Improved system utilization respecting jobs needs under strict power budget

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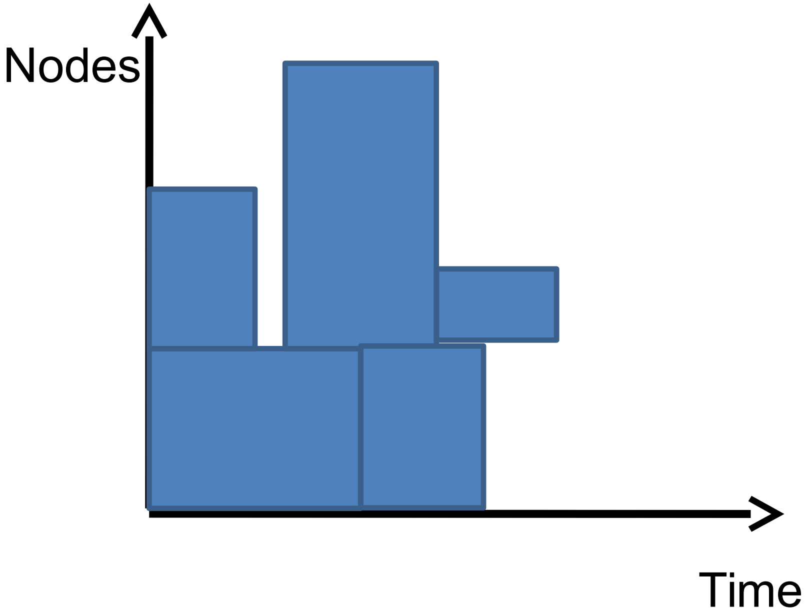
R&D Bull

Introduction

- **Energy efficiency** major requirement in all levels of **hardware and software design**
- Additional constraints: **maximum power capping** or constant power consumption with only small perturbation.
  - If those constraints are met, a power supplier can often provide a significantly lower price, thus increasing the efficiency in terms of TCO.
  - If not there may be fines

Motivation for system-wide powercap

- Need for **centralized mechanism** to dynamically **adapt the instantaneous power** consumption of the whole platform



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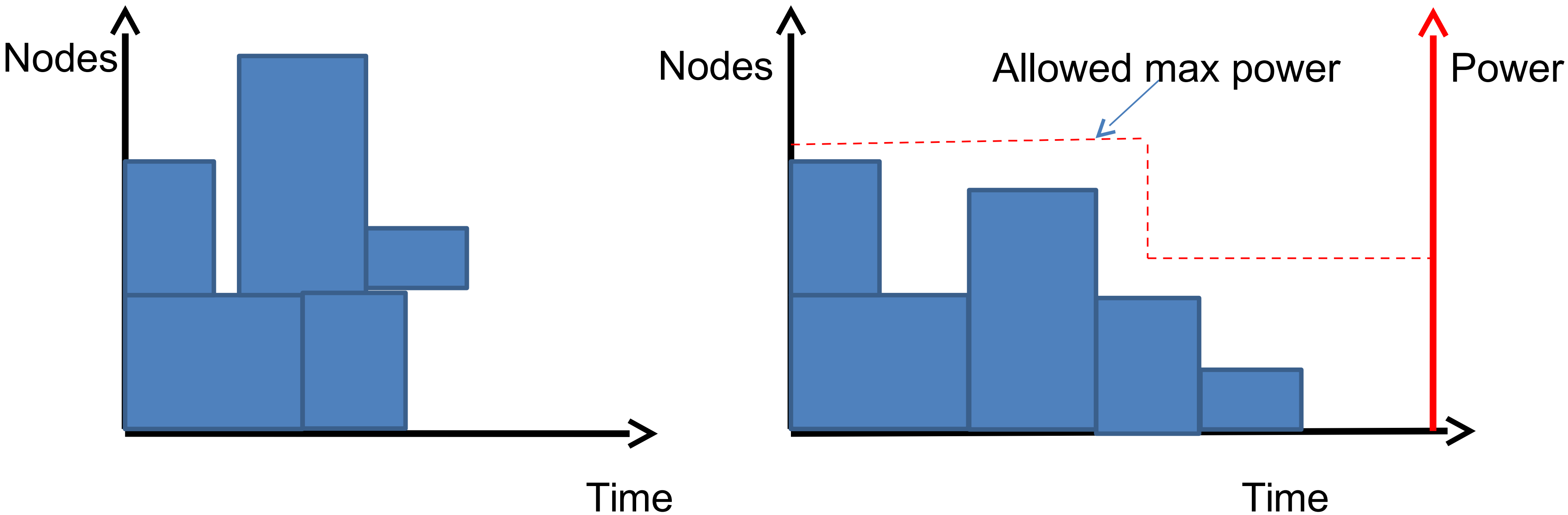

