VM-CPUFreq for x86

Scaling the guest frequency for performance and power savings

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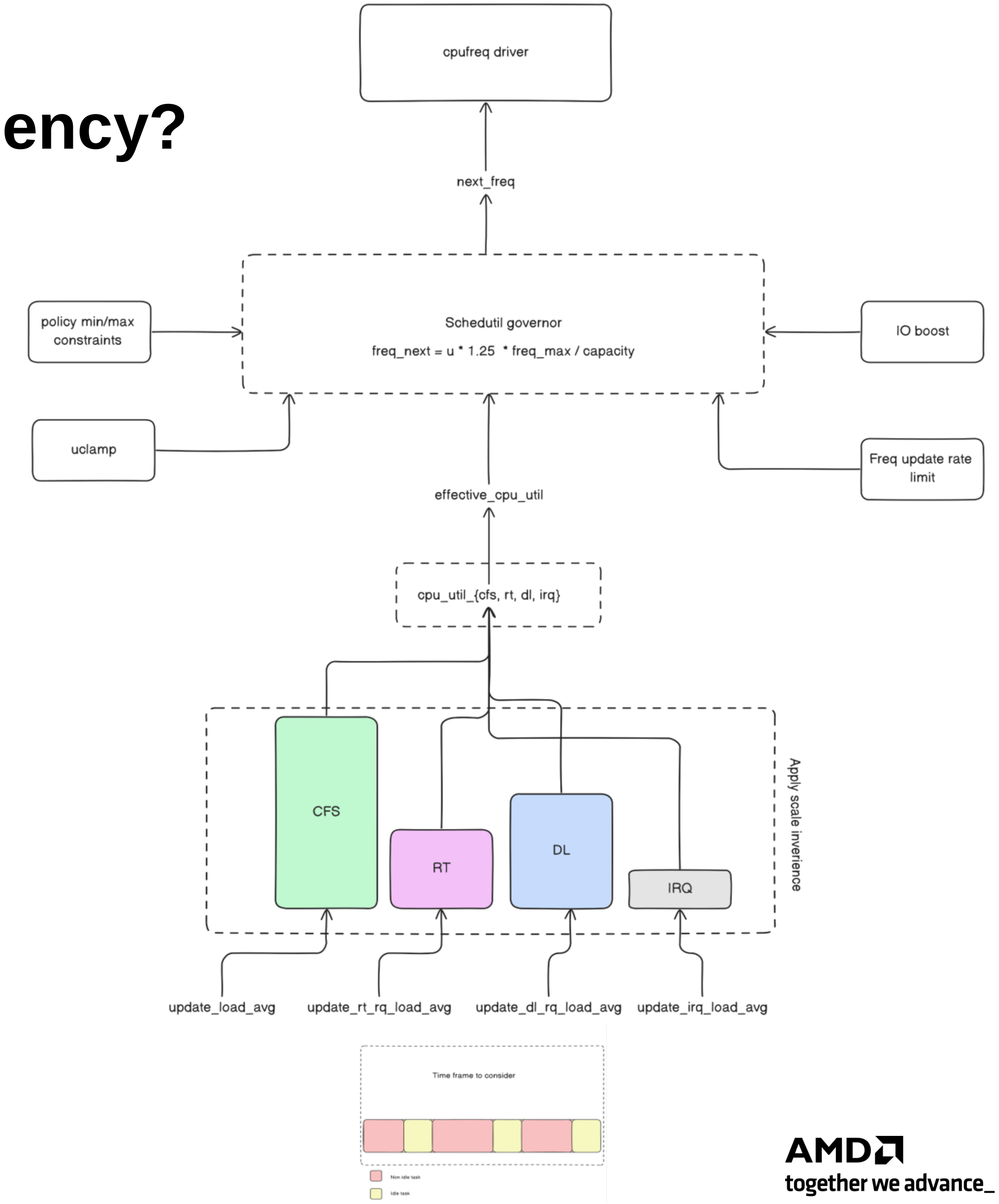
How Linux kernel scales core frequency?

- How Linux kernel decides next frequency to run?
  - Linux kernel determines the next frequency according to current utilization
  - **F_next = 1.25 * utilization * F_max / capacity**
    - Here utilization is effective utilization
    - F_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



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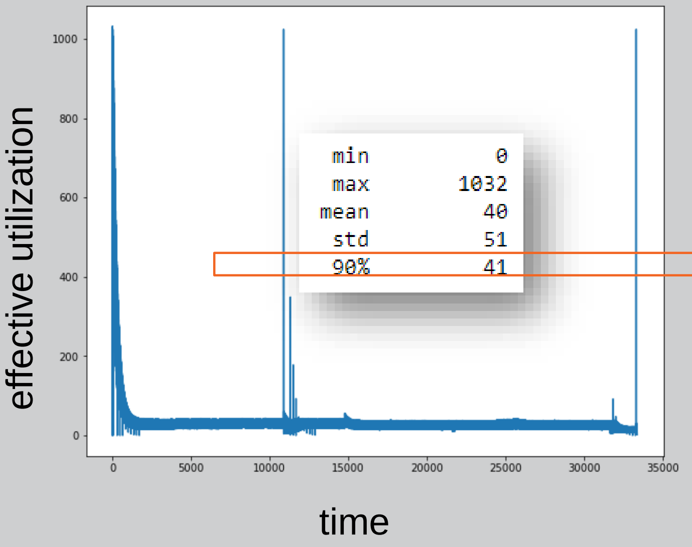
Does it work when Guest is running?

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

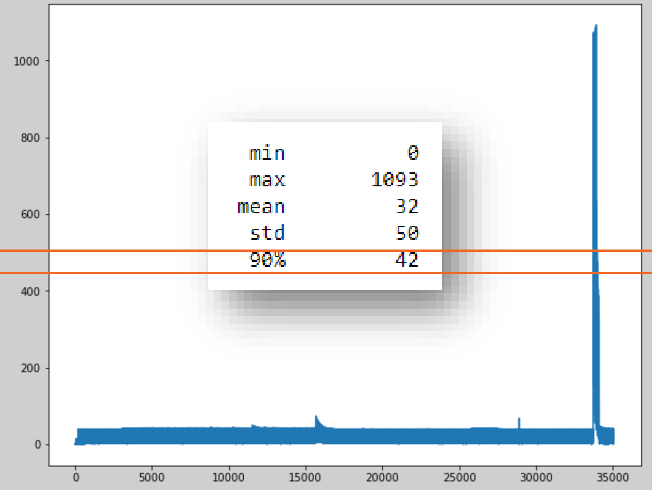
Test system:2 socket server with 4th Generation AMD EPYC™ Processors each with 128 Cores 256 Threads
Max frequency: P0: 1.9 GHz, Turbo: 3.1 GHz, Guest size: 8 vcpu
Core configuration: Pinning vcpu to pcpu, all cores are same capacity

Virtualization case

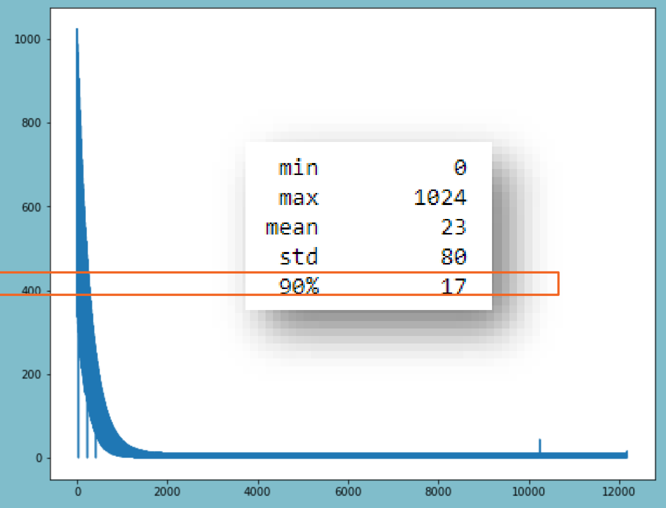
Guest's view



Host's view



BareMetal case



Note: Guest performs HLT on idle causing VM-exit

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Does it work when Guest is running?

