Workload Scheduling and Power Management

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Outline

- Power monitoring
- Reporting stats
- Power saving support
- User cpu frequency requests
- Power management and capping

Power Monitoring

- Slurm provides energy accounting plugins for different infrastructure options
  - **Cray** - Uses existing Cray infrastructure that provides per-node power and energy data from the head node
    - /sys/cray/pm_counters/power → Point-in-time power, in watts.
    - /sys/cray/pm_counters/energy → Accumulated energy, in joules.
  - **IBM AEM** - Uses IBM's Systems Director Active Energy Manager (AEM). Power and energy measurements available on each node
    - /sys/devices/platform/aem.0/{energy1_input,power1_average}
  - Newer IBM POWER systems use OCC (On Chip Controller) to collect system data.

Power Monitoring

- **IPMI** - Gets data from BMC (Baseboard Management Controller) using the IPMI (Intelligent Platform Management Interface) API.
- **RAPL** - Uses Running Average Power Limit (RAPL) sensors on two hardware domains:
  - Package RAPL domain (sockets)
  - DRAM RAPL domain (memory)
  - May require MSR driver
  - Example MSR_PKG_ENERGY_STATUS MSR (Intel IA manual):

63 32 31 0

reserved	total energy consumed

Comparison of IPMI and RAPL

- Energy measurement accuracy
  - IPMI - Good
  - RAPL - Good, but only for CPUs and memory
- Power measurement accuracy
  - IPMI - Poor
  - RAPL - Excellent, but only for CPUs and memory
- Overhead
  - IPMI - Relatively low
  - RAPL - Better than IPMI, no extra Slurm pthread required

Power Monitoring

- **Lenovo XCC** - Gets data from the XClarity Controller.
  - Embedded in every ThinkSystem server on a separate microprocesor.
  - IPMI variant where RAW hexadecimal values are used as commands to access Lenovo's specific OEM functionalities.
  - Ongoing work performed by Felip Moll. Working proof of concept already in place.

Plugin Configuration

- These plugins can be enabled in slurm.conf
- Sample configuration

```
AcctGatherEnergyType=acct_gather_energy/ipmi
AcctGatherNodeFreq=30
```

Power Consumption Reporting

- Available in node state information through scontrol or sview

```
$ scontrol show node
   NodeName=nid00001 …
   CurrentWatts=180 CapWatts=185
   LowestJoules=56 ConsumedJoules=123456
```

- Live job consumption with sstat
- Included in accounting reports with sreport
- Available for accounting and fair-share resource allocations

Power Consumption Reporting

- Available for job profiling
  - Data collected on admin/user-configurable interval
    - JobAcctGatherFrequency=energy=60
    - srun --acctg-freq=energy=30 (overrides previous one)
  - Written to HDF5 format file (or InfluxDB timeseries database since 18.08)
    - Different options configurable in acct_gather.conf
  - Tools available to plot and analyze per-node power consumption through time
    - HDFView, Grafana, ...

Power Saving Mechanism

- Supports powering down nodes that have been idle for some configurable period of time
- Nodes powered up as required
- Configurable rate at which nodes can be powered up or down

https://slurm.schedmd.com/power_save.html

Power Saving Mechanism

- slurm.conf excerpt

```
SuspendTime=120
SuspendRate=60
ResumeRate=300
SuspendProgram=/path/to/suspend_prog
ResumeProgram=/path/to/resume_prog
SuspendTimeout=30
ResumeTimeout=60
SuspendExcNodes=nid[0001-0050]
SuspendExcParts=debug
```

Dynamic Power Management

- Provides a mechanism to cap a cluster's power consumption
- Dynamically re-allocates power available per node based upon <u>actual real-time usage</u>
    - Starts by evenly distributing power cap across all nodes, periodically lowers the cap on nodes using less power and redistributes that power to other nodes
- Nodes using most of their power cap have the cap increased
- Nodes with newly initiated jobs have power cap reset

Dynamic Power Management

- Configurable iteration time and change rates
- Optimizes throughput within power cap with little to no user input and responds quickly to changes in application power consumption
- Currently only available on Cray systems
    - capmc utility used underneath alongside the json-c library
- Used at KAUST on Shaheen II

Power Management Configuration

- slurm.conf options:
  - DebugFlags=power - Enable plugin-specific logging
  - PowerParameters - Defines power cap, various thresholds, rate of changes, etc. (more on next slides)
  - PowerPlugin - Define the plugin to use (e.g. “power/cray”)

Power Parameter Options (1 of 3)

- balance_interval=# - Time interval between attempts to balance power caps. Default is 30 seconds.
- capmc_path=/... - Fully qualified pathname of the capmc command. Default is “/opt/cray/capmc/default/bin/capmc”.
- cap_watts=#[KW|MW] - Power cap across all compute nodes

Power Parameter Options (2 of 3)

