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

Posted by [Andrea Righi](#) on Tue, 15 Jul 2008 20:40:47 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 | 282 ++++++

1 files changed, 282 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..9c53f6c

--- /dev/null

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

@ @ -0,0 +1,282 @ @

+

+       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 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 DEVICE 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 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. 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
+
+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

+

- +\* Try to reduce the cost of calling `cgroup_io_throttle()` on every
- + `submit_bio(READ, ...)`; this is not too much expensive, but the call of
- + `task_subsys_state()` has surely a cost. A possible solution could be to
- + temporarily account I/O in the current `task_struct` and call

- + cgroup\_io\_throttle() only on each X MB of I/O. Or on each Y number of I/O
- + requests as well. Better if both X and/or Y can be tuned at runtime by a
- + userspace tool.
- +
- +\* 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

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Containers mailing list  
Containers@lists.linux-foundation.org  
<https://lists.linux-foundation.org/mailman/listinfo/containers>

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