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

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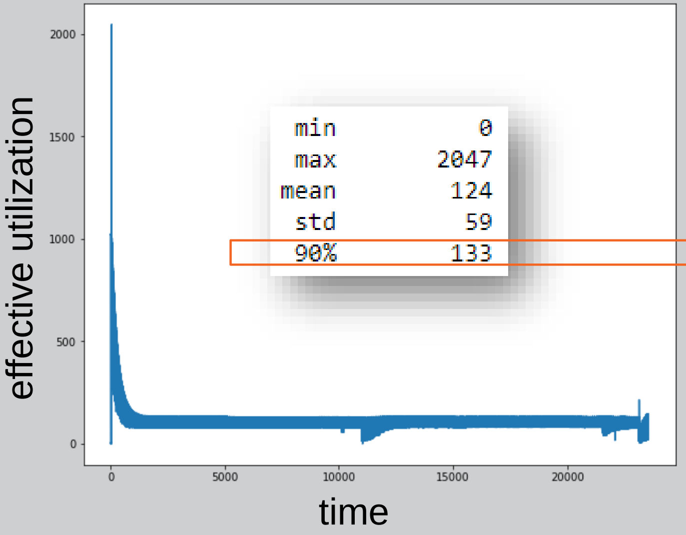
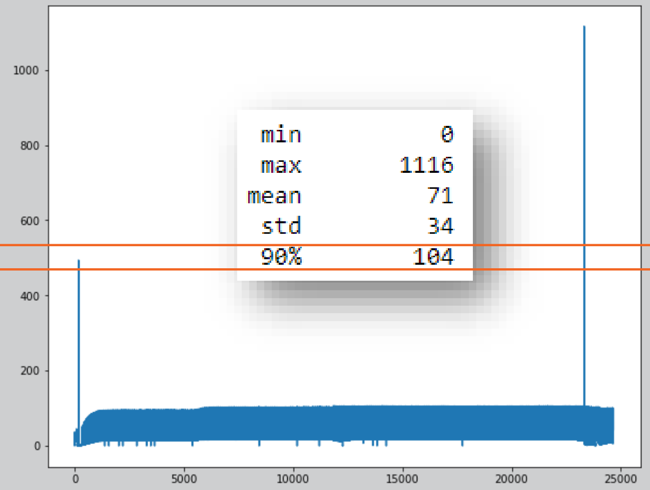
Virtualization case

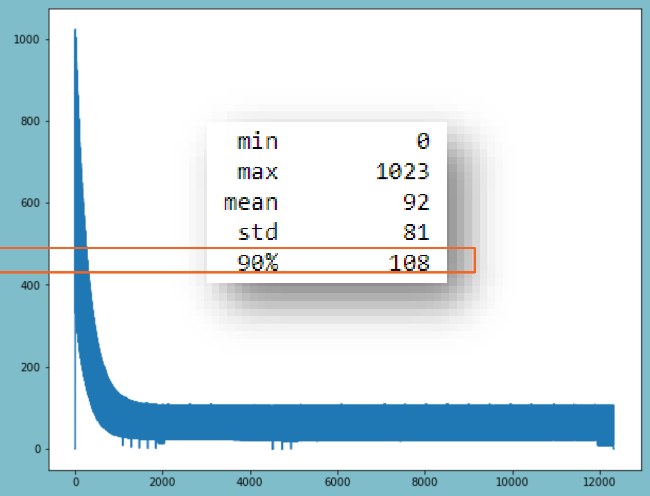
Guest's view



Host's view



BareMetal case



Note: Guest performs HLT on idle causing VM-exit

Does it work when Guest is running?

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

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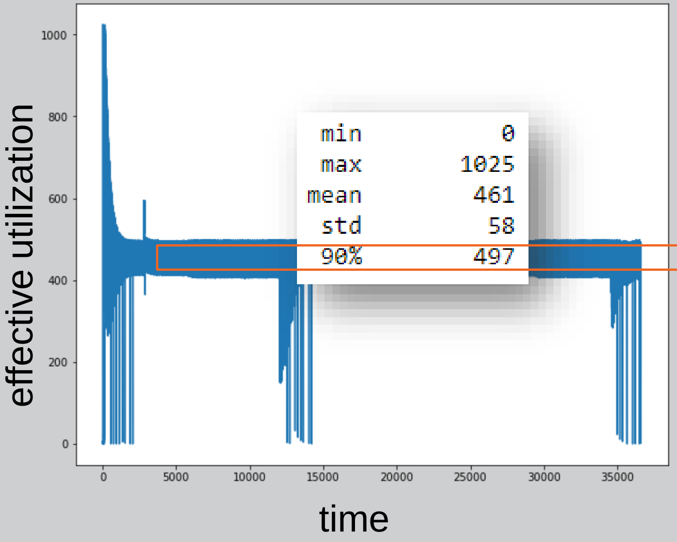
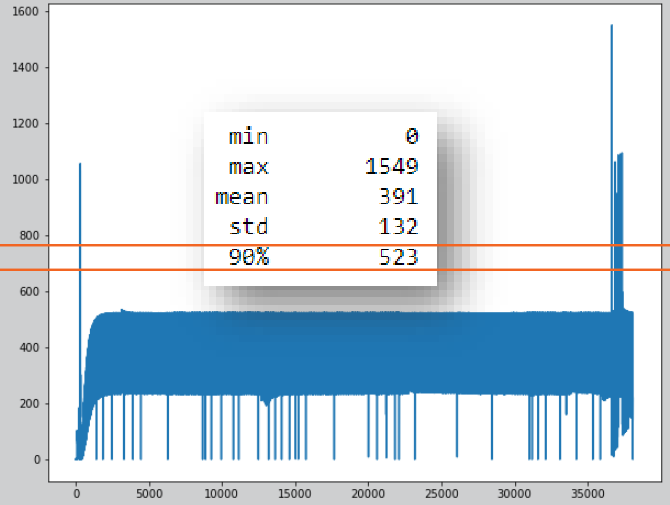
Virtualization case

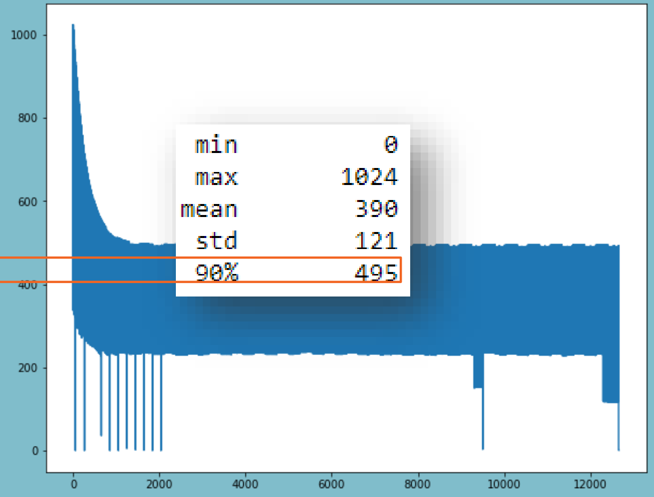
Guest's view



Host's view



BareMetal case



Note: Guest performs HLT on idle causing VM-exit

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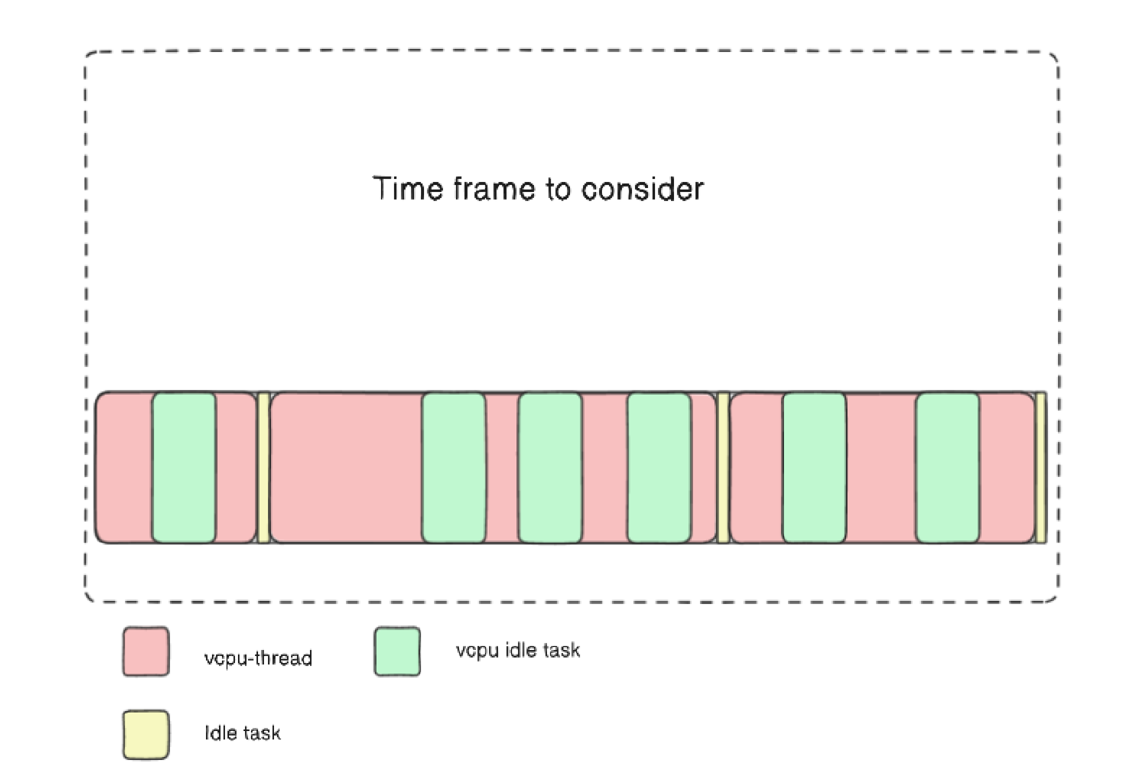
What happens when Guest does not exit when idle

- 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)



