pilot archive file.
pmie2col	Converts the output of the **pmie** utility to multi-column format.
pmieconf	Displays or sets configurable **pmie** variables.
pminfo	Displays information about performance metrics. The metrics are collected either from a live system, or from a Performance Co-Pilot archive file.
pmiostat	Reports I/O statistics for SCSI devices (by default) or **device-mapper** devices (with the **-x dm** option).
pmlc	Interactively configures active **pmlogger** instances.
pmlogcheck	Identifies invalid data in a Performance Co-Pilot archive file.
pmloglabel	Verifies, modifies, or repairs the label of a Performance Co-Pilot archive file.
pmlogsummary	Calculates statistical information about performance metrics stored in a Performance Co-Pilot archive file.
pmprobe	Determines the availability of performance metrics.
pmsocks	Allows access to a Performance Co-Pilot hosts through a firewall.
pmstat	Periodically displays a brief summary of system performance.

Name	Description
pmstore	Modifies the values of performance metrics.
pmtrace	Provides a command line interface to the trace Performance Metrics Domain Agent (PMDA).
pmval	Displays the current value of a performance metric.

A.9. vmstat

Vmstat outputs reports on your system's processes, memory, paging, block input/output, interrupts, and CPU activity. It provides an instantaneous report of the average of these events since the machine was last booted, or since the previous report.

-a

Displays active and inactive memory.

-f

Displays the number of forks since boot. This includes the **fork**, **vfork**, and **clone** system calls, and is equivalent to the total number of tasks created. Each process is represented by one or more tasks, depending on thread usage. This display does not repeat.

-m

Displays slab information.

-n

Specifies that the header will appear once, not periodically.

-s

Displays a table of various event counters and memory statistics. This display does not repeat.

delay

The delay between reports in seconds. If no delay is specified, only one report is printed, with the average values since the machine was last booted.

count

The number of times to report on the system. If no count is specified and delay is defined, **vmstat** reports indefinitely.

-d

Displays disk statistics.

-p

Takes a partition name as a value, and reports detailed statistics for that partition.

-S

Defines the units output by the report. Valid values are **k** (1000 bytes), **K** (1024 bytes), **m** (1000000 bytes), or **M** (1048576 bytes).

-D

Report summary statistics about disk activity.

For detailed information about the output provided by each output mode, see the man page:

```
$ man vmstat
```

A.10. x86_energy_perf_policy

The **x86_energy_perf_policy** tool allows administrators to define the relative importance of performance and energy efficiency. It is provided by the *kernel-tools* package.

To view the current policy, run the following command:

```
# x86_energy_perf_policy -r
```

To set a new policy, run the following command:

```
# x86_energy_perf_policy profile_name
```

Replace profile_name with one of the following profiles.

performance

The processor does not sacrifice performance for the sake of saving energy. This is the default value.

normal

The processor tolerates minor performance compromises for potentially significant energy savings. This is a reasonable saving for most servers and desktops.

powersave

The processor accepts potentially significant performance decreases in order to maximize energy efficiency.

For further details of how to use **x86_energy_perf_policy**, see the man page:

```
$ man x86_energy_perf_policy
```

A.11. turbostat

The **turbostat** tool provides detailed information about the amount of time that the system spends in different states. **Turbostat** is provided by the *kernel-tools* package.

By default, **turbostat** prints a summary of counter results for the entire system, followed by counter results every 5 seconds, under the following headings:

pkg

The processor package number.

core

The processor core number.

CPU

The Linux CPU (logical processor) number.

%c0

The percentage of the interval for which the CPU retired instructions.

GHz

When this number is higher than the value in TSC, the CPU is in turbo mode

TSC

The average clock speed over the course of the entire interval.

%c1, %c3, and %c6

The percentage of the interval for which the processor was in the c1, c3, or c6 state, respectively.

%pc3 or %pc6

The percentage of the interval for which the processor was in the pc3 or pc6 state, respectively.

Specify a different period between counter results with the **-i** option, for example, run **turbostat -i 10** to print results every 10 seconds instead.

Note

Upcoming Intel processors may add additional c-states. As of Red Hat Enterprise Linux 7.0, **turbostat** provides support for the c7, c8, c9, and c10 states.