- decrease_rate=# - Maximum rate of change in power cap of a node under-utilizing its available power. Based upon difference between a node's minimum and maximum power consumption. Default value is 50%.
- increase_rate=# - Maximum rate of change in power cap of a node fully utilizing its available power. Default value is 20%.
- lower_threshold=# - Nodes using less than this percentage of their power cap are subject to the cap being reduced. Default value is 90%.
- upper_threshold=# - Nodes using more than this percentage of their power cap are subject to the cap being increased. Default value is 95%

Example slurm.conf

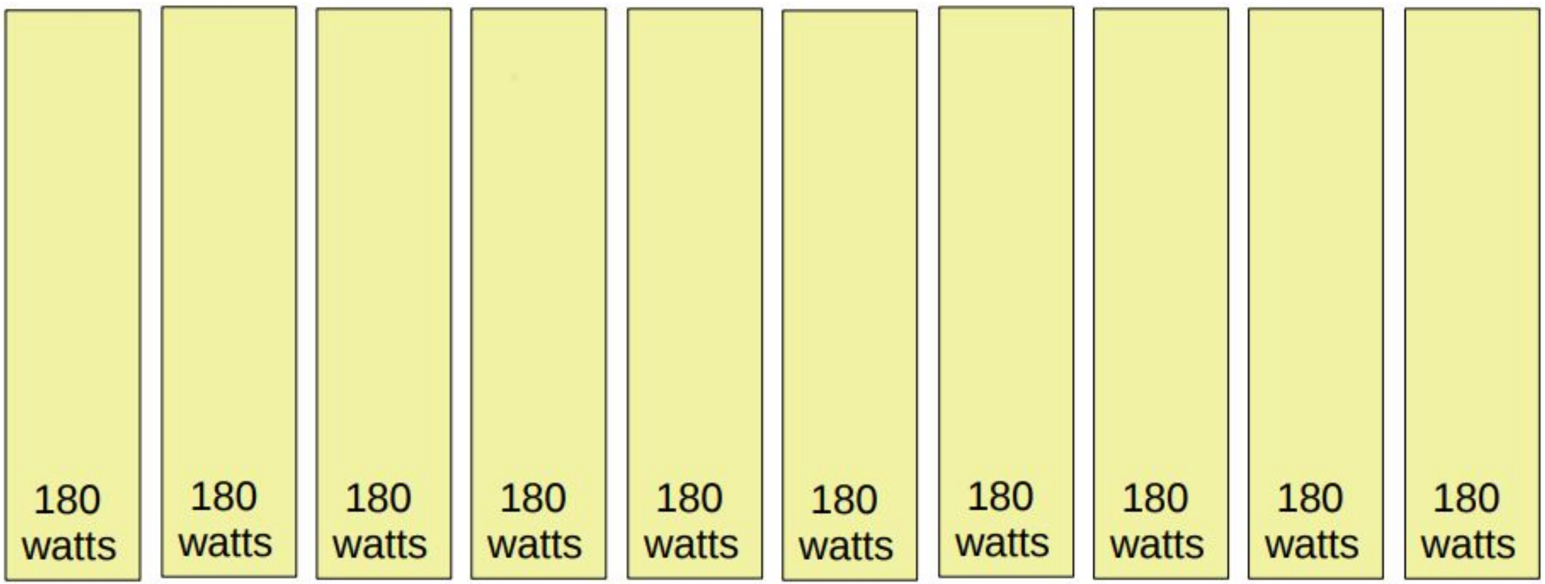
```
#
# Select portions of a slurm.conf file
#
DebugFlags=power     # Use recommended only for testing PowerPlugin=power/cray
PowerParameters=balance_interval=60,cap_watts=1800,decrease_rate=30,increase_rate=10,
lower_threshold=90,upper_threshold=98
```

NOTE: decrease_rate and increase_rate are based upon the difference between a node's minimum and maximum power consumption. If minimum power consumption is 100 watts and maximum power consumption is 300 watts then the maximum rate at which a node's power cap would be decreased is 60 watts ((300 watts – 100 watts) x 30%) while the maximum rate of increase would be increase 20 watts ((300 watts – 100 watts) x 10%).