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First iteration

Power adaptive scheduling

- Power adaptive scheduling is a feature within SLURM appeared in version 15.08
  - Initial algorithms and prototype made by CEA in 2013
  - A second prototype (extended version of the first) has been studied, experimented and published in [Georgiou et al. HPPAC-2015] by BULL + LIG
- *Final implementation (BULL) based upon the layouts framework and its API functions (CEA)*

Yiannis Georgiou, David Glesser, Denis Trystram
Adaptive Resource and Job Management for limited power consumption
In proceedings of IPDPS-HPPAC 2015

Power adaptive scheduling

▶The implementation as appeared in Slurm v15.08 has the following characteristics:

- Based upon layouts framework
  - -for internal represantation of resources power
  - -Only logical/static represantation of power
  - -Fine granularity down to cores

▶Power Reductions take place through following techniques coordinated by the scheduler:

– Letting Idle nodes
– Powering-off unused nodes (using default SLURM mecanism)
– Running nodes in lower CPU Frequencies (respecting –-cpu-freq allowed frequencies)

Layouts Framework

- **Supercomputers become more complex structures**
  - Not all the resources **characteristics are taken into account** by the RJMS:
    - Power Consumption per Component, Electrical Connections, Communications roles

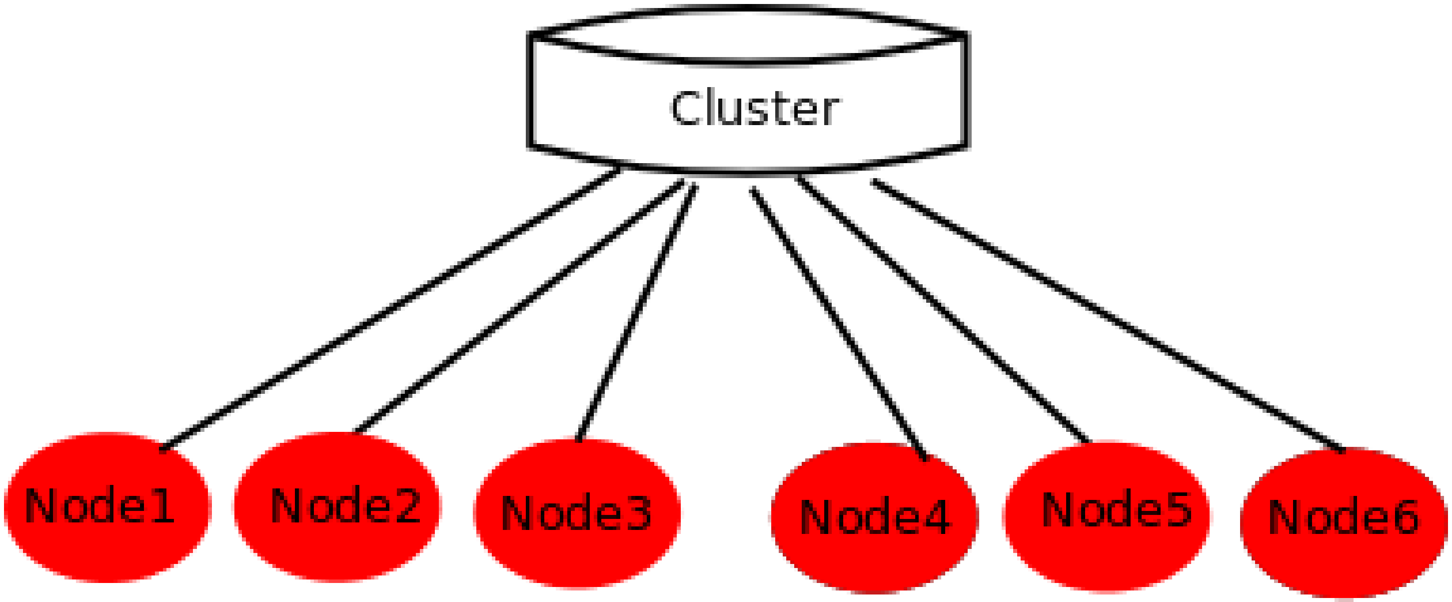
  - These charcateristics can give **valuable information** that may be used to **optimize automatic decisions:**
    - Scheduling, Energy Efficiency, Scalability

