Power Capping Linux

Agenda

- Context
- System Power Management Issues
- Power Capping Overview
- Power capping participants
- Recommendations
- Introduction of Linux Power Capping Framework

Power Hungry World

- Worldwide, the digital warehouses use about 30 billion watts of electricity
  - Equivalent to the output of 30 nuclear power plants
- On average, using only 6 percent to 12 percent of the electricity powering their servers to perform computations.
- The rest was essentially used to keep servers idling and ready in case of a surge in activity that could slow or crash their operations.

Source: http://www.nytimes.com/2012/09/23/technology/data-centers-waste-vast-amounts-of-energy-belying-industry-image.html?pagewanted=all&_r=0

Unpredictability of battery life

"Many report unpredictable spikes in battery use, and batteries becoming unnervingly hot, even when used outdoors in the shade."

Read more: http://www.dailymail.co.uk/sciencetech/article-2055562/Apple-iPhone-4S-battery-dies-12-hours--users-forced-ways-patch-mend.html#ixzz2dJ5L1Uqz

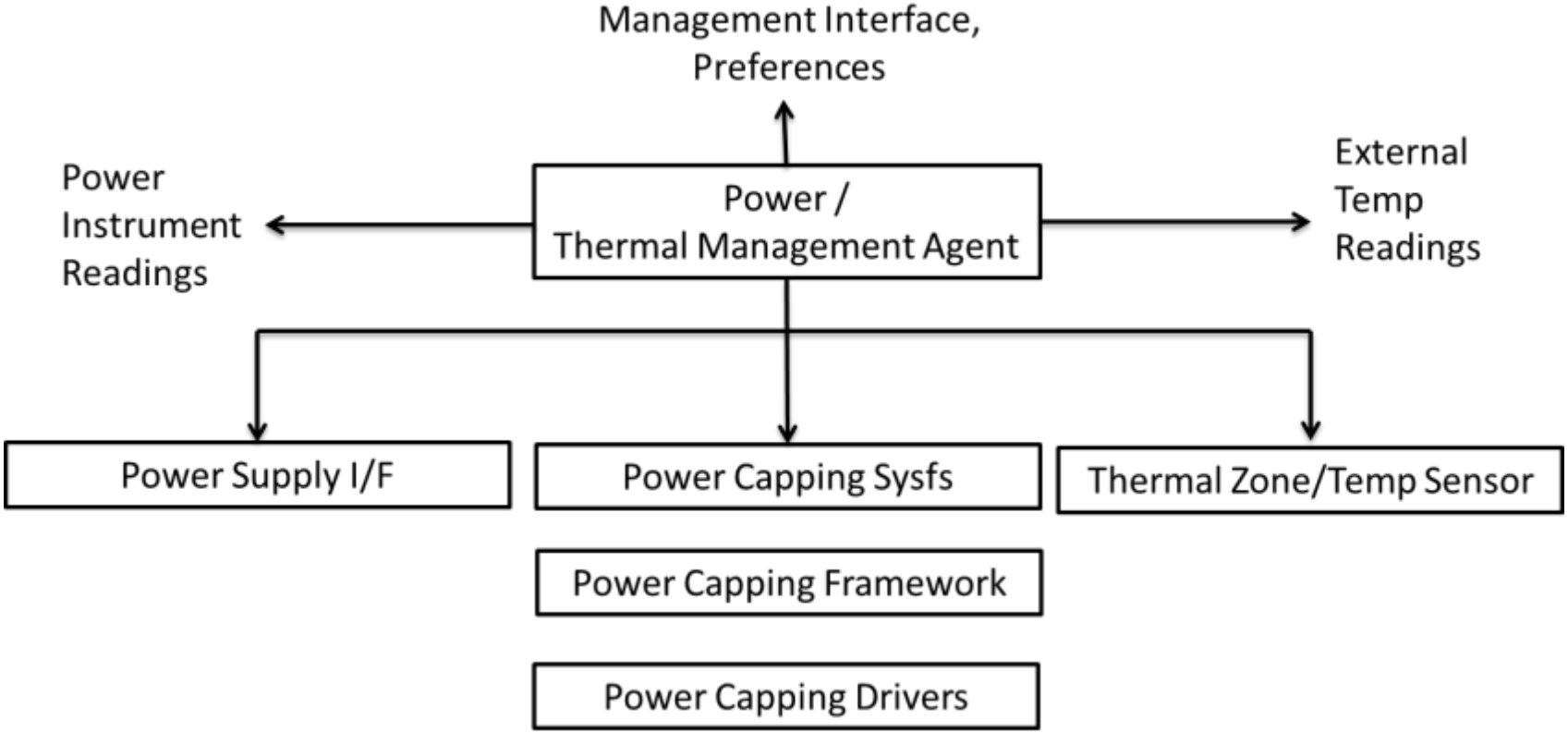
Constrained by Power and Thermal

- Thinner and more power efficient mobile devices
  - Limited power delivery capacity
  - Limited cooling capacity
  - Battery life predictability
  - Aggressive power budgeting
- Unexpected peaks in system utilization
- Handling catastrophic thermal/power exceptions are never graceful

Power Capping Linux Overview

- Monitoring power usage
- Limit power consumed by devices at runtime
- Redistribution of power to meet power budget at system level
- Maximize performance
- Maximize efficiency
- Avoid critical conditions

Power Capping Usage Model



Power Capping Participants

- CPUs
- GPUs
- DRAM
- Others
  - Multimedia sub system
  - Wireless sub system
  - IO

Power Capping Ideas

- “Drink” less individually
  - Device performance states
  - Throttling states
- Let the lions handle it (reduce head counts)
  - CPU core offline
  - Reduce number of active lanes on an IO bus
- Beyond nature
  - Take turns (Idle injection)
  - Avoid fighting / catastrophic shutdown