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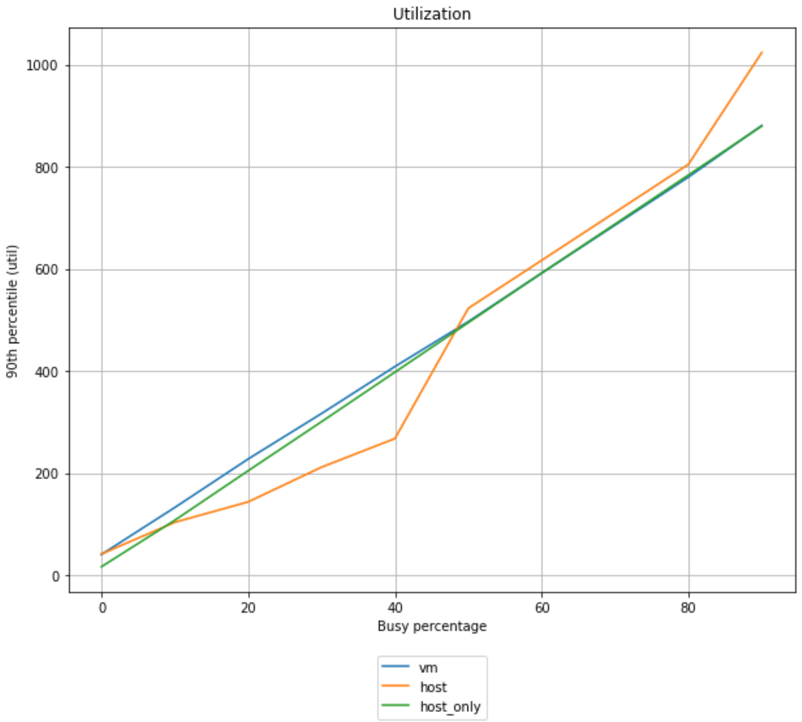
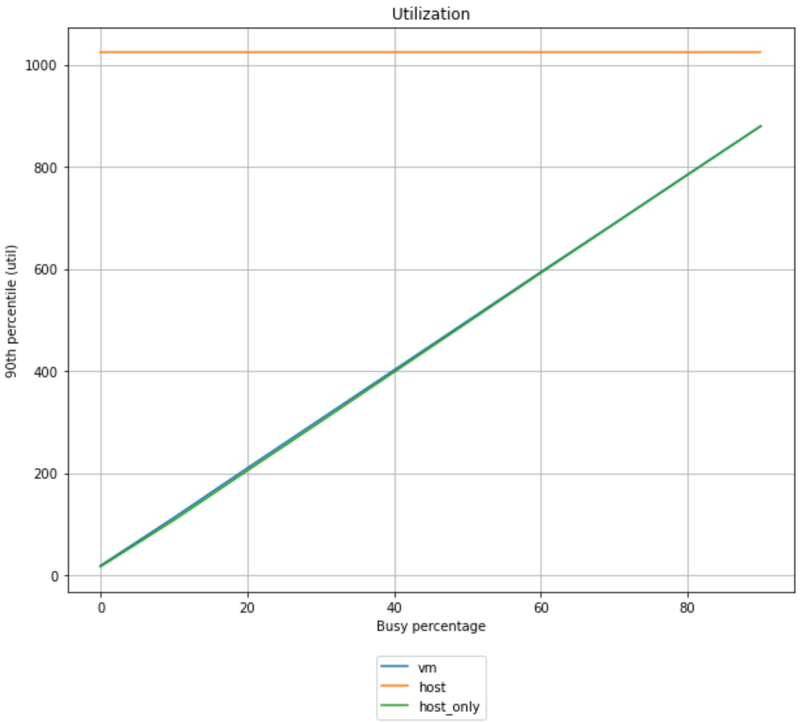
CPU’s util_avg When Guest is Running

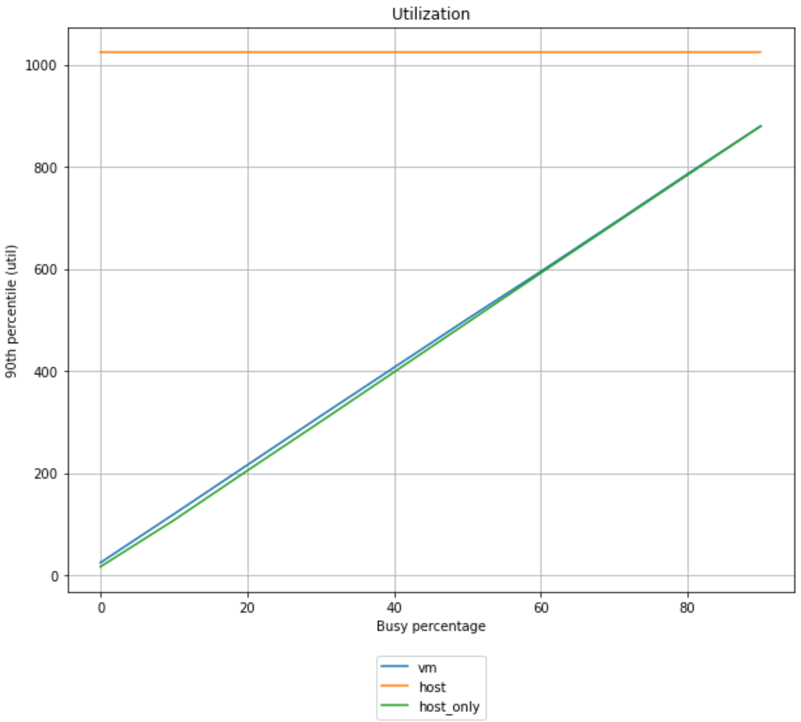
guest halt



guest poll



guest mwait



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
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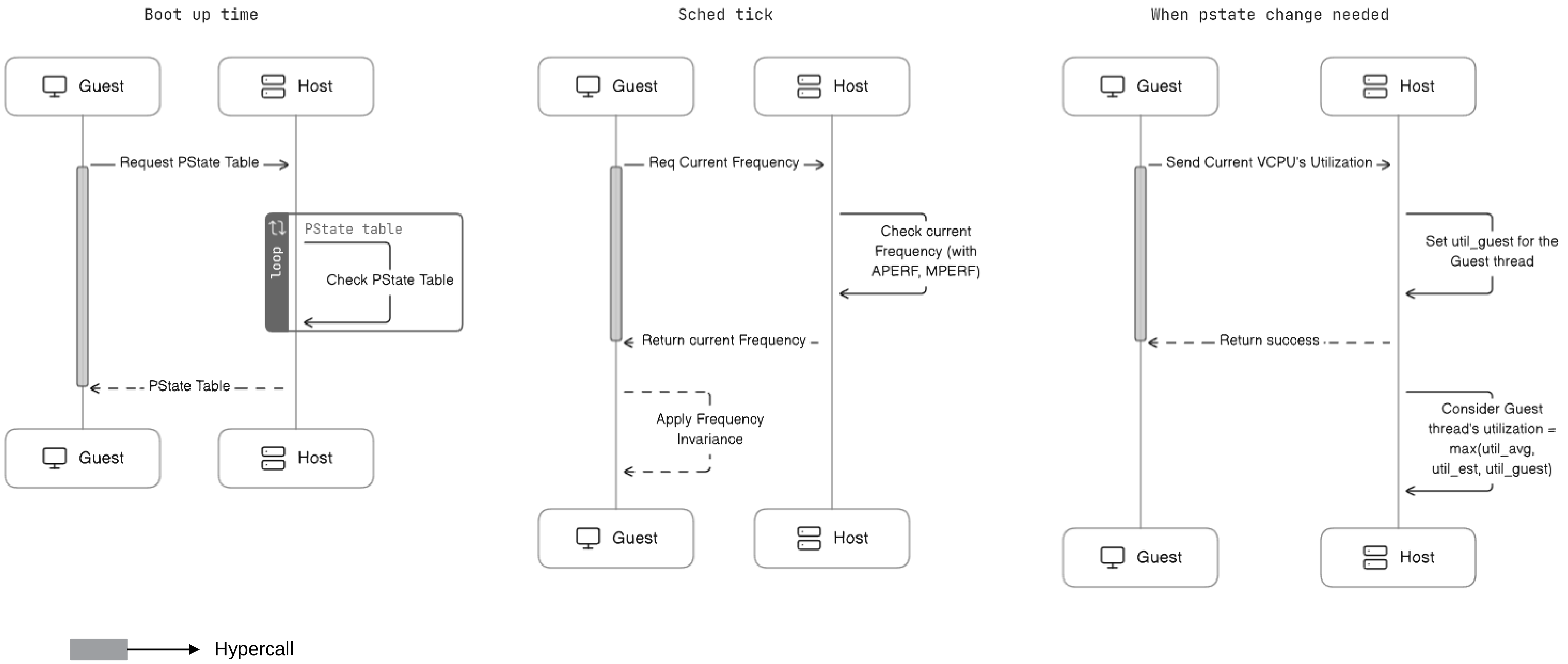
VM-CPUFreq Patches by Google

- Patch: "[RFC PATCH v2 0/6] Improve VM CPUfreq and task placement behavior"
  - https://lore.kernel.org/lkml/20230331014356.1033759-1-davidai@google.com/
  - 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/
  - 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