Layouts framework appeared in Slurm v15.08

Slurm User Group presentation, Sep 2015:
http://slurm.schedmd.com/SLUG15/slurm_layouts_framework.pdf

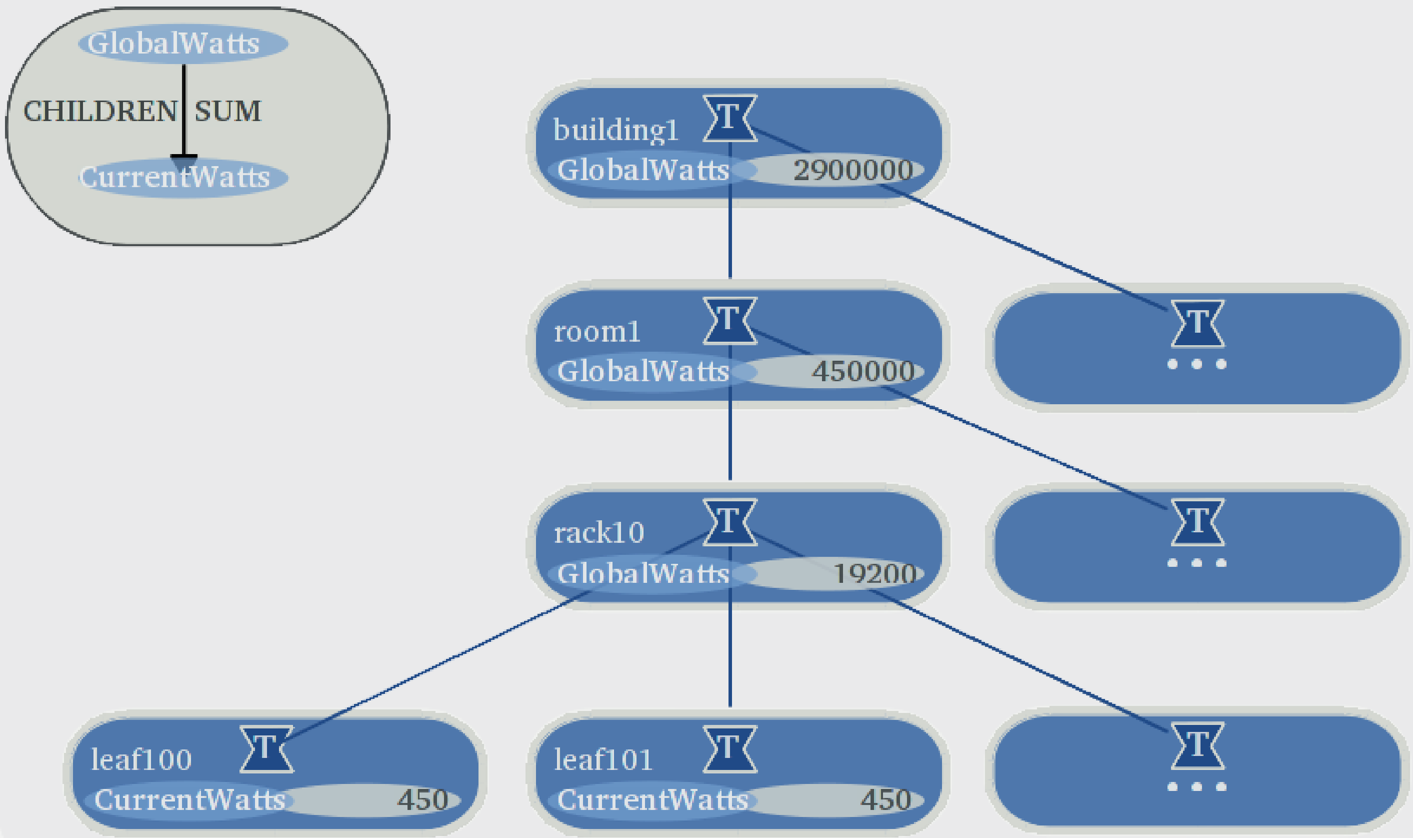
Layouts Framework

- One Cluster