Power Capping Techniques

- **CPU**
  - Dynamic performance states (aka P-state) adjustment
  - Dynamic throttling states (aka T-state) adjustment
  - Processor offline
  - Idle injection
  - ACPI power meter
  - ACPI processor aggregator
- **CPU/ DRAM / GPU**
  - Running Average Power Limit (RAPL)

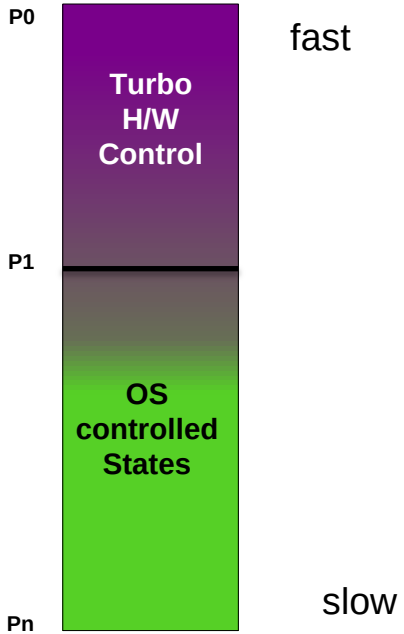
Power Capping Measurements

- Test Setup
  - Intel Ivy Bridge Dual Core
  - Linux 3.11.rc3
  - Power meter: Yokogawa WT210
  - Test load: openssl speed sha256

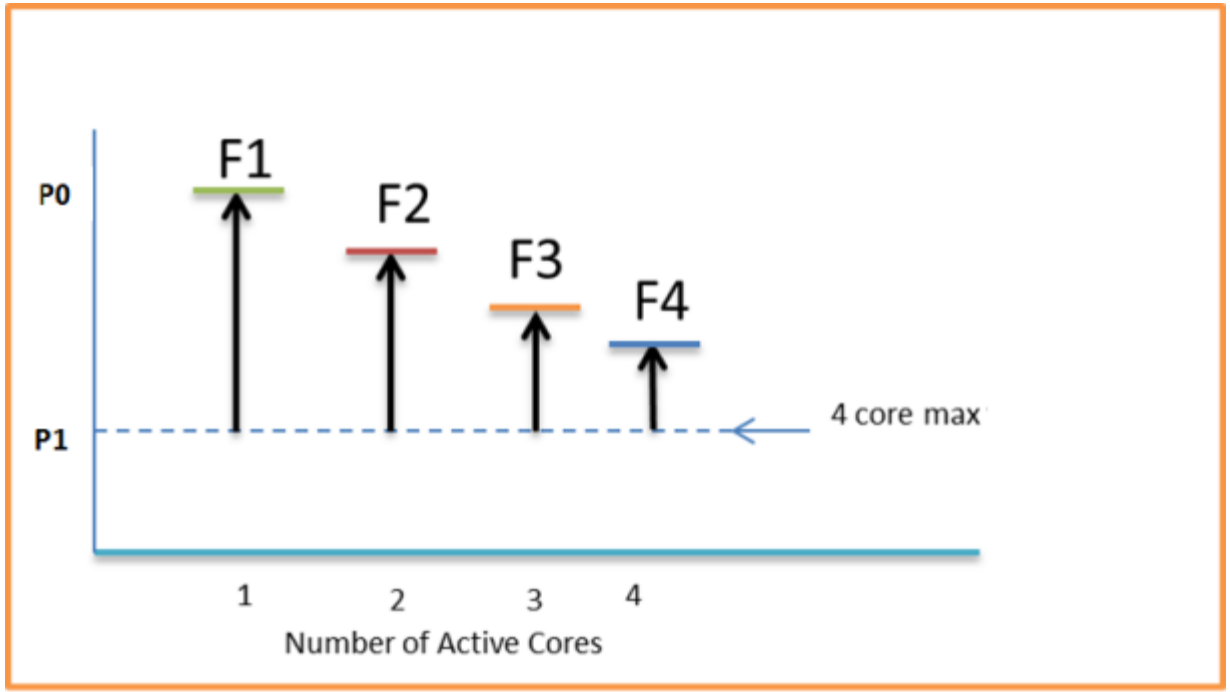
P-States

- P-state: a voltage/frequency pair
- P1 : Guaranteed performance
- Pn-P1 range in OS control/request
- P0: Max possible performance under HW control

(Power = $C \cdot V^2 \cdot f$)



