
Subject: [PATCH -mm 1/3] i/o bandwidth controller documentation

Posted by [Andrea Righi](#) on Tue, 22 Jul 2008 20:58:57 GMT

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Documentation of the block device I/O bandwidth controller: description, usage, advantages and design.

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Documentation/controllers/io-throttle.txt | 328 +++++
1 files changed, 328 insertions(+), 0 deletions(-)
create mode 100644 Documentation/controllers/io-throttle.txt

diff --git a/Documentation/controllers/io-throttle.txt b/Documentation/controllers/io-throttle.txt

new file mode 100644

index 0000000..f6b8bb9

--- /dev/null

+++ b/Documentation/controllers/io-throttle.txt

@@ -0,0 +1,328 @@

+

+ Block device I/O bandwidth controller

+

+-----

+1. DESCRIPTION

+

+This controller allows to limit the I/O bandwidth of specific block devices for
+specific process containers (cgroups) imposing additional delays on I/O
+requests for those processes that exceed the limits defined in the control
+group filesystem.

+

+Bandwidth limiting rules offer better control over QoS with respect to priority
+or weight-based solutions that only give information about applications'
+relative performance requirements. Nevertheless, priority based solutions are
+affected by performance bursts, when only low-priority requests are submitted
+to a general purpose resource dispatcher.

+

+The goal of the I/O bandwidth controller is to improve performance
+predictability and provide performance isolation of different control groups
+sharing the same block devices.

+

+NOTE #1: If you're looking for a way to improve the overall throughput of the
+system probably you should use a different solution.

+

+NOTE #2: The current implementation does not guarantee minimum bandwidth
+levels, the QoS is implemented only slowing down I/O "traffic" that exceeds the
+limits specified by the user; minimum I/O rate thresholds are supposed to be
+guaranteed if the user configures a proper I/O bandwidth partitioning of the
+block devices shared among the different cgroups (theoretically if the sum of

+all the single limits defined for a block device doesn't exceed the total I/O
+bandwidth of that device).

+

+-----

+2. USER INTERFACE

+

+A new I/O bandwidth limitation rule is described using the file
+blockio.bandwidth.

+

+The same file can be used to set multiple rules for different block devices
+relative to the same cgroup.

+

+2.1. Configure I/O bandwidth limiting rules

+

+The syntax to configure a limiting rule is the following:

+

+# /bin/echo DEV:BW:STRATEGY:BUCKET_SIZE > CGROUP/blockio.bandwidth

+

+ DEV is the name of the device the limiting rule is applied to.

+

+ BW is the maximum I/O bandwidth on DEV allowed by CGROUP; bandwidth must be
+ expressed in bytes/s. A generic I/O bandwidth limiting rule for a block
+ device DEV can be removed setting the BW value to 0.

+

+ STRATEGY is the throttling strategy used to throttle the applications' I/O
+ requests from/to device DEV. At the moment two different strategies can be
+ used:

+

+ 0 = leaky bucket: the controller accepts at most B bytes ($B = BW * \text{time}$);
+ further I/O requests are delayed scheduling a timeout for
+ the tasks that made those requests.

+

+ Different I/O flow

+

+ | | |
+ | v |
+ | v
+ v

+

+
+ \ /

+ \ / leaky-bucket

+

+ ---
+ |||
+ vvv

+ Smoothed I/O flow

+

+ 1 = token bucket: BW tokens are added to the bucket every seconds; the bucket
+ can hold at the most BUCKET_SIZE tokens; I/O requests are
+ accepted if there are available tokens in the bucket; when

+ a request of N bytes arrives N tokens are removed from the
 + bucket; if fewer than N tokens are available the request is
 + delayed until a sufficient amount of token is available in
 + the bucket.

```
+      Tokens (I/O rate)
+      0
+      0
+      0
+      ..... <--
+      \  /  | Bucket size (burst limit)
+      \ooo/  |
+      --- <--'
+      |ooo
+ Incoming --->|---> Conforming
+ I/O      |oo I/O
+ requests -->|--> requests
+      |
+      ---->|
```

+ Leaky bucket is more precise than token bucket to respect the bandwidth
 + limits, because bursty workloads are always smoothed. Token bucket, instead,
 + allows a small irregularity degree in the I/O flows (burst limit), and, for
 + this, it is better in terms of efficiency (bursty workloads are not smoothed
 + when there are sufficient tokens in the bucket).