  - **with multiple views (representing new characteristics)** of the same resources



Slurm Layouts Framework
Example of Automatic Update

Power : autoupdate of values by inheritance



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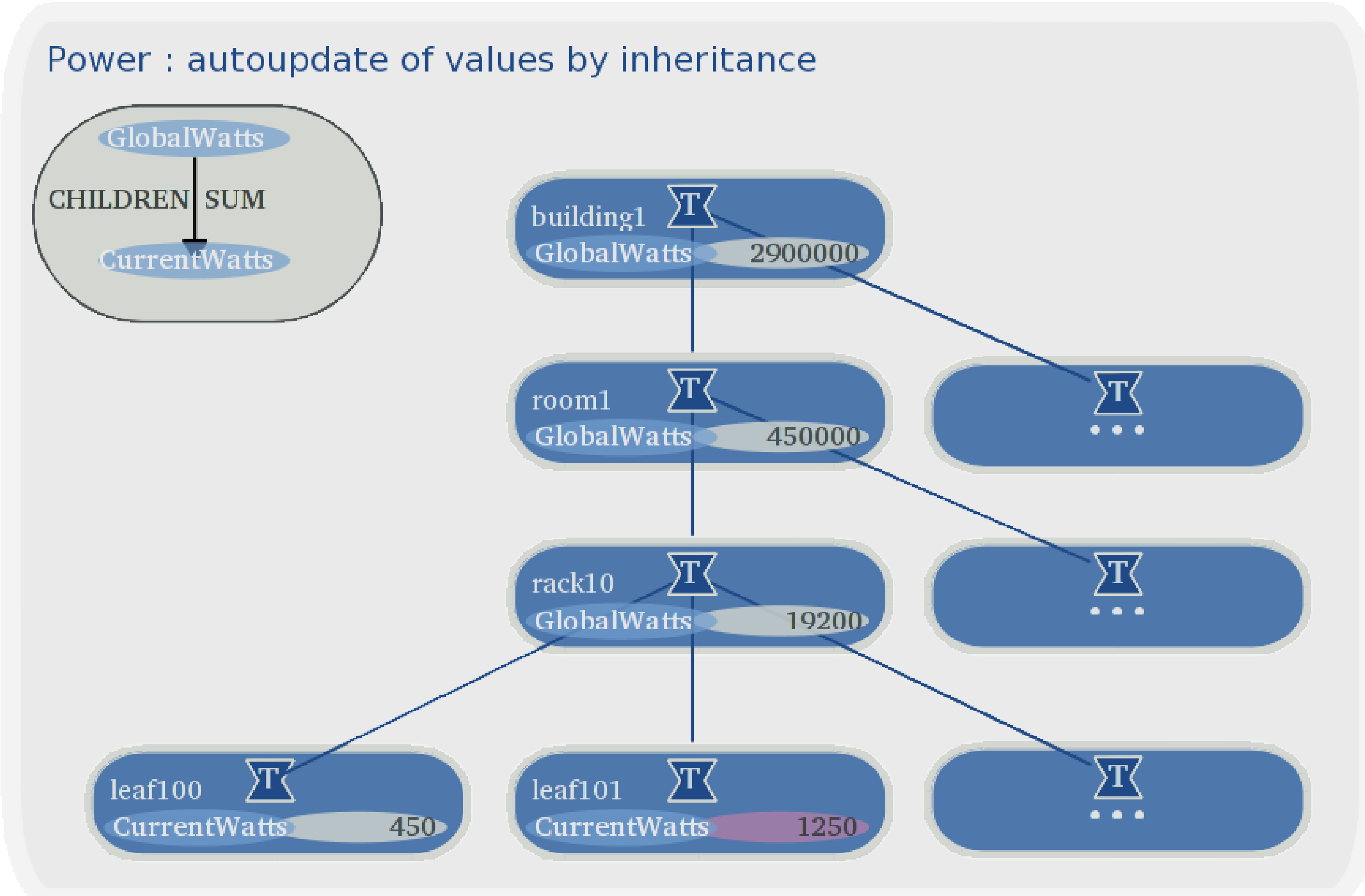