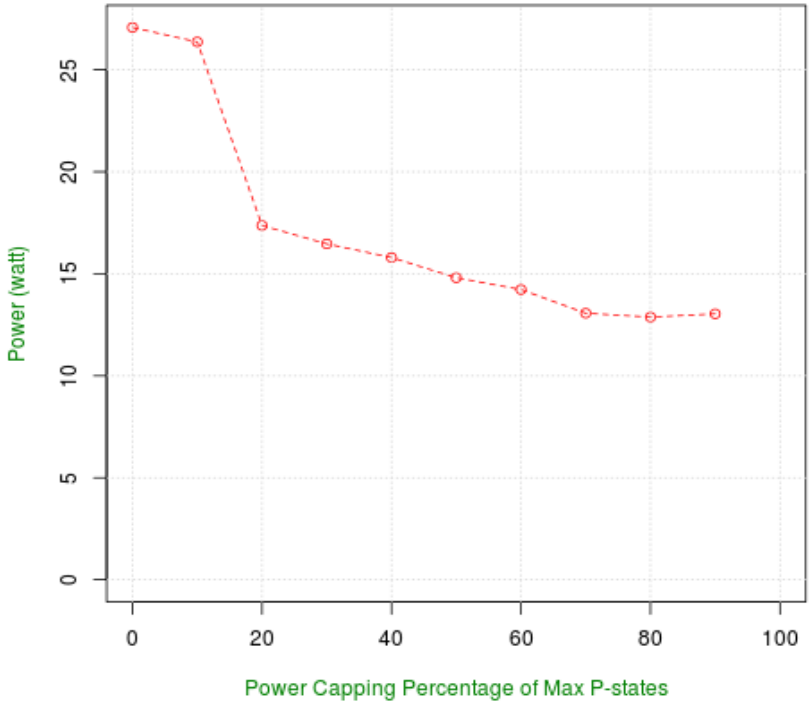
Turbo States

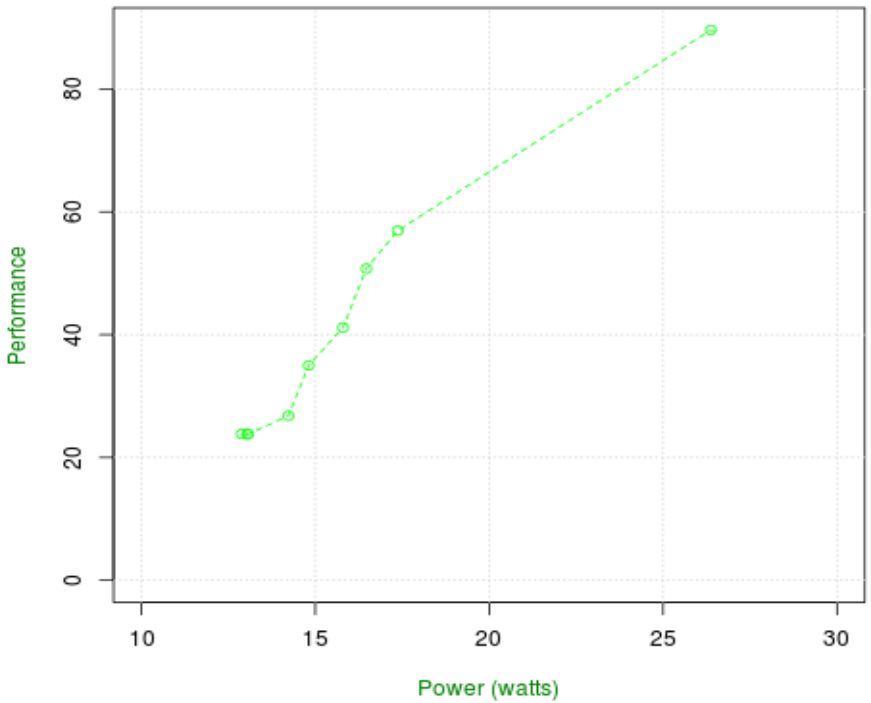


Controlling P-states

- Intel P State Driver
  - sysfs: max_perf_pct, min_perf_pct, no_turbo
- CPUFREQ
  - Sysfs: scaling_max_freq, scaling_min_freq, scaling_setspeed
- Thermal Cooling device
  - sysfs: /sys/class/thermal/cooling_device# /type = “Processor”
- RAPL (Running Average Power Limit)
  - sysfs: via power capping framework

P States Performance (Using Intel P State Driver)

