Mind the Gaps: Honoring LC reservations in the presence of BEs

Graduate Category

1 Motivation

Cloud providers like AWS, or containerization systems like Kubernetes, support reserving CPU for *latency critical* (LC) services. Developers choose reservations based on expected peak load [8, 12, 13], but load is variable, leading to a utilization problem.

Best effort (BE) workloads do not have reservations, so providers run them opportunistically on the same resources as LCs reserved; the resource that this work focuses on is CPU. The challenge is to honor resource reservations for LCs while opportunistically running BEs.

Surprisingly, current popular scheduling systems fail to honor reservations. *Figure* 1 shows the latency of an endpoint in a web application in Kubernetes that gets a user's feed, and the throughput of a BE image resize job, both running on the same cores. The mean response latency jumps from ~7ms to ~15ms after starting the BE.

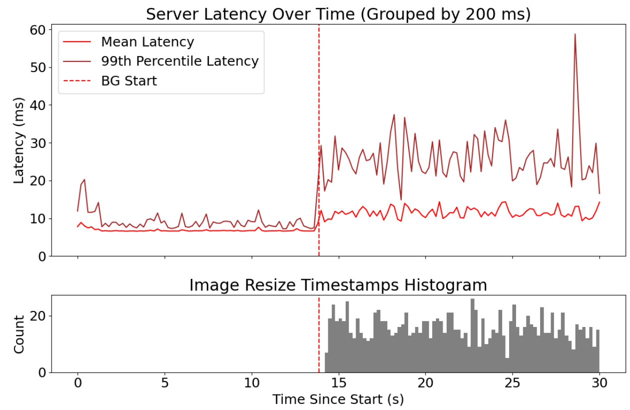

Figure 1: In Kubernetes, running a BE has latency impacts on an LC with reservations

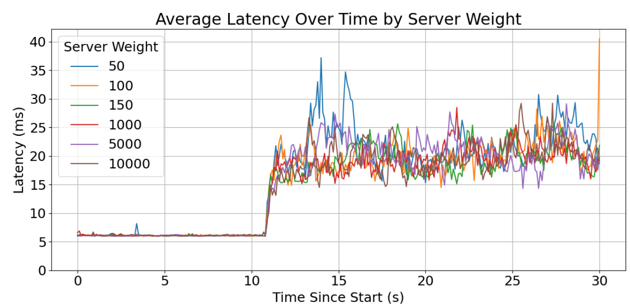

Figure 2: the weight of the server has little impact on how much the weight 1 BE task interferes

2 Background & Problem

All Open Container Initiative compliant containers, including Kubernetes, enforce CPU reservations using `cgroups`' weight interface [2, 10, 11], as do VM frameworks, including Firecracker and libvirt [1, 3, 4].

A simplified experiment shows `cgroups` weights are unable to enforce reservations. We run a simple CPU-bound server sharing 4 cores with an image resize job, each in their own group. `cgroups` supports weights in the range [1,10000]; Figure 2 shows running the server with any weight above 50 does not change the latency impact of the BE.

This latency impact happens because the BE occasionally runs uncontended on one core, while another has queued server threads. Figure 3 shows this happening in the trace: on core 6, the red BE runs for 10ms, while blue server threads are queued on the other cores.

This happens because weights are only enforced within per-CPU runqueues. Load balancing eventually remedies imblances, but runs less frequently than scheduling. For workloads with request processing times in the millisecond range, waiting for the load balancer affects processing times.

In order to globally enforce weights, each scheduling decision would require a search of all runqueues for potentially higher-weight processes, which is too costly.

3 Related work

Wasted Cores [9] improves the idle behavior of Linux, whereas we change the API to the scheduler.

Linux's `sched_idle` policy addresses the observed weight inversion, but is inadequate: running the microbenchmark using `sched_idle` leads to a mean latency increase from 6ms to 8ms.

Other schedulers run primarily in userspace in order to work around the kernel scheduler [5–7]. This paper avoids doing so by identifying the core problem and addressing it.

4 Approach

Our approach replaces weights with priority scheduling.

Enforcing priorities requires fewer global runqueue searches than weights, because searches only need to happen on *class boundary crossings*: on *exit*, when switching to running a

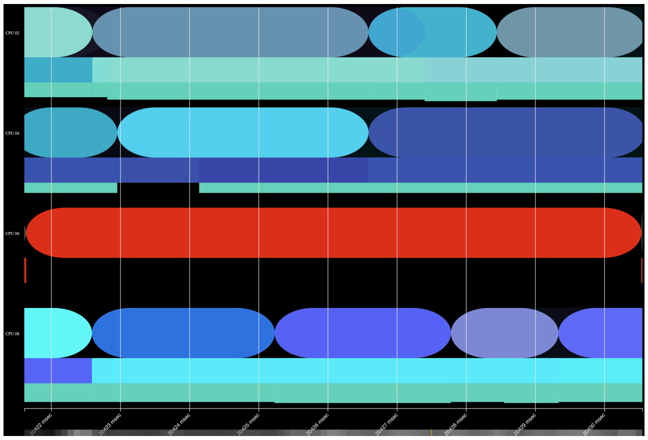

Figure 3: Core 6 runs an image resize process, unaware that the other cores have queued server threads