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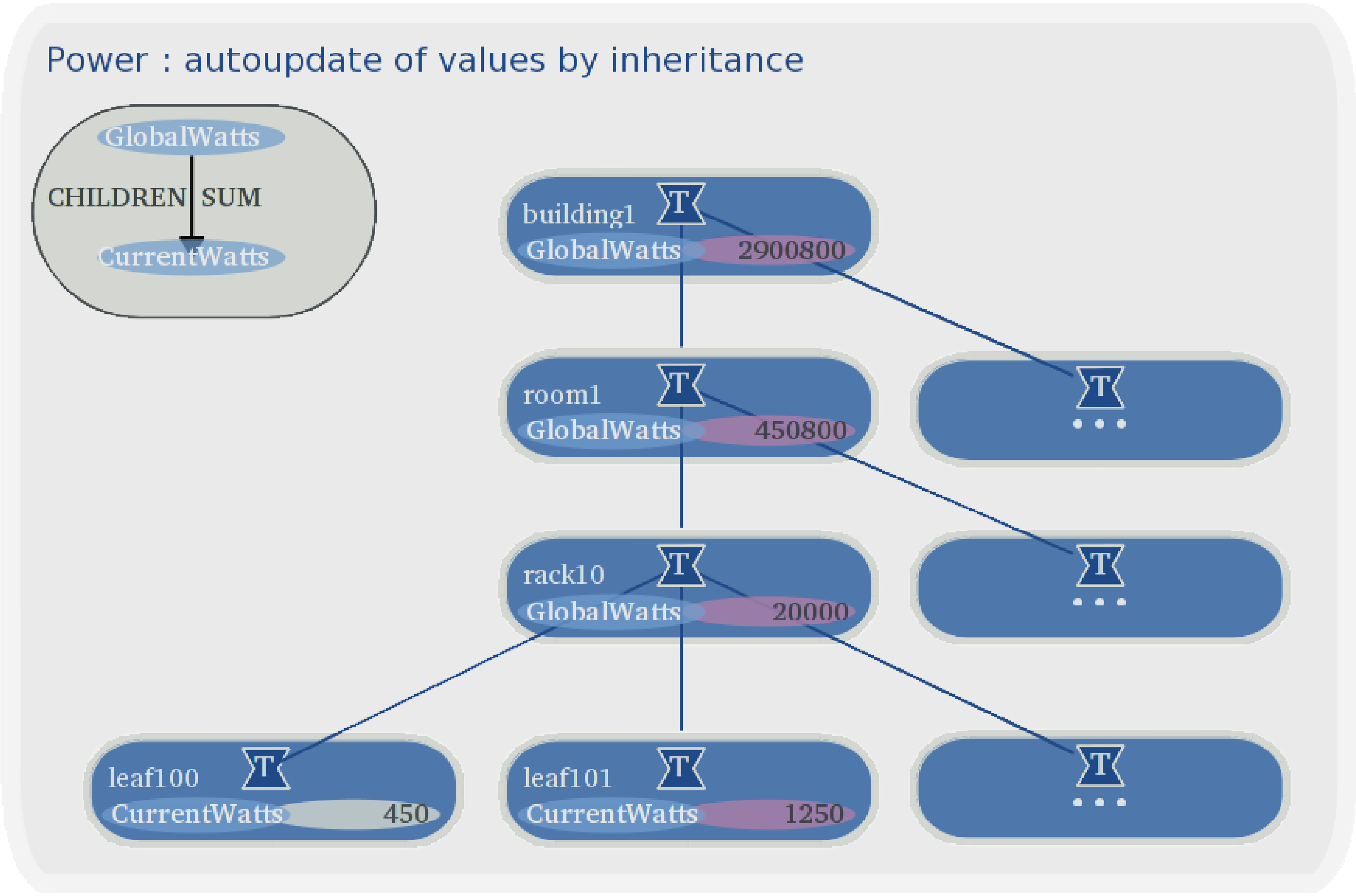
Example of Automatic Update