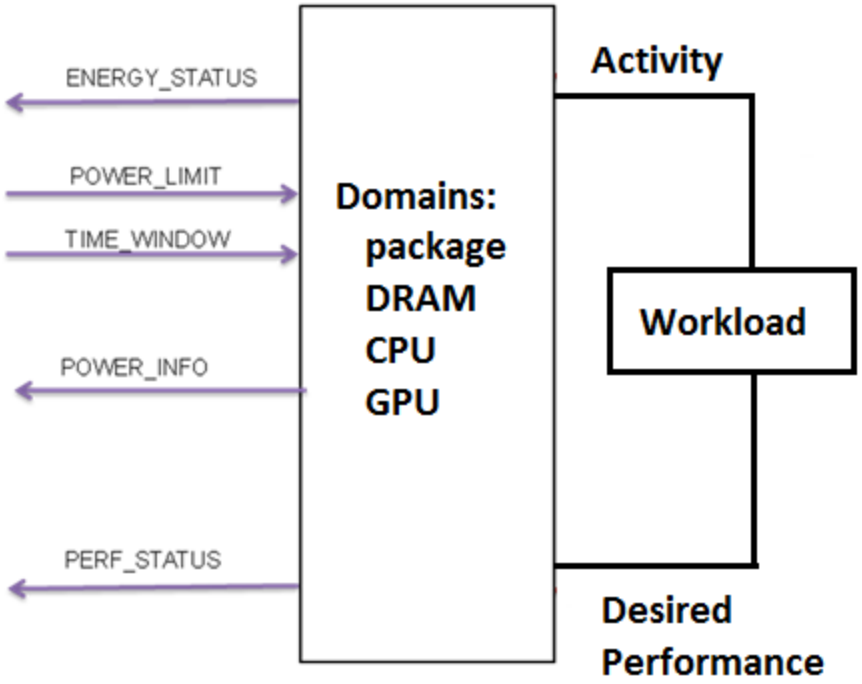




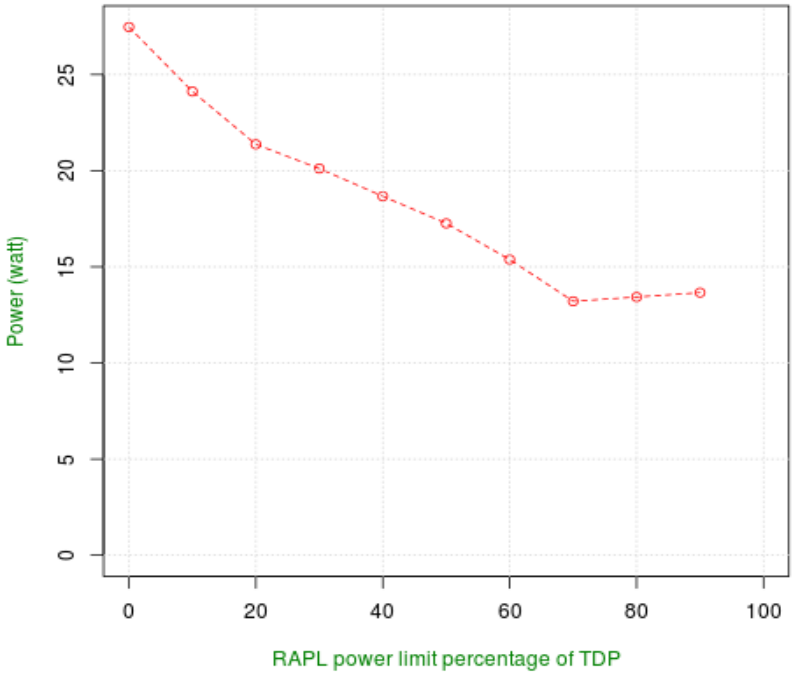
RAPL

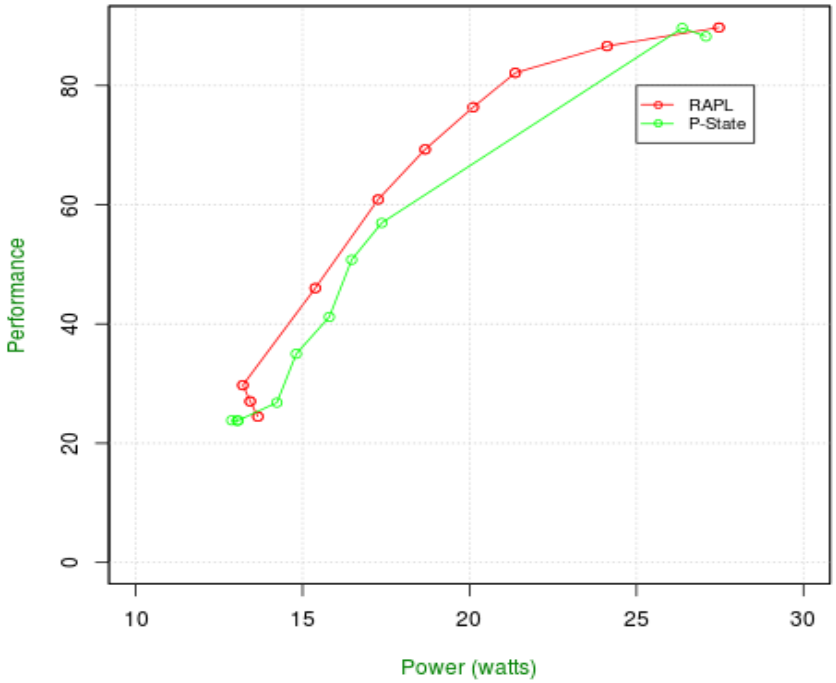
- Power monitoring capability
  - Very accurate, model based, per domain built-in power meter
  - Throttle duration
- Power Limiting
- Performance feedback mechanism
  - Notification when OS requested P-state is denied
- Implemented close to processor
- Interface via MSR, PCIe config space

RAPL Domains and Interfaces



RAPL Performance



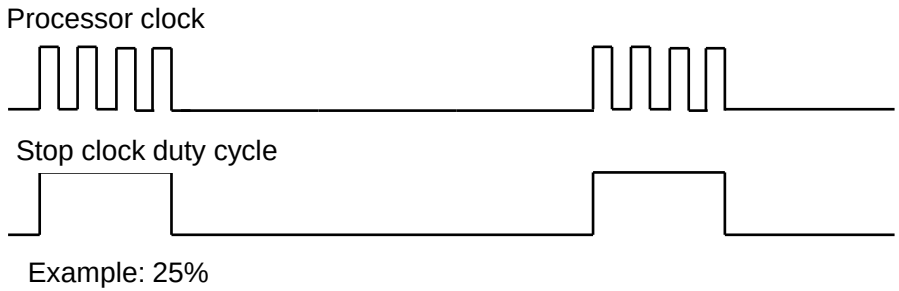


RAPL DRAM Power Limit

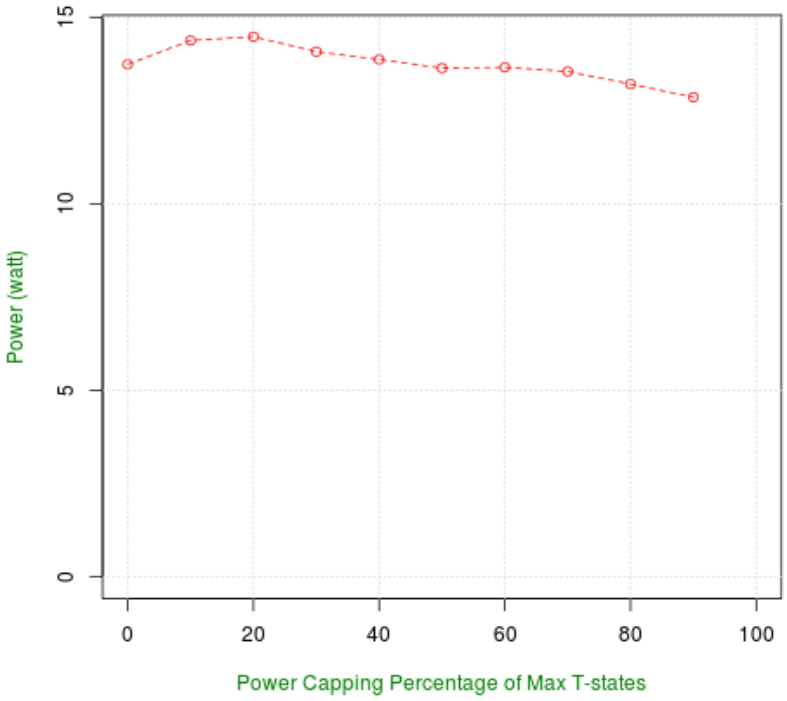
- Throttles DRAM Bandwidth
- Significant DRAM throttling tend to be power inefficient
  - First throttle CPUs