A.12. numastat

The **numastat** tool is provided by the *numactl* package, and displays memory statistics (such as allocation hits and misses) for processes and the operating system on a per-NUMA-node basis. The default tracking categories for the **numastat** command are outlined as follows:

numa_hit

The number of pages that were successfully allocated to this node.

numa_miss

The number of pages that were allocated on this node because of low memory on the intended node. Each **numa_miss** event has a corresponding **numa_foreign** event on another node.

numa_foreign

The number of pages initially intended for this node that were allocated to another node instead. Each **numa_foreign** event has a corresponding **numa_miss** event on another node.

interleave_hit

The number of interleave policy pages successfully allocated to this node.

local_node

The number of pages successfully allocated on this node, by a process on this node.

other_node

The number of pages allocated on this node, by a process on another node.

Supplying any of the following options changes the displayed units to megabytes of memory (rounded to two decimal places), and changes other specific **numastat** behaviors as described below.

-c

Horizontally condenses the displayed table of information. This is useful on systems with a large number of NUMA nodes, but column width and inter-column spacing are somewhat unpredictable. When this option is used, the amount of memory is rounded to the nearest megabyte.

-m

Displays system-wide memory usage information on a per-node basis, similar to the information found in **/proc/meminfo**.

-n

Displays the same information as the original numastat command (**numa_hit**, **numa_miss**, **numa_foreign**, **interleave_hit**, **local_node**, and **other_node**), with an updated format, using megabytes as the unit of measurement.

-p pattern

Displays per-node memory information for the specified pattern. If the value for pattern is comprised of digits, **numastat** assumes that it is a numerical process identifier. Otherwise, **numastat** searches process command lines for the specified pattern.

Command line arguments entered after the value of the **-p** option are assumed to be additional patterns for which to filter. Additional patterns expand, rather than narrow, the filter.

-s

Sorts the displayed data in descending order so that the biggest memory consumers (according to the total column) are listed first.

Optionally, you can specify a node, and the table will be sorted according to the node column. When using this option, the node value must follow the **-s** option immediately, as shown here:

```
numastat -s2
```

Do not include white space between the option and its value.

-v

Displays more verbose information. Namely, process information for multiple processes will display detailed information for each process.

display detailed information for each process.

-V

Displays numastat version information.

-z

Omits table rows and columns with only zero values from the displayed information. Note that some near-zero values that are rounded to zero for display purposes will not be omitted from the displayed output.

A.13. numactl

Numactl lets administrators run a process with a specified scheduling or memory placement policy. **Numactl** can also set a persistent policy for shared memory segments or files, and set the processor affinity and memory affinity of a process.

Numactl provides a number of useful options. This appendix outlines some of these options and gives suggestions for their use, but is not exhaustive.

--hardware

Displays an inventory of available nodes on the system, including relative distances between nodes.

--membind

Ensures that memory is allocated only from specific nodes. If there is insufficient memory available in the specified location, allocation fails.

--cpunodebind

Ensures that a specified command and its child processes execute only on the specified node.

--phycpubind

Ensures that a specified command and its child processes execute only on the specified processor.

--localalloc

Specifies that memory should always be allocated from the local node.

--preferred

Specifies a preferred node from which to allocate memory. If memory cannot be allocated from this specified node, another node will be used as a fallback.

For further details about these and other parameters, see the man page:

```
$ man numactl
```

A.14. numad

numad is an automatic NUMA affinity management daemon. It monitors NUMA topology and resource usage within a system in order to dynamically improve NUMA resource allocation and management.

Note that when **numad** is enabled, its behavior overrides the default behavior of automatic NUMA balancing.

A.14.1. Using numad from the command line

To use **numad** as an executable, just run:

```
# numad
```

While **numad** runs, its activities are logged in **/var/log/numad.log**. It will run until stopped with the following command:

```
# numad -i 0
```

Stopping **numad** does not remove the changes it has made to improve NUMA affinity. If system use changes significantly, running **numad** again will adjust affinity to improve performance under the new conditions.

To restrict **numad** management to a specific process, start it with the following options.

```
# numad -S 0 -p pid
```

-p *pid*

This option adds the specified *pid* to an explicit inclusion list. The process specified will not be managed until it meets the **numad** process significance threshold.

-S 0

This sets the type of process scanning to **0**, which limits **numad** management to explicitly included processes.