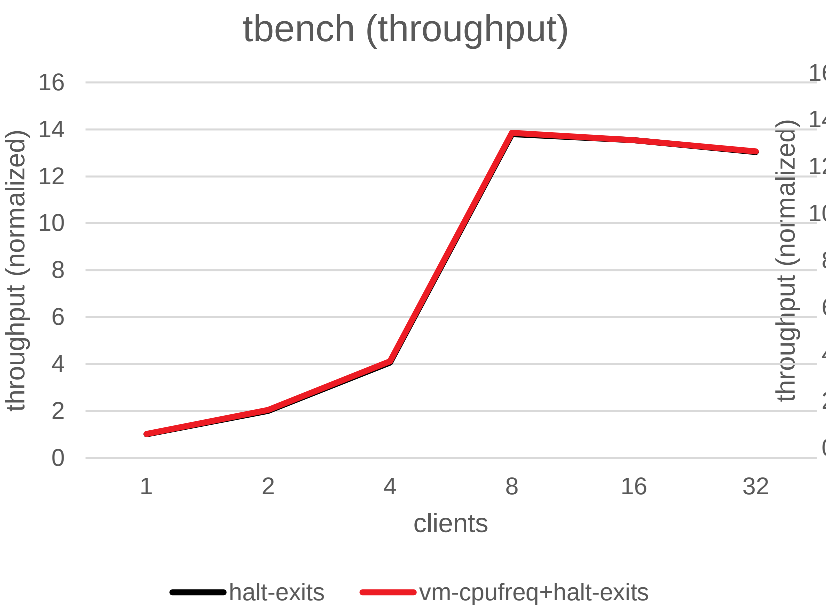


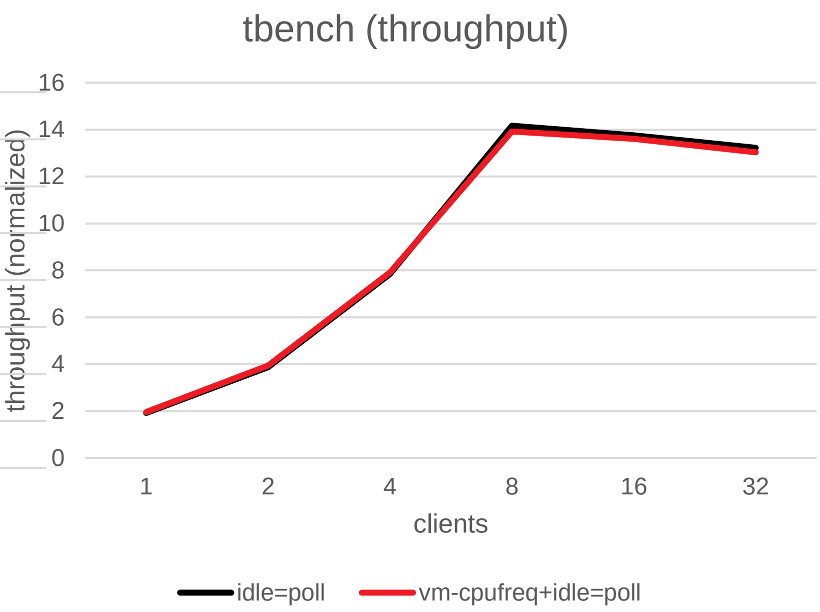
Results

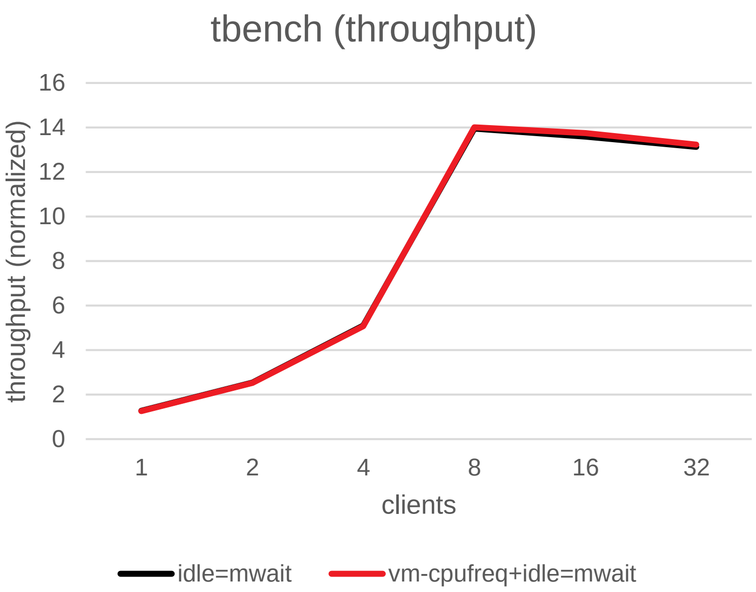
- Test setup
  - 2 socket server with 4th Generation AMD EPYC™ Processors each with 128 Cores 256 Threads
  - Max frequency: P0: 1.9 GHz, Turbo: 3.1 GHz
  - Guest size: 8 vcpu / 16 vcpu
  - Guest's vcpu threads are pinned to PCPUs.
  - Core configuration: all cores are same capacity
- Kernel versions
  - Test kernel 1: 6.6-rc6
  - Test kernel 2: 6.6-rc6 + vm-cpufreq v2 rebased and added support for x86
- Workloads

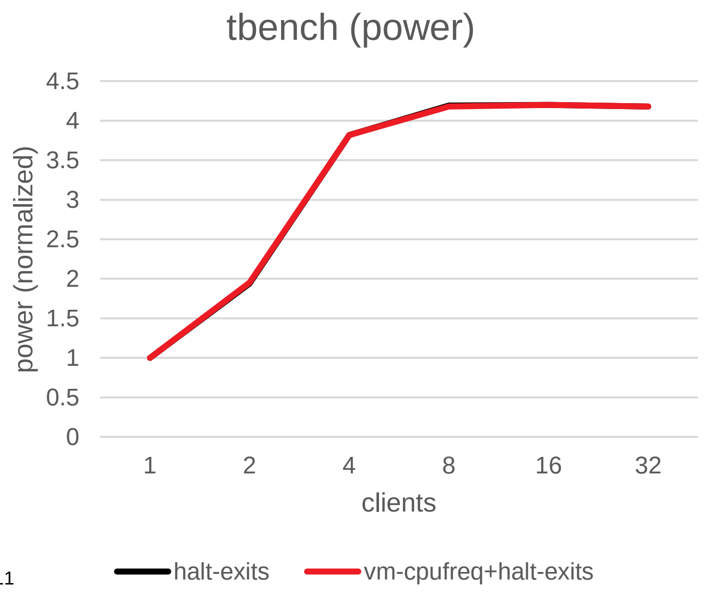
Benchmark name	License	Repository/source
tbench/dbench	GPL 3	https://www.samba.org/ftp/unpacked/dbench/
kernbench	GPL 2	https://github.com/linux-test-project/ltp/tree/master/utils/benchmark/kernbench-0.42

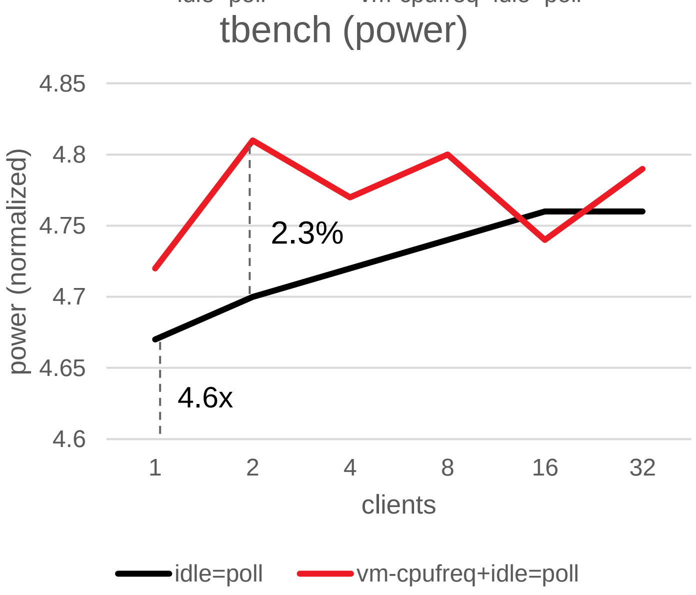
Results (8 vcpu)