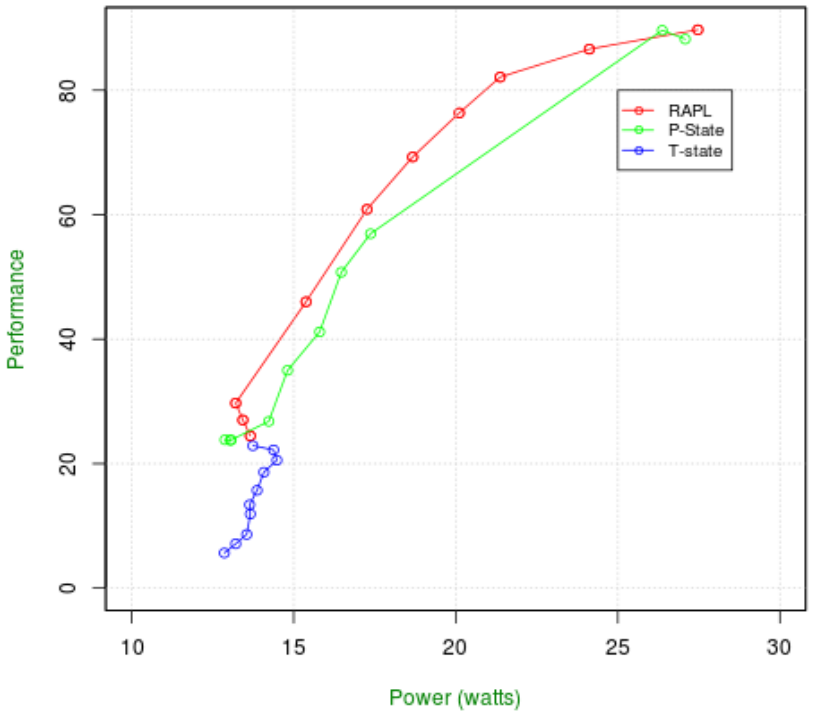
T-States

- Allow Software Controlled Clock modulation
- Controls stop clock duty cycle
  - Time period for clock signal to drive processor
- Controlled via thermal cooling device interface for processor



T-States Performance



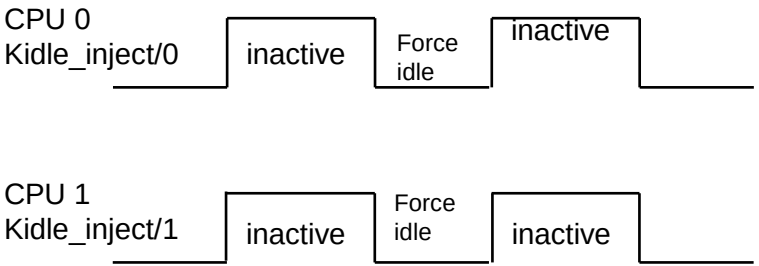


Idle Injection

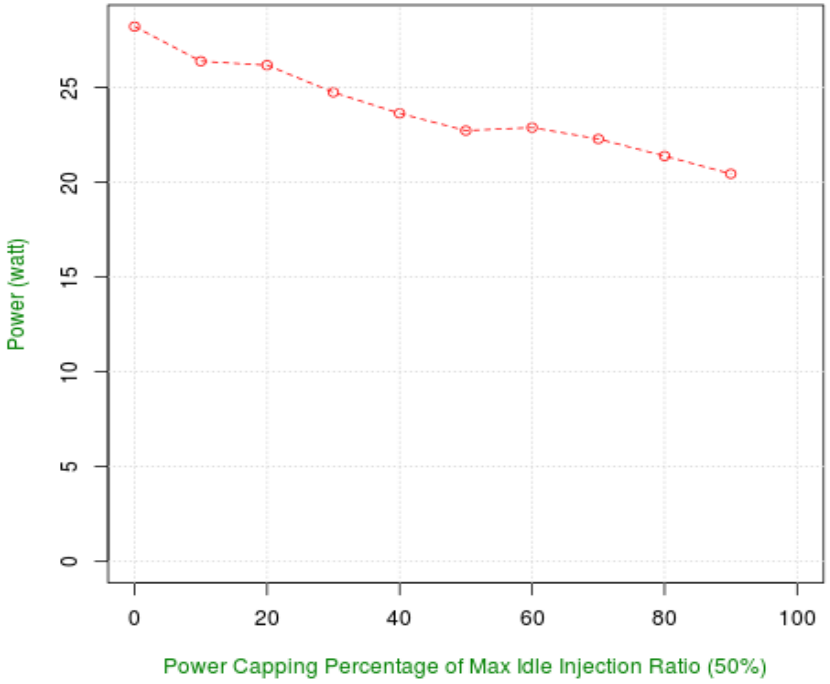
- Idle states (C-states) get deeper in modern processors
- Synchronized idle time across all cores achieves the maximum power benefit