Example Time 0 - initial state

- PowerParameters=balance_interval=60,cap_watts=1800,decrease_rate=30,increase_rate=10,lower_threshold=90,upper_threshold=98
- 10 compute nodes each with maximum power consumption of 200 watts and minimum of 100 watts
- Configured power cap of 1800 watts available
- Set each node's power cap to 180 watts (1800 / 10)

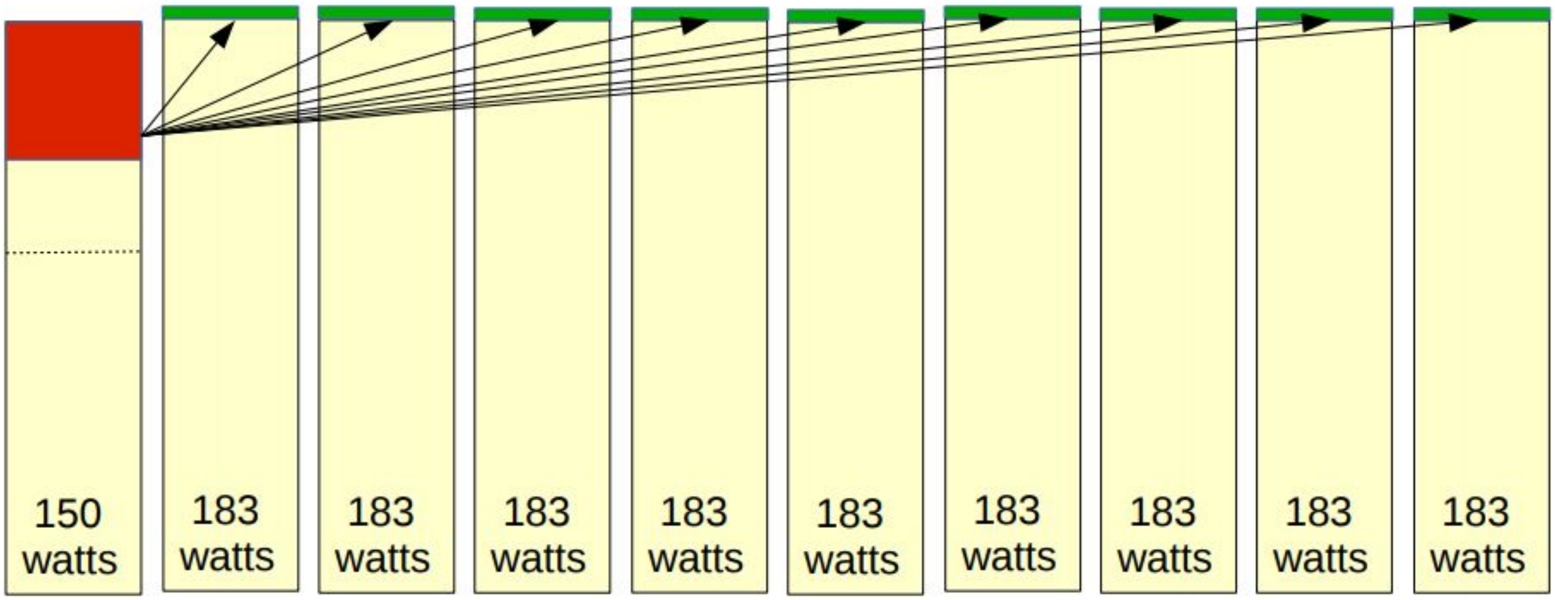
Example Time 0 - initial state



Example Time 60s - initial state

- One node is using 110 watts, others at 180 watts
- That 110 watt node is below lower_threshold (180 watts x 90% = 162 watts), so its cap gets reduced by the lesser of half the difference ((180 watts – 110 watts) / 2 = 35 watts) or decrease_rate (200 watts -100 watts x 30% = 30 watts), so that node's cap is reduced from 180 watts to 150 watts.
- We now have 1650 watts available to distribute over the remaining 9 nodes, or 183 watts per node (1650 watts / 9 nodes)

Example Time 60s



Dynamic Power Management

- Guidelines, slides and more examples available here:

https://slurm.schedmd.com/power_mgmt.html
https://slurm.schedmd.com/SLUG15/Power_mgmt.pdf

User Power Management Controls

- User's can specify desired frequency range and/or CPU governor

```
$ srun --cpu-freq=low-medium:conservative  ….
$ srun --cpu-freq=performance …
$ srun --cpu-freq=2400 ...
```

  - /sys/devices/system/cpu/cpuX/cpufreq/
    - scaling_setspeed
    - scaling_governor
    - ...

Areas of Interest

- User management of GPU frequency similar to CPU controls
- User specified power budget on jobs
- Controlled rate of change in power consumption (ramp up/down)
- Scheduled power availability changes (e.g. more power available at night)
- Schedule workload to optimize performance within power budgets through time

Areas of Concern

- Infrastructure needs to support power floor for ramp down
  - Not typically available today
- Will users specify power requirements?
- Will users specify reasonable time limits?
  - Needed for power budget scheduling
- Heuristics likely needed achieve good scheduling performance given (likely) poor guidance from users

Extra HPC PowerStack Notes

- Efficiently managing procured power on HPC is challenging due to different reasons, including
  - Processor manufacturing variability and increasing heterogeneity of node-level components
  - Vendor-specific mechanisms to measure metrics
- Some projects, most notably the Power API efforts, discuss interfaces that form a good starting point for full stack integration
- HPC community needs a *hollistic* stack for power and energy management