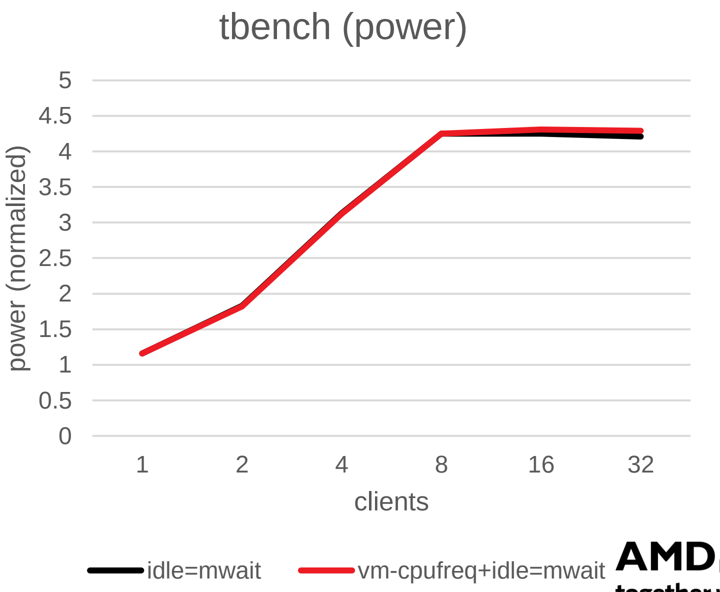












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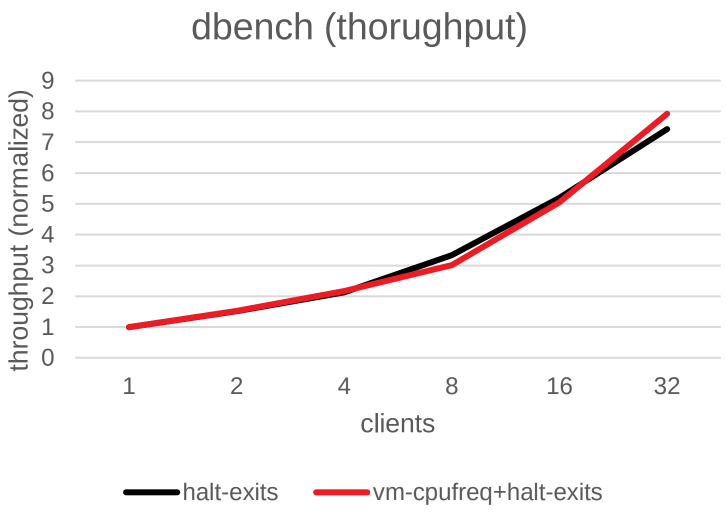