+ BUCKET_SIZE is used only with token bucket (STRATEGY == 1) and defines the
 + size of the bucket in bytes.

+ CGROUP is the name of the limited process container.

+Also the following syntaxes are allowed:

+ remove an I/O bandwidth limiting rule
 + # /bin/echo DEV:0 > CGROUP/blockio.bandwidth

+ configure a limiting rule using leaky bucket throttling (ignore bucket size):
 + # /bin/echo DEV:BW:0 > CGROUP/blockio.bandwidth

+2.2. Show I/O bandwidth limiting rules

+All the defined rules and statistics for a specific cgroup can be shown reading
 +the file blockio.bandwidth. The following syntax is used:

```
+ $ cat CGROUP/blockio.bandwidth
+ MAJOR MINOR BW STRATEGY LEAKY_STAT BUCKET_SIZE BUCKET_FILL TIME_DELTA
```

+ MAJOR is the major device number of DEV (defined above)

```

+
+- MINOR is the minor device number of DEV (defined above)
+
+- BW, STRATEGY and BUCKET_SIZE are the same parameters defined above
+
+- LEAKY_STAT is the amount of bytes currently allowed by the I/O bandwidth
+ controller (only used with leaky bucket strategy - STRATEGY == 0)
+
+- BUCKET_FILL represents the amount of tokens present in the bucket (only used
+ with token bucket strategy - STRATEGY == 1)
+
+- TIME_DELTA can be one of the following:
+ - the amount of jiffies elapsed from the last I/O request (token bucket)
+ - the amount of jiffies during which the bytes given by LEAKY_STAT have been
+ accumulated (leaky bucket)
+
+Multiple per-block device rules are reported in multiple rows
+(DEVi, i = 1 .. n):
+
+$ cat CGROUP/blockio.bandwidth
+MAJOR1 MINOR1 BW1 STRATEGY1 LEAKY_STAT1 BUCKET_SIZE1 BUCKET_FILL1
TIME_DELTA1
+MAJOR1 MINOR1 BW2 STRATEGY2 LEAKY_STAT2 BUCKET_SIZE2 BUCKET_FILL2
TIME_DELTA2
+...
+MAJORn MINORn BWn STRATEGYn LEAKY_STATn BUCKET_SIZEn BUCKET_FILLn
TIME_DELTAn
+
+2.3 Configure I/O operations/sec limiting rules
+
+The syntax to limit I/O operations/sec is the following:
+
+# /bin/echo DEV:IOPS > CGROUP/blockio.iops
+
+- DEV is the name of the device the limiting rule is applied to.
+
+- IOPS is the number of the maximum I/O operations per second that can be
+ issued on device DEV by the tasks belonging to cgroup CGROUP. The I/O
+ operations limit can be removed setting IOPS to 0.
+
+2.4 Show I/O operations/sec limiting rules
+
+The I/O operations limits and statistics for a specific cgroup can be shown
+reading the file blockio.ops. The following syntax is used:
+
+$ cat CGROUP/blockio.iops
+MAJOR MINOR IOPS IOPS_STAT TIME_DELTA
+