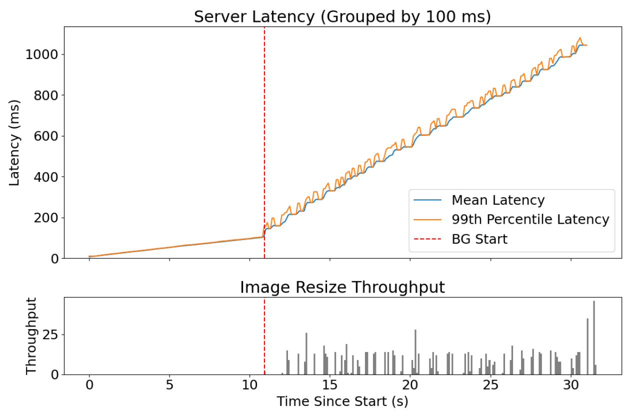

Figure 4: when running the server in real time, throttling degrades performance at high load

low-class process, and on *entry*, when enqueueing a high-class process. These checks ensure that a core running a BE thread t knows there are no queued LC threads anywhere: the *exit* check ensures there's none when starting to run t, and the *entry* check ensures if one wakes up while running t, it will interrupt t.

Linux enforces priority across scheduling classes, but higher class schedulers are designed for real-time applications. Additionally, Linux throttles them under high load in order to not starve the default class. We see this happening in Figure 4, where throttling leads to spikes in the BE's throughput and corresponding spikes in the server's latency.

We design a new scheduling class `BeClass` that sits at a lower priority than the default one, and enforces LCs' uncontended access to reserved CPUs. To enforce reservations under high load, without throttling LCs or killing BEs, `BeClass` uses *parking*, wherein user-space code never runs, only kernel-level services. We implement this strict priority in Linux.

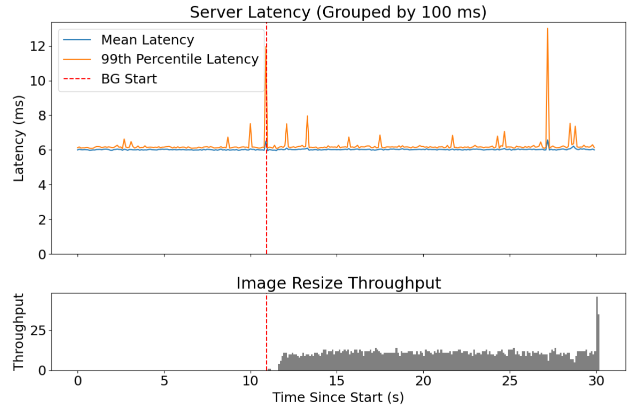

Figure 5: `BeClass` isolates the server's latencies from BE jobs

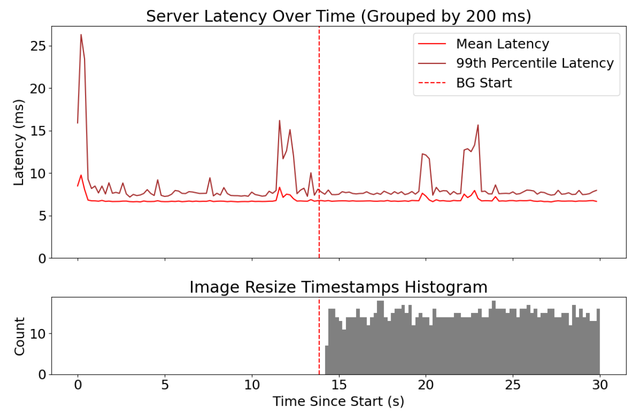

Figure 6: Kubernetes using `BeClass` honors reservations, unlike in Figure 1

5 Results

We re-run the microbenchmark using `BeClass`; the results are in Figure 5. As desired, the latency of the server remains stable after the BE starts, and the BE runs only in gaps where cores would otherwise be idle.

We run the Kubernetes application using `BeClass`. Figure 6 shows that the baseline mean latency of the LC server stays around 6.5ms after starting the the BE.

Figure 7 shows parking enables the server to keep its reservation even under sustained 100% load. We run the same client load as Figure 4, with `BeClass` parking the BE. Notice that the BE does not make progress until the end, when the server is done processing.

6 Contributions

We identify a serious limitation of `cgroups` weights: they are unable to honor the reservations of LC applications in the presence BE workloads. We show that this is because Linux uses per-core runqueues.

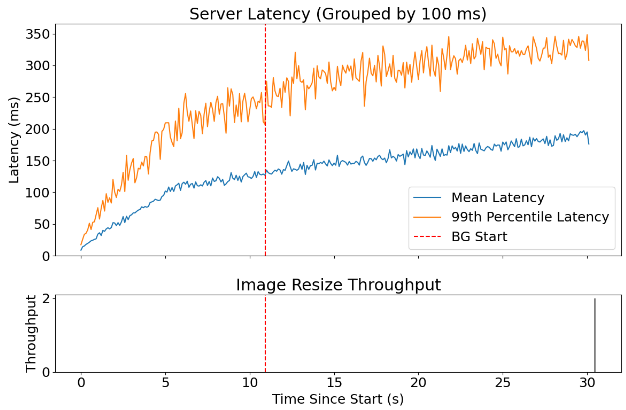

Figure 7: `BeClass` starves BE user-space threads, leaving all CPU-time to the LC

We propose an API that separates BE from LC by introducing `BeClass`. `BeClass` ensures that no BE is ever running when an LC is queued, and requires fewer cross-core interactions than a weight-based approach to do so.

We implement this strict priority in Linux.

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