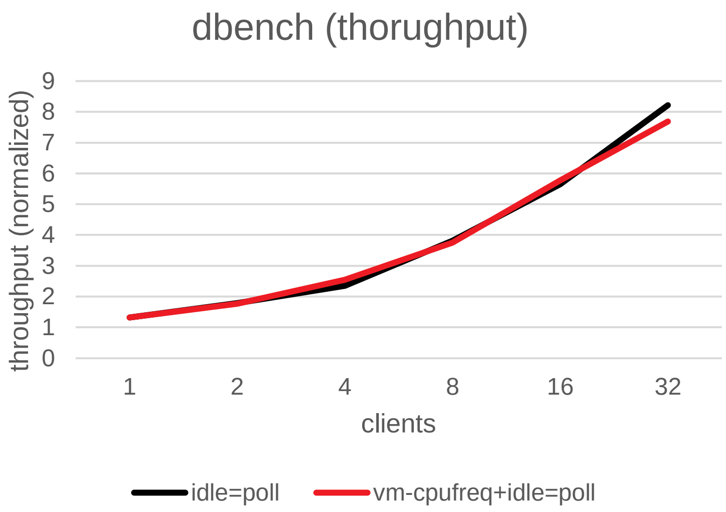

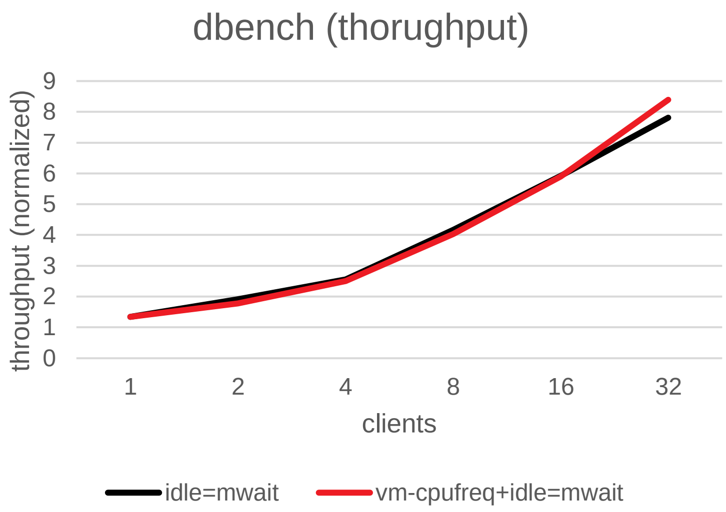

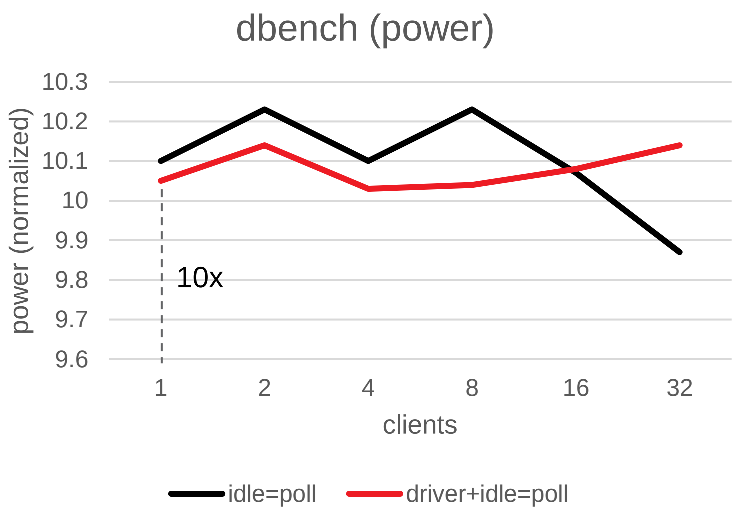

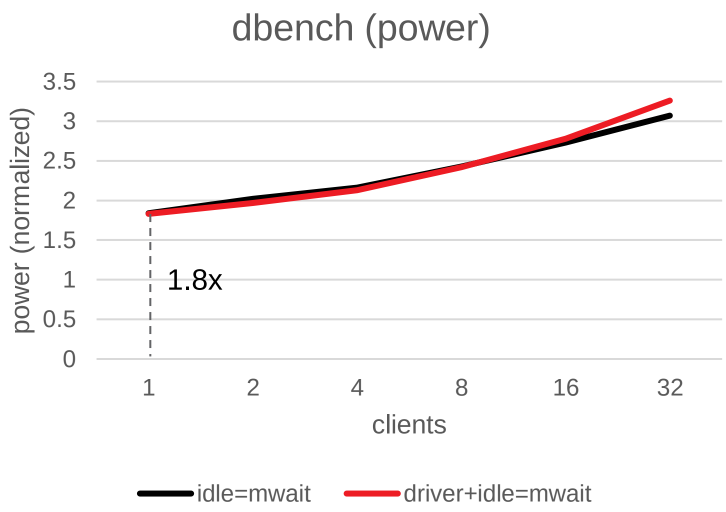

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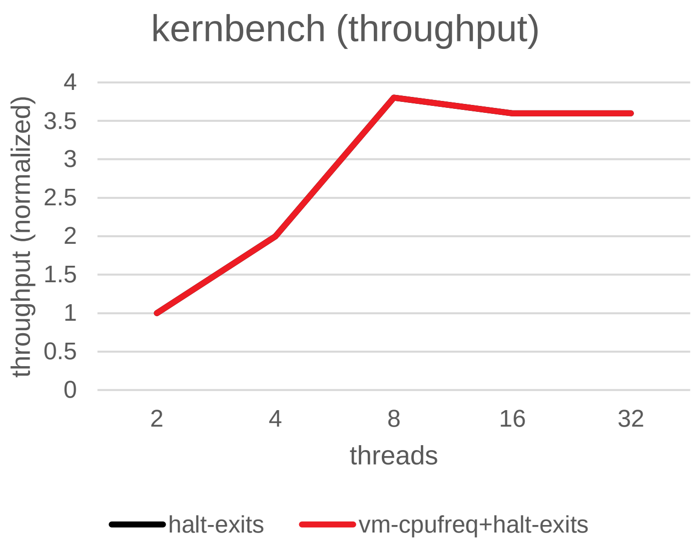
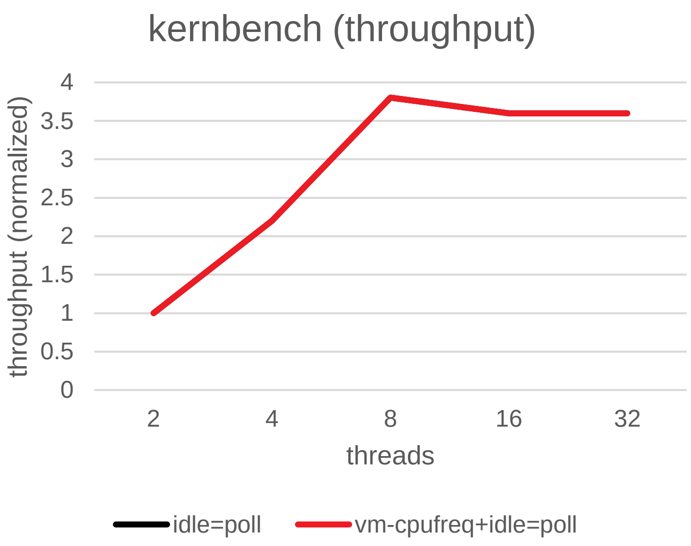
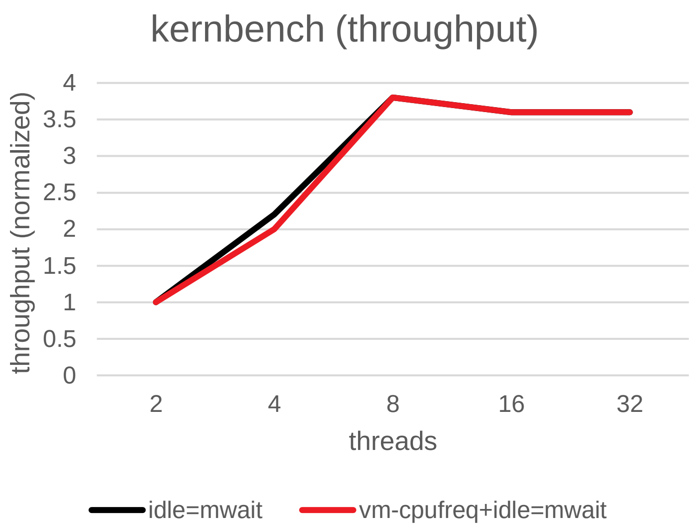
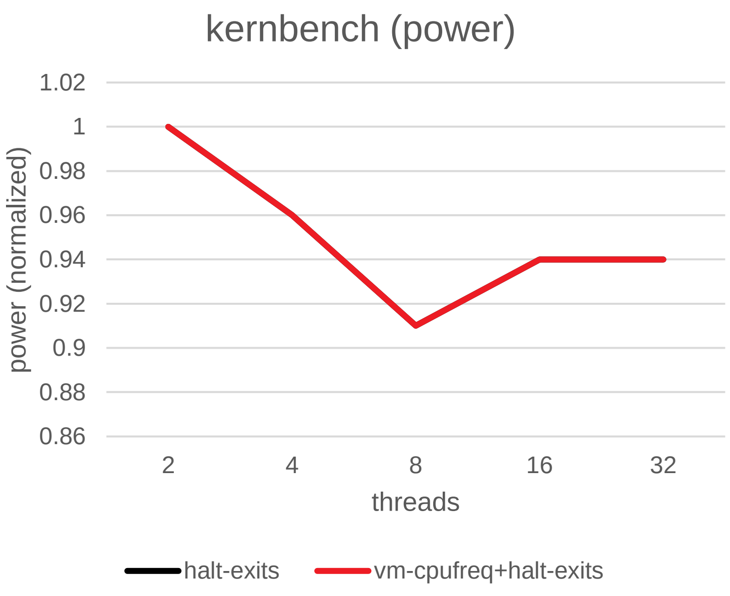
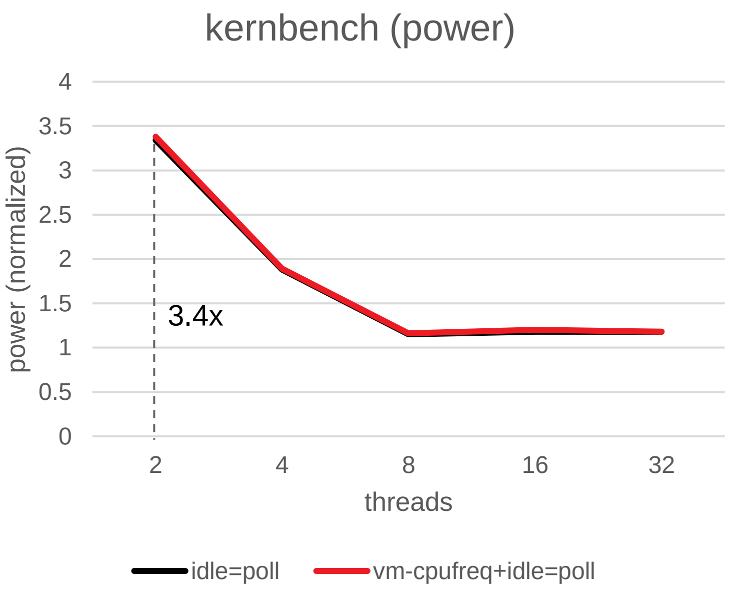
Results (8 vcpu)

