VM-CPUFreq for x86

Scaling the guest frequency for performance and power savings

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How Linux kernel scales core frequency?

• How Linux kernel decides next frequency to run?
  • Linux kernel determines the next frequency according to current utilization
  • \( F_{\text{next}} = 1.25 \times \text{utilization} \times \frac{F_{\text{max}}}{\text{capacity}} \)
    • Here utilization is effective utilization
    • \( F_{\text{max}} \) is the maximum frequency of the core
    • Capacity is the max capacity of the core

• How is effective utilization calculated?
  • Effective utilization is aggregated value of utilizations of all run queues on a CPU

• How is utilization calculated?
  • This is calculated for each task (PELT) and every task_tick:
    • How much time the task ran is the utilization of that task
  • Also, kernel adds the previous utilizations with EWMA algorithm
Does it work when Guest is running?

Workload:
Loop: (Busy: 0%, Idle: 100%)

Virtualization case

Host’s view

Guest’s view

Test system: 2 socket server with 4th Generation AMD EPYC™ Processors each with 128 Cores 256 Threads
Max frequency: P0: 1.9 GHz, Turbo: 3.1 GHz, Guest size: 8 vcpu
Core configuration: Pinning vcpu to pcpu, all cores are same capacity

BareMetal case

Note: Guest performs HLT on idle causing VM-exit
Does it work when Guest is running?

Workload:
Loop: (Busy: 10%, Idle: 90%)

Test system: 2 socket server with 4th Generation AMD EPYC™ Processors each with 128 Cores 256 Threads
Max frequency: P0: 1.9 GHz, Turbo: 3.1 GHz, Guest size: 8 vcpu
Core configuration: Pinning vcpu to pcpu, all cores are same capacity

Note: Guest performs HLT on idle causing VM-exit
Does it work when Guest is running?

Workload:
Loop: (Busy: 50%, Idle: 50%)

Test system: 2 socket server with 4th Generation AMD EPYC™ Processors each with 128 Cores 256 Threads
Max frequency: P0: 1.9 GHz, Turbo: 3.1 GHz, Guest size: 8 vcpu
Core configuration: Pinning vcpu to pcpu, all cores are same capacity

Virtualization case

Guest’s view

Host’s view

BareMetal case

Note: Guest performs HLT on idle causing VM-exit
What happens when Guest does not exit when idle

- Some **cloud providers do not want guest to perform vm-exit** when guest thread is idle
  - Reason: To achieve **lower latency**
  - Side effect: **Higher power consumption** and host’s utilization calculation goes wrong
- Common approaches to avoid vm-exit
  - **Partially** avoid vm-exit by using haltpoll driver
  - **Completely** avoid vm-exit with idle=poll or idle=mwait
  - Use MWAIT inside the guest (Certain x86 processors, including AMD EPYC ones allow this)
CPU’s util_avg When Guest is Running

Test system: 2 socket server with 4th Generation AMD EPYC™ Processors each with 128 Cores 256 Threads
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**guest halt**

**guest poll**

**guest mwait**
VM-CPUFreq Patches by Google

• Patch: “[RFC PATCH v2 0/6] Improve VM CPUfreq and task placement behavior”
  • [https://lore.kernel.org/lkml/20230331014356.1033759-1-davidai@google.com/](https://lore.kernel.org/lkml/20230331014356.1033759-1-davidai@google.com/)
  • Focuses on ARM big LITTLE architecture and their problem for guest workload’s task placement
  • Focuses on pinned VM but VM can exit when idle.
  • Uses a hypercall to communicate the guest utilization data with the host.

• Patch: “[PATCH v3 0/2] Improve VM CPUfreq and task placement behavior”
  • [https://lore.kernel.org/lkml/20230731174613.4133167-1-davidai@google.com/](https://lore.kernel.org/lkml/20230731174613.4133167-1-davidai@google.com/)
  • Shares the guest utilization with the host via a MMIO mechanism.
  • VMM patches are for CrosVM
  • VMM needs to update the util_clamp to clamp utilization of the vcpu thread based on the utilization obtained via MMIO
  • No performance improvements compared to v2

• For x86 servers the problem is bit different
  • The problem is not about task placement as x86 servers have cores with same capacity
  • The problem is when guest doesn’t exit on idle, host’s view of vcpu thread’s utilization is incorrect.
  • There is a scope of performance and power improvements
  • We choose v2 for our evaluation on x86.
How VM-CPUFreq is implemented for x86
Results