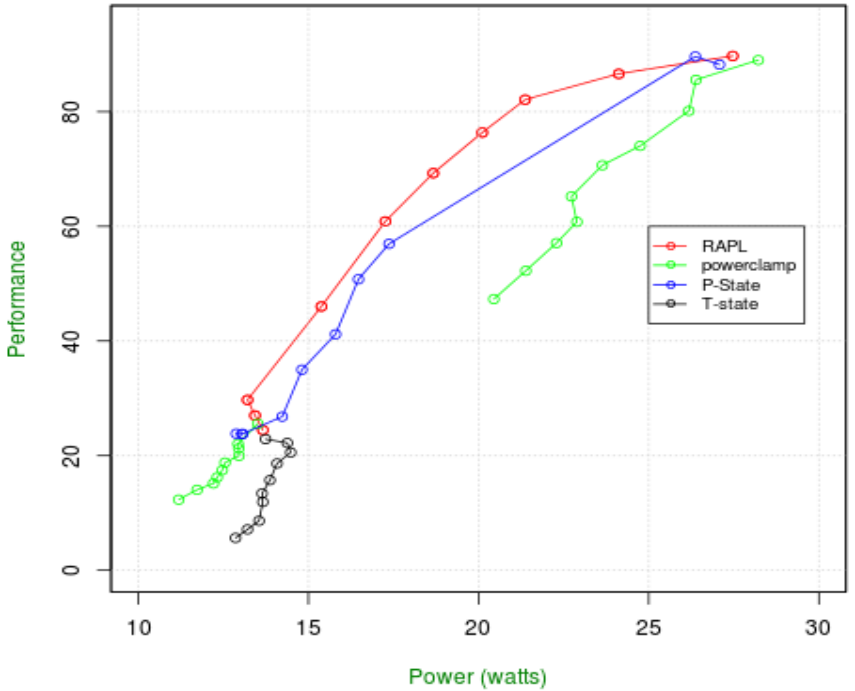
Idle Injection

- Implemented by Intel Power Clamp Driver
  - sysfs: /sys/class/thermal/cooling_device# /type = “intel_powerclamp”
- Monitors and enforces idle time for each online CPU
- User selectable idle ratio from 0 to 50%



Idle Injection Performance

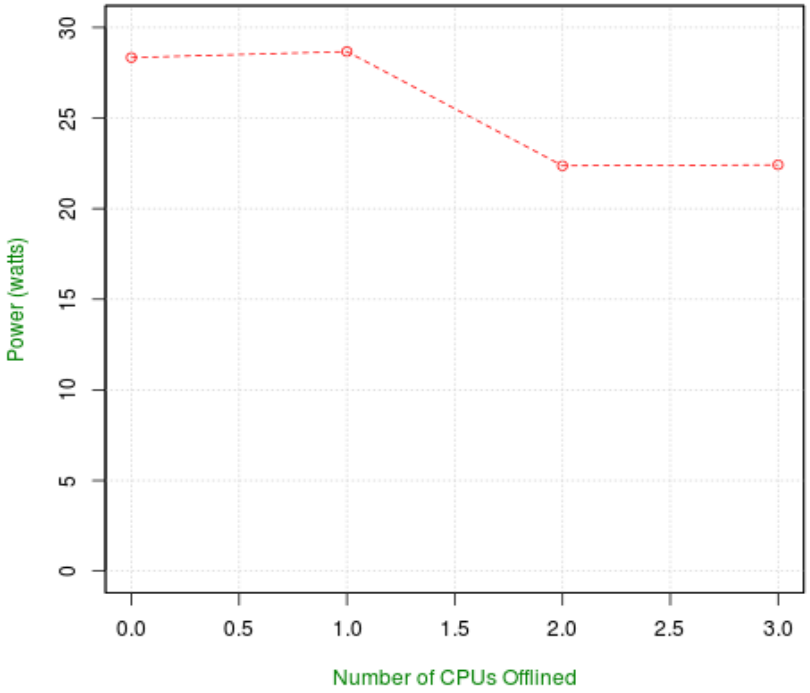


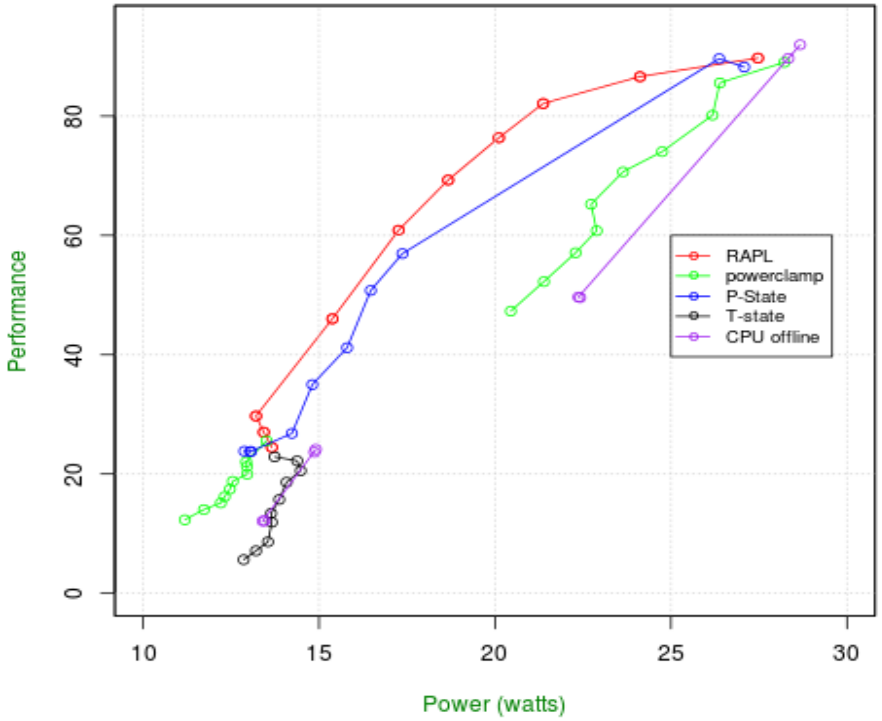


CPU Offline

- Migrate activity on current CPU to new CPU
  - Processes, interrupts, timers
- Logical online/offline CPUs using sysfs interface
  - sysfs: /sys/devices/system/cpu/cpu#/online
- Conditional physical offline/online
  - depends on BIOS and kernel build flags
- Limited CPU 0 offline