```

```

+- MAJOR is the major device number of DEV (defined above)
+
+- MINOR is the minor device number of DEV (defined above)
+
+- IOPS is the I/O operations/sec limit
+
+- IOPS_STAT is the number of I/O operations accumulated by the iops counter
+
+- TIME_DELTA can be one of the following:
+ - the amount of jiffies during which the number of I/O operations reported in
+   IOPS_STAT have been accumulated
+
+Multiple per-block device rules are reported in multiple rows
+(DEVi, i = 1 .. n):
+
+$ cat CGROUP/blockio.bandwidth
+MAJOR1 MINOR1 IOPS1 IOPS_STAT1 TIME_DELTA1
+MAJOR2 MINOR2 IOPS2 IOPS_STAT2 TIME_DELTA2
+...
+MAJORn MINORn IOPSn IOPS_STATn TIME_DELTAn
+
+2.5. Examples
+
+* Mount the cgroup filesystem (blockio subsystem):
+ # mkdir /mnt/cgroup
+ # mount -t cgroup -oblockio blockio /mnt/cgroup
+
+* Instantiate the new cgroup "foo":
+ # mkdir /mnt/cgroup/foo
+ --> the cgroup foo has been created
+
+* Add the current shell process to the cgroup "foo":
+ # /bin/echo $$ > /mnt/cgroup/foo/tasks
+ --> the current shell has been added to the cgroup "foo"
+
+* Give maximum 1MiB/s of I/O bandwidth on /dev/sda for the cgroup "foo", using
+ leaky bucket throttling strategy:
+ # /bin/echo /dev/sda:$((1024 * 1024)):0:0 > \
+ > /mnt/cgroup/foo/blockio.bandwidth
+ # sh
+ --> the subshell 'sh' is running in cgroup "foo" and it can use a maximum I/O
+   bandwidth of 1MiB/s on /dev/sda
+
+* Give maximum 8MiB/s of I/O bandwidth on /dev/sdb for the cgroup "foo", using
+ token bucket throttling strategy, bucket size = 8MiB:
+ # /bin/echo /dev/sdb:$((8 * 1024 * 1024)):1:$((8 * 1024 * 1024)) > \
+ > /mnt/cgroup/foo/blockio.bandwidth
+ # sh

```

```

+ --> the subshell 'sh' is running in cgroup "foo" and it can use a maximum I/O
+   bandwidth of 1MiB/s on /dev/sda (controlled by leaky bucket throttling)
+   and 8MiB/s on /dev/sdb (controlled by token bucket throttling)
+
+* Run a benchmark doing I/O on /dev/sda and /dev/sdb; I/O limits and usage
+ defined for cgroup "foo" can be shown as following:
+ # cat /mnt/cgroup/foo/blockio.bandwidth
+ 8 16 8388608 1 0 8388608 -522560 48
+ 8 0 1048576 0 737280 0 0 216
+
+* Extend the maximum I/O bandwidth for the cgroup "foo" to 16MiB/s on /dev/sda:
+ # /bin/echo /dev/sda:$((16 * 1024 * 1024)):0:0 > \
+ > /mnt/cgroup/foo/blockio.bandwidth
+ # cat /mnt/cgroup/foo/blockio.bandwidth
+ 8 16 8388608 1 0 8388608 -84432 206436
+ 8 0 16777216 0 0 0 0 15212
+
+* Remove limiting rule on /dev/sdb for cgroup "foo":
+ # /bin/echo /dev/sdb:0:0:0 > /mnt/cgroup/foo/blockio.bandwidth
+ # cat /mnt/cgroup/foo/blockio.bandwidth
+ 8 0 16777216 0 0 0 0 110388
+
+* Set a maximum of 100 I/O operations/sec to /dev/sdc for cgroup "foo":
+ # /bin/echo /dev/sdc:100 > /mnt/cgroup/foo/blockio.iops
+ # cat /mnt/cgroup/foo/blockio.iops
+ 8 32 100 0 232268
+
+* Remove limiting rule for I/O operations from /dev/sdc for cgroup "foo":
+ # /bin/echo /dev/sdc:0 > /mnt/cgroup/foo/blockio.iops
+
+-----
+3. ADVANTAGES OF PROVIDING THIS FEATURE
+
+* Allow I/O traffic shaping for block device shared among different cgroups
+* Improve I/O performance predictability on block devices shared between
+ different cgroups
+* Limiting rules do not depend of the particular I/O scheduler (anticipatory,
+ deadline, CFQ, noop) and/or the type of the underlying block devices
+* The bandwidth limitations are guaranteed both for synchronous and
+ asynchronous operations, even the I/O passing through the page cache or
+ buffers and not only direct I/O (see below for details)
+* It is possible to implement a simple user-space application to dynamically
+ adjust the I/O workload of different process containers at run-time,
+ according to the particular users' requirements and applications' performance
+ constraints
+* It is even possible to implement event-based performance throttling
+ mechanisms; for example the same user-space application could actively
+ throttle the I/O bandwidth to reduce power consumption when the battery of a