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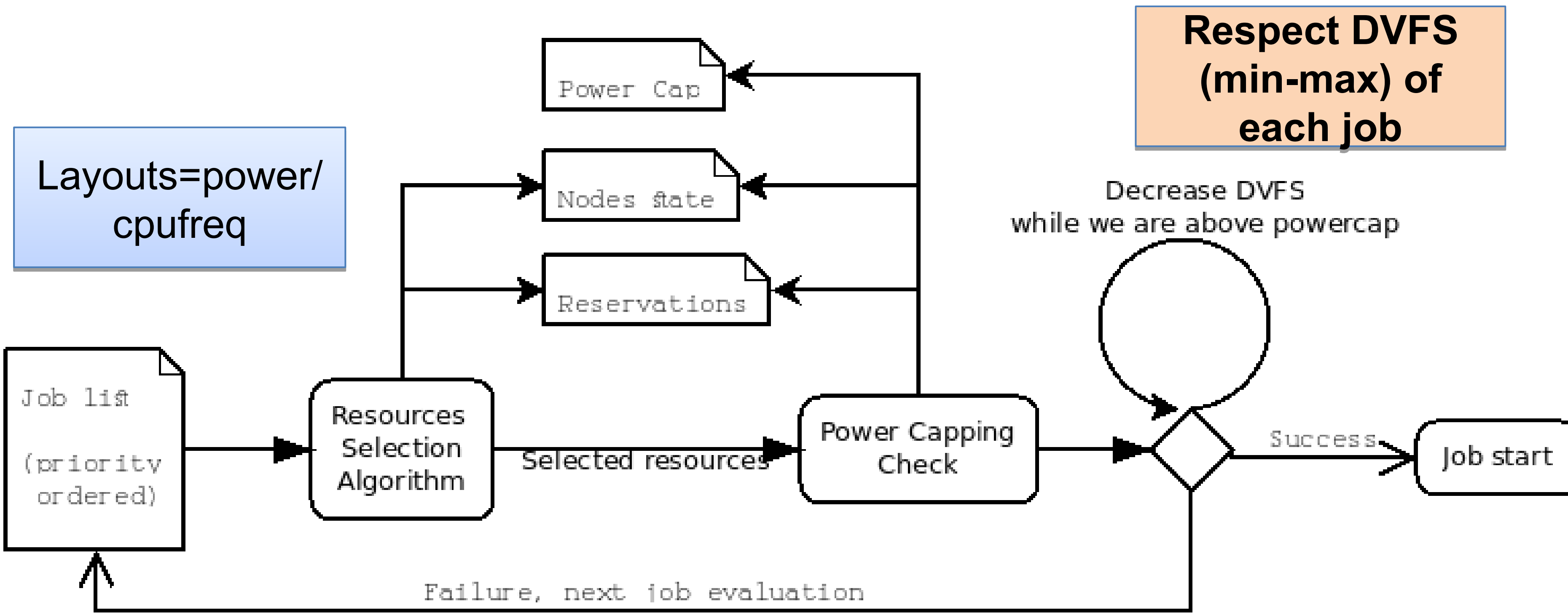
Static Power Layout Configuration

```
[root@nd25 slurm]#cat /etc/layouts.d/power.conf

Entity=Cluster Type=Center CurrentSumPower=0 IdleSumWatts=0 MaxSumWatts=0
Enclosed=node[0-5039]

Entity=node0 Type=Node CurrentPower=0 IdleWatts=0 MaxWatts=0 DownWatts=14
PowerSaveWatts=14 CoresCount=0 LastCore=15 Enclosed=virtualcore[0-15]
Cpufreq1=1200000 Cpufreq2=1400000 Cpufreq3=1600000 Cpufreq4=1800000
Cpufreq5=2000000 Cpufreq6=2200000 Cpufreq7=2400000 NumFreqChoices=7

Entity=node1 Type=...

Entity=core[0-80639] Type=Core CurrentCorePower=0 IdleCoreWatts=7
MaxCoreWatts=22 CurrentCoreFreq=0 Cpufreq1Watts=12 Cpufreq2Watts=13
Cpufreq3Watts=15 Cpufreq4Watts=16 Cpufreq5Watts=17 Cpufreq6Watts=18
Cpufreq7Watts=20
```