For further information about available **numad** options, refer to the **numad** man page:

```
$ man numad
```

A.14.2. Using numad as a service

While **numad** runs as a service, it attempts to tune the system dynamically based on the current system workload. Its activities are logged in **/var/log/numad.log**.

To start the service, run:

```
# systemctl start numad.service
```

To make the service persist across reboots, run:

```
# chkconfig numad on
```

For further information about available **numad** options, refer to the **numad** man page:

```
$ man numad
```

A.14.3. Pre-placement advice

numad provides a pre-placement advice service that can be queried by various job management systems to provide assistance with the initial binding of CPU and memory resources for their processes. This pre-placement advice is available regardless of whether **numad** is running as an executable or a service.

A.14.4. Using numad with KSM

If KSM is in use on a NUMA system, change the value of the **/sys/kernel/mm/ksm/merge_nodes** parameter to **0** to avoid merging pages across NUMA nodes. Otherwise, KSM increases remote memory accesses as it merges pages across nodes. Furthermore, kernel memory accounting statistics can eventually contradict each other after large amounts of cross-node merging. As such, **numad** can become confused about the correct amounts and locations of available memory, after the KSM daemon merges many memory pages. KSM is beneficial only if you are overcommitting the memory on your system. If your system has sufficient free memory, you may achieve higher performance by turning off and disabling the KSM daemon.

A.15. OProfile

OProfile is a low overhead, system-wide performance monitoring tool provided by the *oprofile* package. It uses the performance monitoring hardware on the processor to retrieve information about the kernel and executables on the system, such as when memory is referenced, the number of second-level cache requests, and the number of hardware interrupts received. OProfile is also able to profile applications that run in a Java Virtual Machine (JVM).

OProfile provides the following tools. Note that the legacy **opcontrol** tool and the new **operf** tool are mutually exclusive.

ophelp

Displays available events for the system's processor along with a brief description of each.

opimport

Converts sample database files from a foreign binary format to the native format for the system. Only use this option when analyzing a sample database from a different architecture.

opannotate

Creates annotated source for an executable if the application was compiled with debugging symbols.

opcontrol

Configures which data is collected in a profiling run.

operf

Intended to replace **opcontrol**. The **operf** tool uses the Linux Performance Events subsystem, allowing you to target your profiling more precisely, as a single process or system-wide, and allowing OProfile to co-exist better with other tools using the performance monitoring hardware on your system. Unlike **opcontrol**, no initial setup is required, and it

can be used without the root privileges unless the **--system-wide** option is in use.

opreport

Retrieves profile data.

oprofiled

Runs as a daemon to periodically write sample data to disk.

Legacy mode (**opcontrol**, **oprofiled**, and post-processing tools) remains available, but is no longer the recommended profiling method.

For further information about any of these commands, see the OProfile man page:

```
$ man oprofile
```

A.16. taskset

The **taskset** tool is provided by the *util-linux* package. It allows administrators to retrieve and set the processor affinity of a running process, or launch a process with a specified processor affinity.

Important

taskset does not guarantee local memory allocation. If you require the additional performance benefits of local memory allocation, Red Hat recommends using **numactl** instead of taskset.

To set the CPU affinity of a running process, run the following command:

```
# taskset -c processors pid
```

Replace *processors* with a comma delimited list of processors or ranges of processors (for example, **1,3,5-7**. Replace *pid* with the process identifier of the process that you want to reconfigure.

To launch a process with a specified affinity, run the following command:

```
# taskset -c processors -- application
```

Replace *processors* with a comma delimited list of processors or ranges of processors. Replace *application* with the command, options and arguments of the application you want to run.

For more information about **taskset**, see the man page:

```
$ man taskset
```

A.17. SystemTap

SystemTap is extensively documented in its own guides. The Red Hat Enterprise Linux 7 versions of the *SystemTap Beginner's Guide* and the *SystemTap TapSet Reference* are both available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

Appendix B. Revision History

Revision 10.10-41 **Mon May 30 2016** **Milan Navrátil**
Asynchronous update.

Revision 10.08-38 **Wed Nov 11 2015** **Jana Heves**
Version for 7.2 GA release.

Revision 0.3-23 **Tue Feb 17 2015** **Laura Bailey**
Building for RHEL 7.1 GA.

Revision 0.3-3 **Mon Apr 07 2014** **Laura Bailey**
Rebuilding for RHEL 7.0 GA.