- Test setup
  - 2 socket server with 4th Generation AMD EPYC™ Processors each with 128 Cores 256 Threads
  - Max frequency: P0: 1.9 GHz, Turbo: 3.1 GHz
  - Guest size: 8 vcpu / 16 vcpu
  - Guest’s vcpu threads are pinned to PCPUs.
  - Core configuration: all cores are same capacity

- Kernel versions
  - Test kernel 1: 6.6-rc6
  - Test kernel 2: 6.6-rc6 + vm-cpufreq v2 rebased and added support for x86

- Workloads

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<th>Repository/source</th>
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</tr>
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**Results (8 vcpu)**

**tbench (throughput)**

- **Idle=poll**
- **vm-cpufreq+idle=poll**

**tbench (power)**

- **Idle=poll**
- **vm-cpufreq+idle=poll**

**tbench (power)**

- **Idle=mwait**
- **vm-cpufreq+idle=mwait**

**Performance Metrics**

- **Throughput (normalized)**
- **Power (normalized)**

**Comparison**

- **idle=poll** vs **vm-cpufreq+idle=poll**
- **idle=mwait** vs **vm-cpufreq+idle=mwait**

**Power Reduction**

- **idle=mwait** vs **vm-cpufreq+idle=mwait**: 2.3% reduction
- **idle=poll** vs **vm-cpufreq+idle=poll**: 4.6x improvement
Results (8 vcpu)

- **dbench (throughput)**
  - `halt-exits`
  - `vm-cpufreq+halt-exits`

- **dbench (power)**
  - `halt-exits`
  - `driver+halt-exits`

- **dbench (throughput)**
  - `idle=poll`
  - `vm-cpufreq+idle=poll`

- **dbench (power)**
  - `idle=mwait`
  - `vm-cpufreq+idle=mwait`

- **dbench (throughput)**
  - `idle=mwait`
  - `vm-cpufreq+idle=mwait`
Results (8 vcpu)

Kernbench (throughput):
- **halt-exits**
- **vm-cpufreq+halt-exits**

Kernbench (power):
- **idle=poll**
- **vm-cpufreq+idle=poll**

- **idle=mwait**
- **vm-cpufreq+idle=mwait**

Normalized throughput and power values are shown for different configurations and thread counts.

- **3.4x**
- **1.2x**
Results (16 vcpu)

`tbench (throughput)`

- `halt-exits`
- `vm-cpufreq+halt-exits`

`tbench (power)`

- `halt-exits`
- `vm-cpufreq+halt-exits`

- `idle=poll`
- `vm-cpufreq+idle=poll`

- `idle=mwait`
- `vm-cpufreq+idle=mwait`
Results (16 vcpu)

**dbench (throughput)**

- **halt-exits**
- **vm-cpufreq+halt-exits**

**dbench (power)**

- **halt-exits**
- **vm-cpufreq+halt-exits**

**idle=poll**

- **vm-cpufreq+idle=poll**

**idle=mwait**

- **vm-cpufreq+idle=mwait**

12% but high variation

16.5x

2.5x
CPU’s util_avg When Guest is Running with VM-CPUFreq

Test system: 2 socket server with 4th Generation AMD EPYC™ Processors each with 128 Cores 256 Threads
Max frequency: P0: 1.9 GHz, Turbo: 3.1 GHz, Guest size: 8 vcpu
Core configuration: Pinning vcpu to pcpu, all cores are same capacity
Summary and Next steps

• Not seeing any significant performance or power improvements with vm-cpufreq.

• Current vm-cpufreq v2 patches only add lower bound for the vcpu thread utilization
  • Between the guest’s utilization and the host CPU utilization, we pick the one which is higher.
  • This is not useful for saving power when the guest vCPU is POLL-idling.

• Even if we use uclamp min and max to exactly match Guest’s view of utilization to Host’s utilization, we don’t see any improvements.
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Backup slides
Patch to match VCPU threads utilization exactly

```c
diff --git a/arch/x86/kvm/x86.c b/arch/x86/kvm/x86.c
index d48acf62b2d1..2d2a3bfc8282 100644
--- a/arch/x86/kvm/x86.c
+++ b/arch/x86/kvm/x86.c
@@ -9828,11 +9828,12 @@ static int kvm_sched_get_cur_cpufreq(struct kvm_vcpu *vcpu)
     static int kvm_sched_set_util(struct kvm_vcpu *vcpu, u64 val)
     {
         struct sched_attr attr = {
-           .sched_flags = SCHED_FLAG_UTIL_GUEST,
+           .sched_flags = SCHED_FLAG_UTIL_CLAMP,
             
         int ret;

         attr.sched_util_min = val;
+        attr.sched_util_max = val;

         ret = sched_setattr_nocheck(current, &attr);
```