```

- + mobile device is running low (power throttling) or when the temperature of a
- + hardware component is too high (thermal throttling)

+

+-----

+4. DESIGN

+

- +The I/O throttling is performed imposing an explicit timeout, via
- +`schedule_timeout_killable()` on the processes that exceed the I/O bandwidth
- +dedicated to the cgroup they belong to. I/O accounting happens per cgroup.

+

- +It just works as expected for read operations: the real I/O activity is reduced
- +synchronously according to the defined limitations.

+

- +Write operations, instead, are modeled depending of the dirty pages ratio
- +(write throttling in memory), since the writes to the real block devices are
- +processed asynchronously by different kernel threads (`pdflush`). However, the
- +dirty pages ratio is directly proportional to the actual I/O that will be
- +performed on the real block device. So, due to the asynchronous transfers
- +through the page cache, the I/O throttling in memory can be considered a form
- +of anticipatory throttling to the underlying block devices.

+

- +Multiple re-writes in already dirtied page cache areas are not considered for
- +accounting the I/O activity. This is valid for multiple re-reads of pages
- +already present in the page cache as well.

+

- +This means that a process that re-writes and/or re-reads multiple times the
- +same blocks in a file (without re-creating it by `truncate()`, `ftruncate()`,
- +`creat()`, etc.) is affected by the I/O limitations only for the actual I/O
- +performed to (or from) the underlying block devices.

+

- +Multiple rules for different block devices are stored in a linked list, using
- +the `dev_t` number of each block device as key to uniquely identify each element
- +of the list. RCU synchronization is used to protect the whole list structure,
- +since the elements in the list are not supposed to change frequently (they
- +change only when a new rule is defined or an old rule is removed or updated),
- +while the reads in the list occur at each operation that generates I/O. This
- +allows to provide zero overhead for cgroups that do not use any limitation.

+

- +WARNING: per-block device limiting rules always refer to the `dev_t` device
- +number. If a block device is unplugged (i.e. a USB device) the limiting rules
- +defined for that device persist and they are still valid if a new device is
- +plugged in the system and it uses the same major and minor numbers.

+

- +NOTE: explicit sleeps are **not** imposed on tasks doing asynchronous I/O (AIO)
- +operations; AIO throttling is performed returning `-EAGAIN` from `sys_io_submit()`.
- +Userspace applications must be able to handle this error code opportunely.

+

+-----

+5. TODO

+

+* Think an alternative design for general purpose usage; special purpose usage
+ right now is restricted to improve I/O performance predictability and
+ evaluate more precise response timings for applications doing I/O. To a large
+ degree the block I/O bandwidth controller should implement a more complex
+ logic to better evaluate real I/O operations cost, depending also on the
+ particular block device profile (i.e. USB stick, optical drive, hard disk,
+ etc.). This would also allow to appropriately account I/O cost for seeky
+ workloads, respect to large stream workloads. Instead of looking at the
+ request stream and try to predict how expensive the I/O cost will be, a
+ totally different approach could be to collect request timings (start time /
+ elapsed time) and based on collected informations, try to estimate the I/O
+ cost and usage (idea proposed by Andrew Morton <akpm@linux-foundation.org>).

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1.5.4.3

Containers mailing list

Containers@lists.linux-foundation.org

<https://lists.linux-foundation.org/mailman/listinfo/containers>