CPU Offline Performance





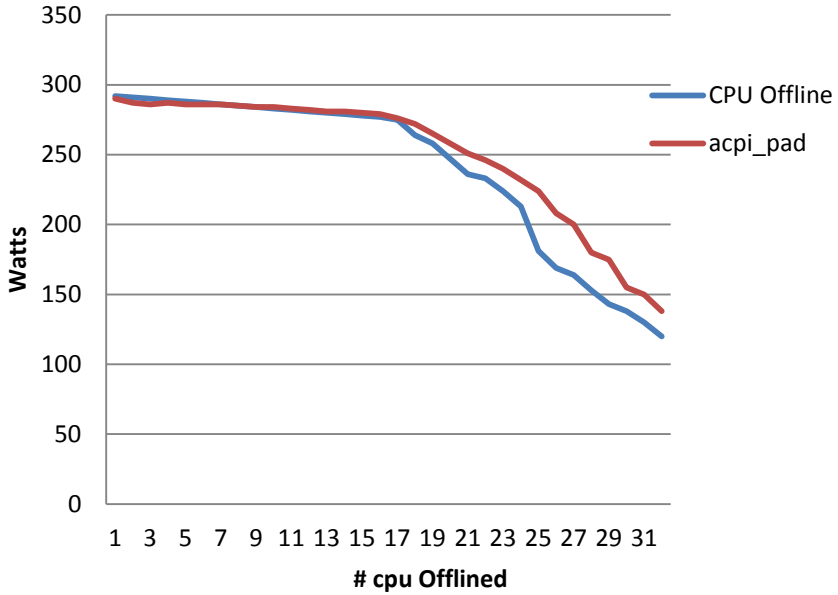
ACPI Power Meter

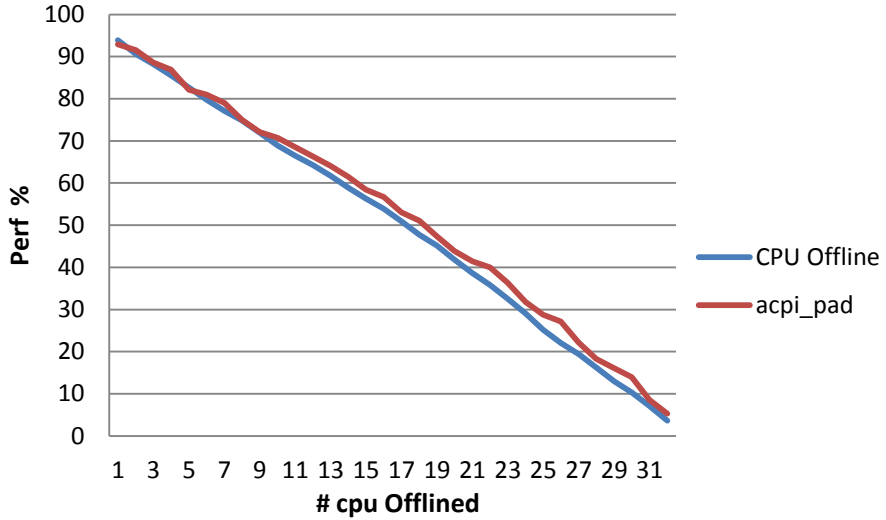
- Expose power meter support defined in ACPI 4.0
- Depends on BIOS support
- Interface to read power over a configurable interval
- Trip point configuration for notification
- Configuration for power capping parameters
  - power#_cap_min/power#_cap_max

ACPI Processor Aggregator(ACPI_PAD)

- Triggered by ACPI notification only
- Used to resolve short term thermal emergencies
- Not a CPU Offline/online but has similar affect
- Doesn’t affect cupset
- Puts affected CPUs in deep C states