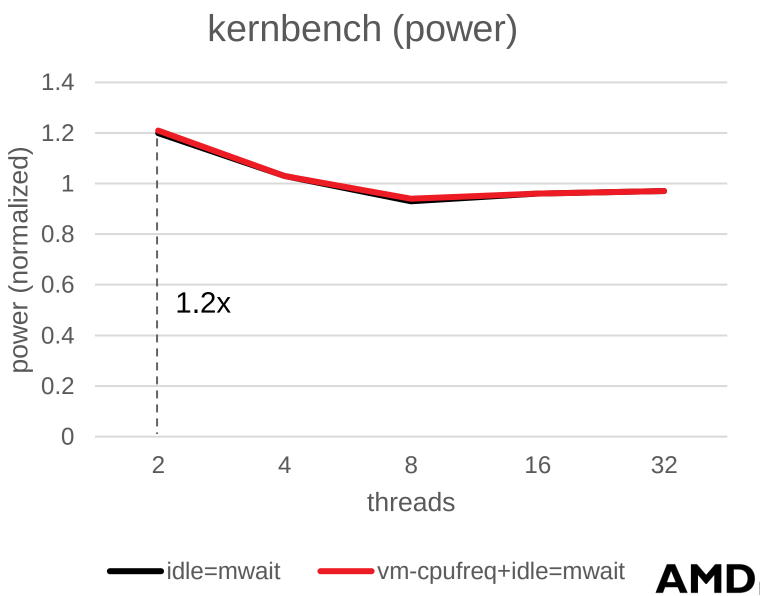




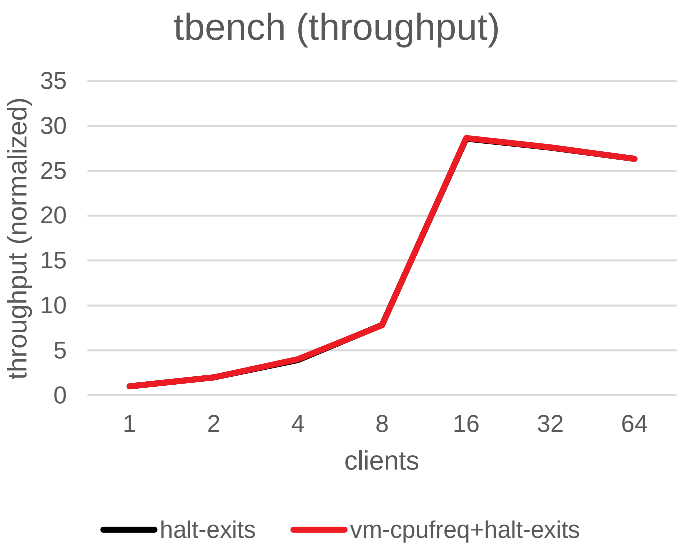


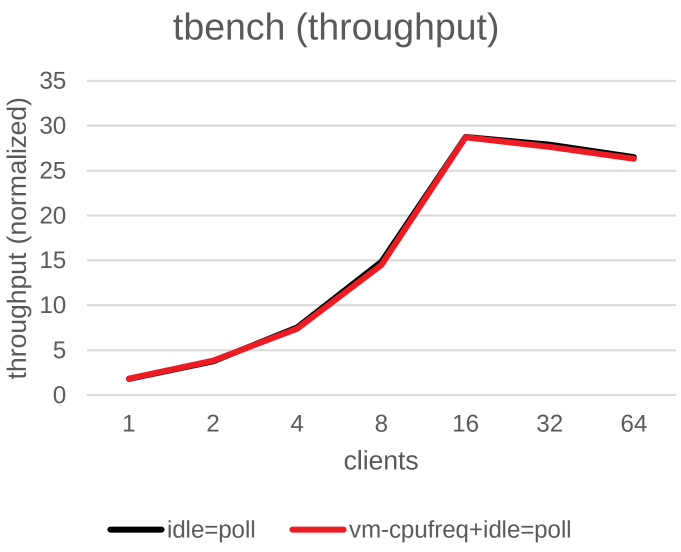


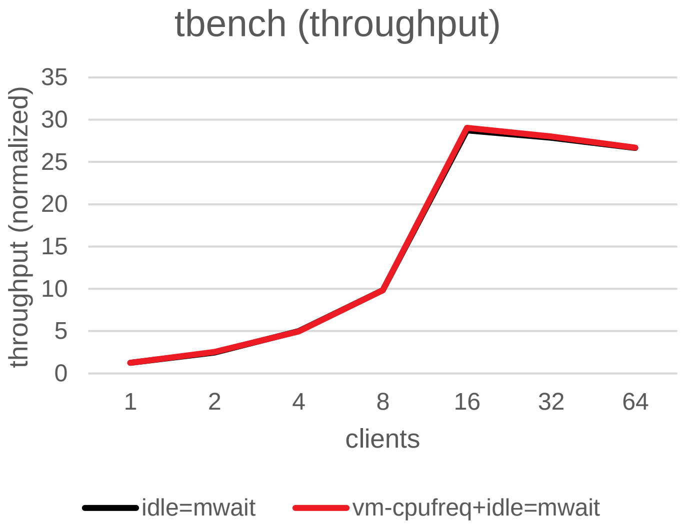


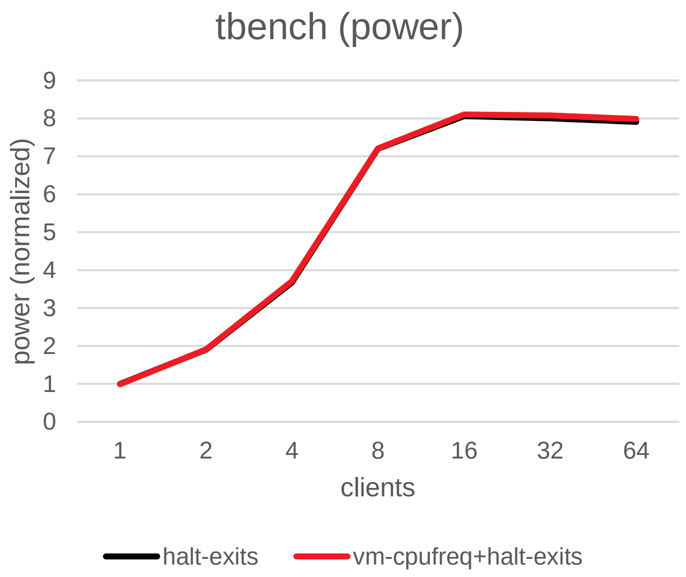


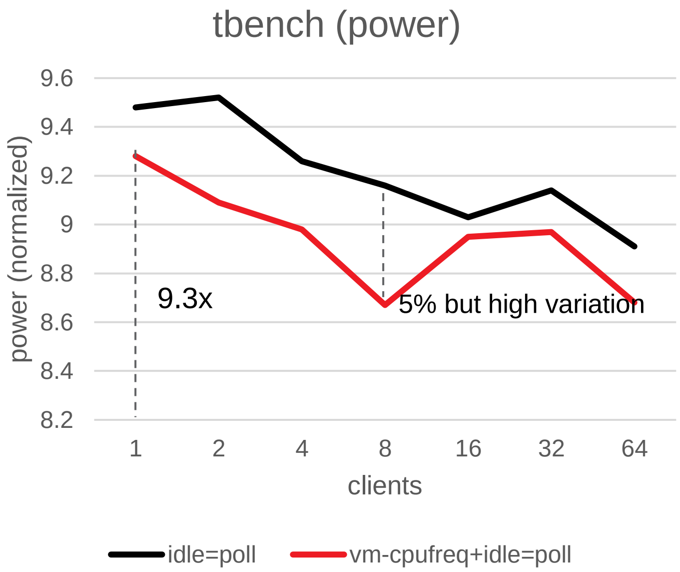
Results (16 vcpu)

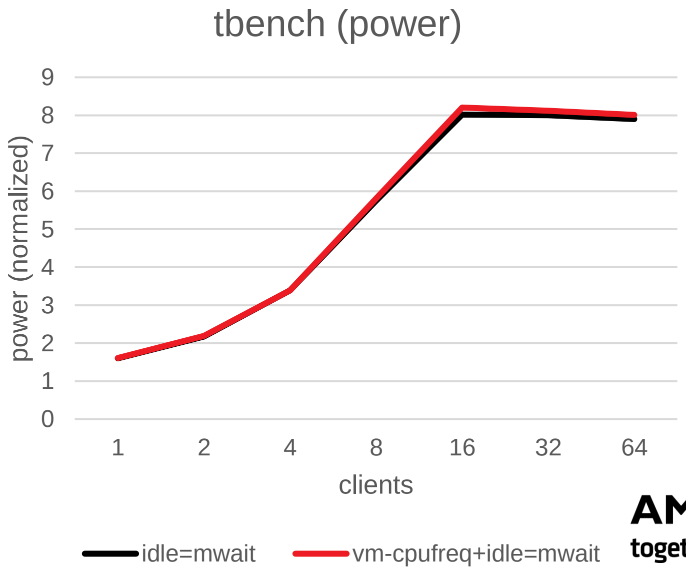












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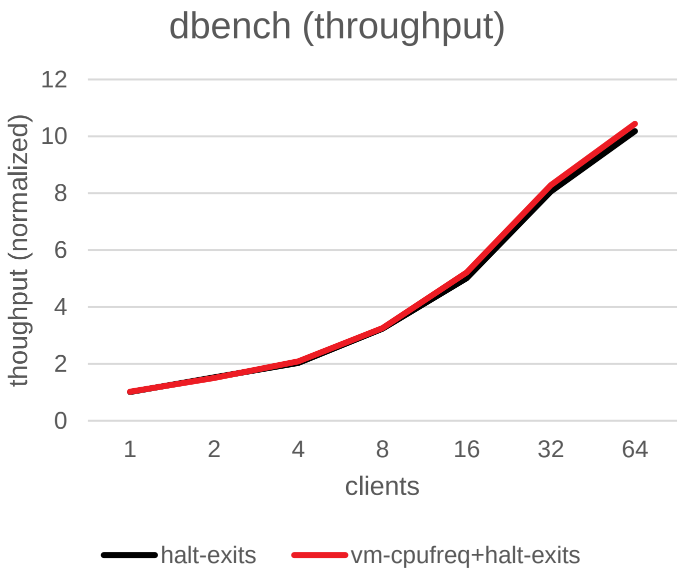
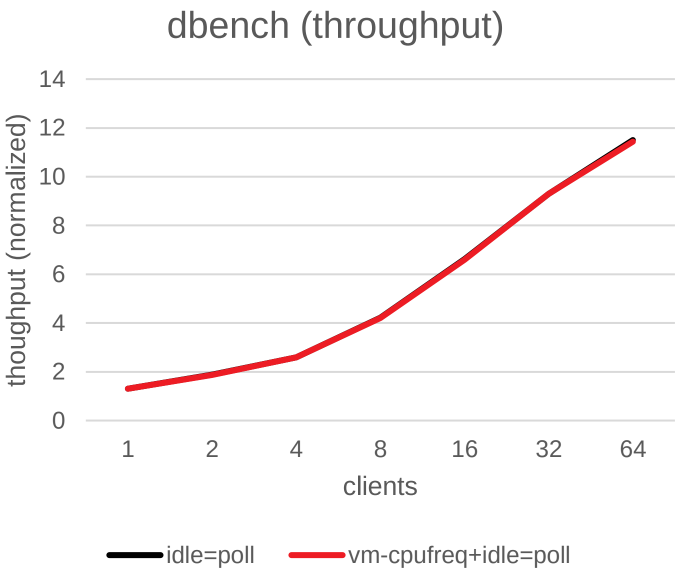
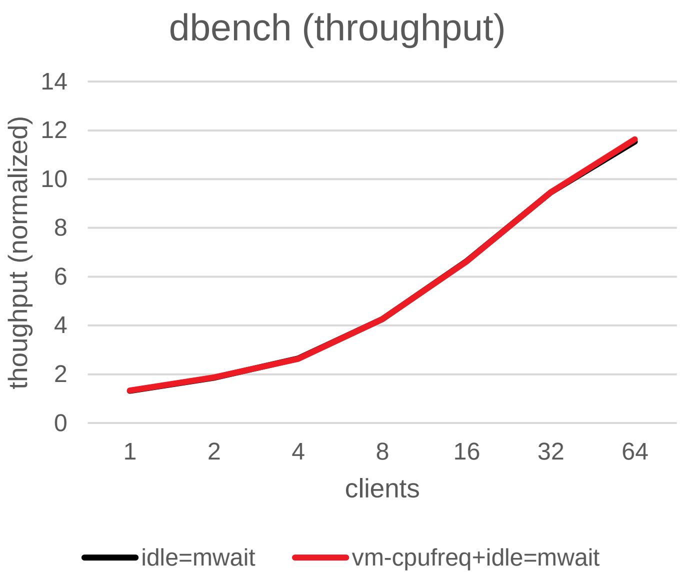
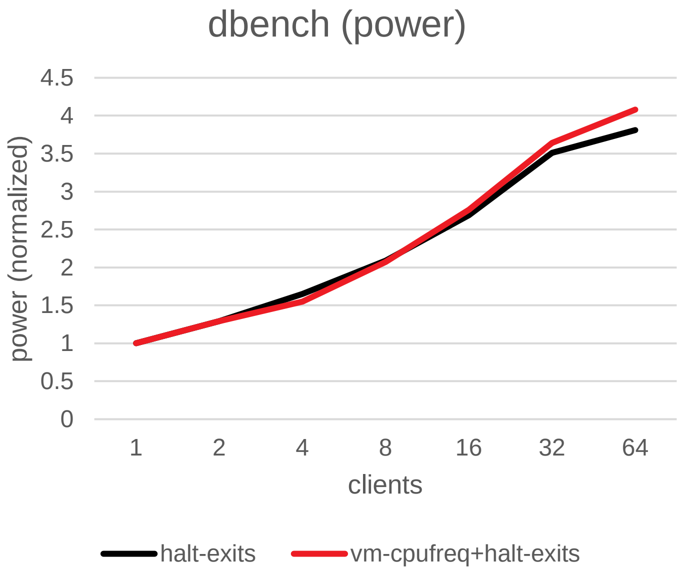
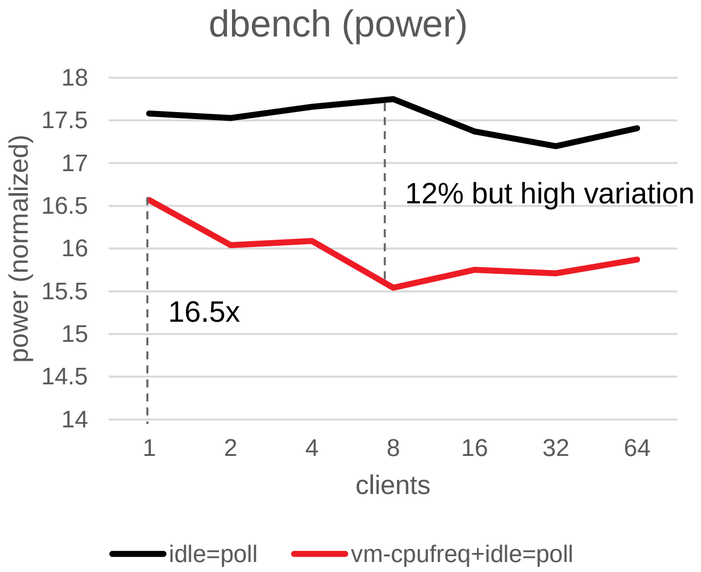
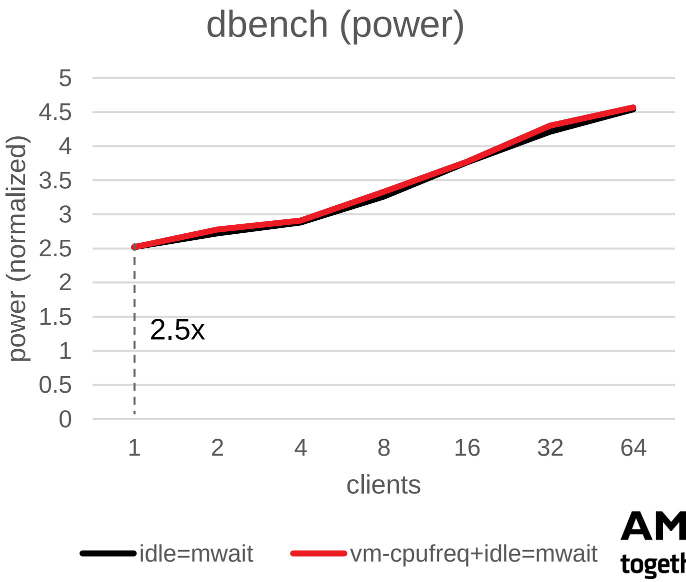






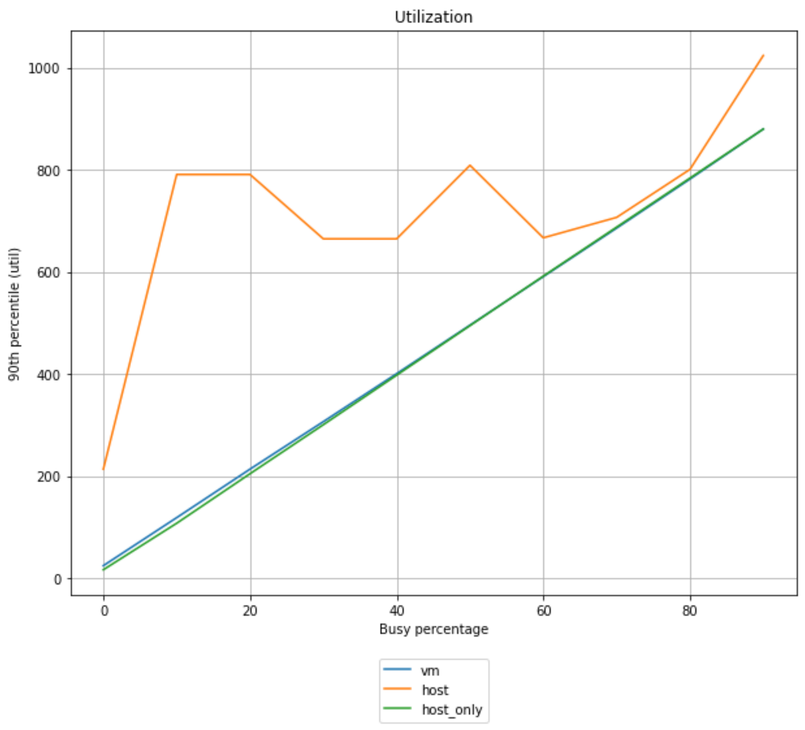




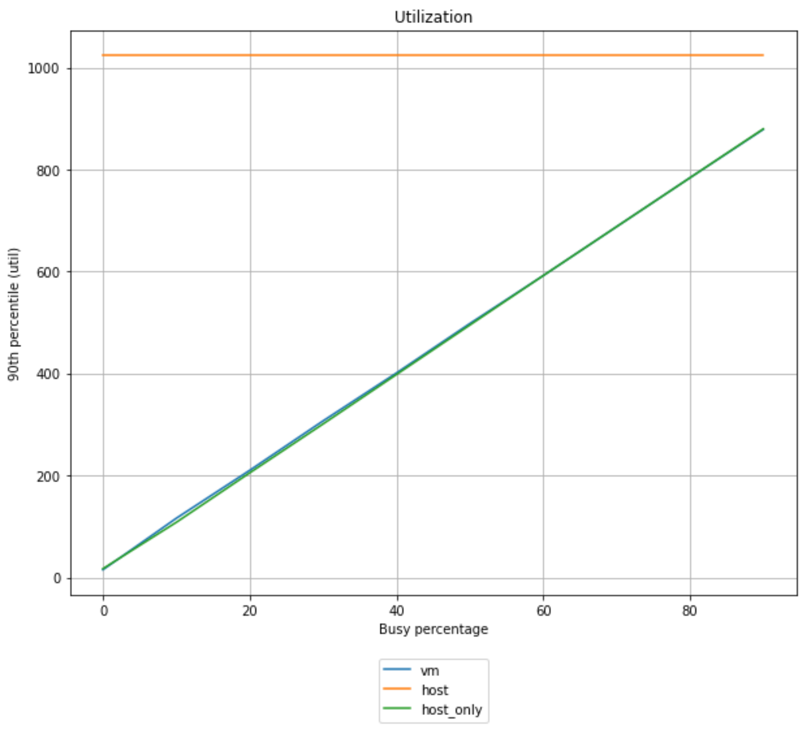


CPU's util_avg When Guest is Running with VM-CPUFreq

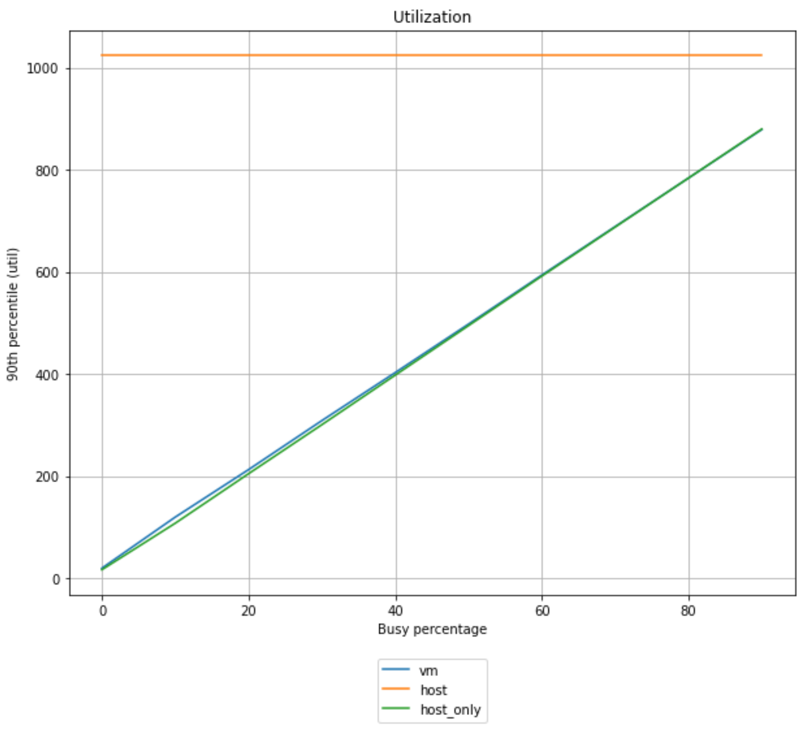
guest halt



guest poll



guest mwait



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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

```
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);
```


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