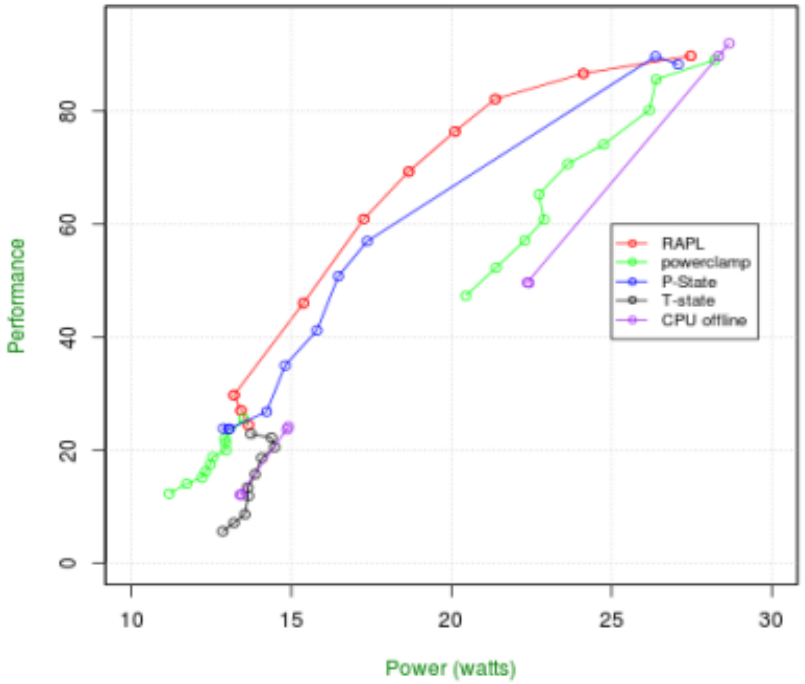
ACPI_PAD Vs. CPU Offline





Test platform: Intel Romley 2 socket system

Recommendations

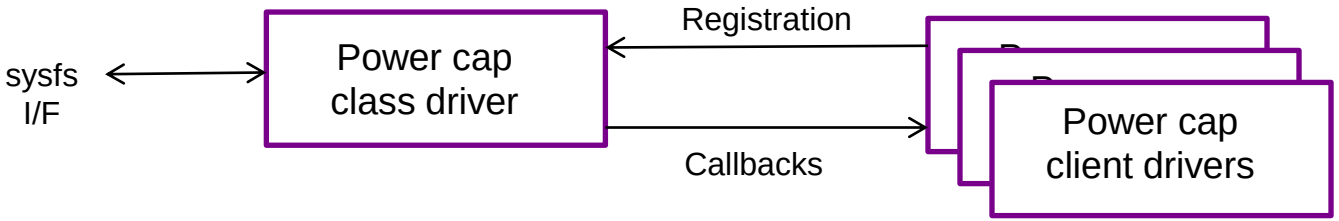


- In applicable range
  - RAPL
  - P State
  - Idle Injection
  - CPU Offline
  - T States

Linux Power Capping Framework

- Interface
  - Set power limits
  - read current power for a system or a sub-system
- Client driver API
- Avoid code duplication
- RFC: http://lwn.net/Articles/562015/

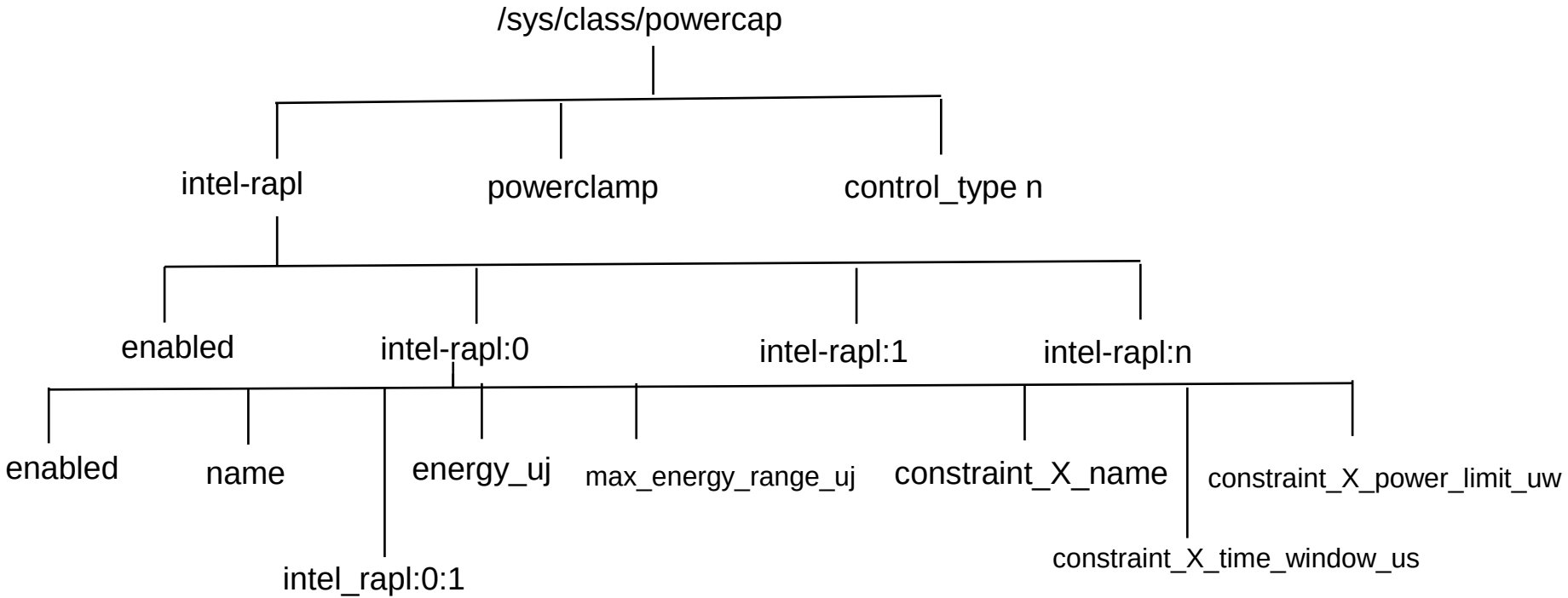
Linux Power Capping Framework Class



Power Capping Class Features

- Allow multiple power zones
  - Power zone: Independent unit which has capability to measure and enforce power
- Allow parent child relationship among zones
- Exports Sys-FS Interface (monitoring and control)
  - Get Current energy consumption per power zone
  - Set Power limit per zone
- Power capping driver interface (kernel API)

Power Capping Sys-FS hierarchy example



Power Capping sysfs

- Arranged as a tree, with root as a control type
- Control type : Method to implement power capping. E.g. intel-rapl
- A control type contains multiple power zones
- Power zone node names are qualified with the control type, E.g. intel-rapl:0, intel-rapl:1
- Each power zone can have children as power zones
- Parent child relationship should be based on the relationship of power. E.g. When child power limit is applied, parent power is also affected

Takeaways*

- Prefer direct hardware interface
  - Prefer RAPL for power capping from P0 to Pn over indirect control via P-state governor
- Consider Idle injection instead of CPU Offline for extended power capping range, maybe platform dependent.
- Pay attention to hardware trend, e.g. deeper idle
- Reconsider the effectiveness of legacy features
  - e.g. T-states

Suggestions on Improving Power Capping Framework?

(*Disclaimer: only based on the test result shown in the slides, not an official recommendation by Intel)

Q&A

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Thank You