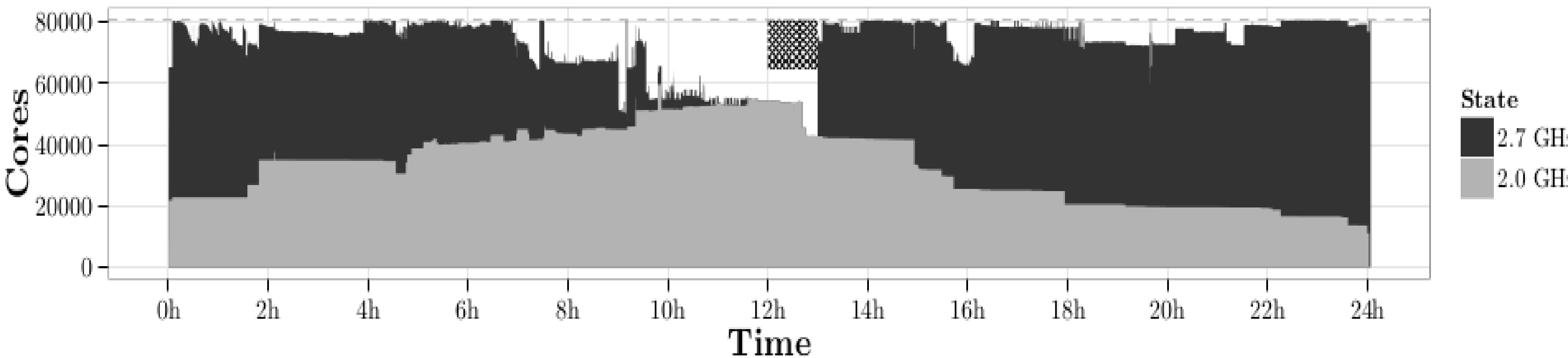
Algorithm: DVFS Power Adaptive Scheduling

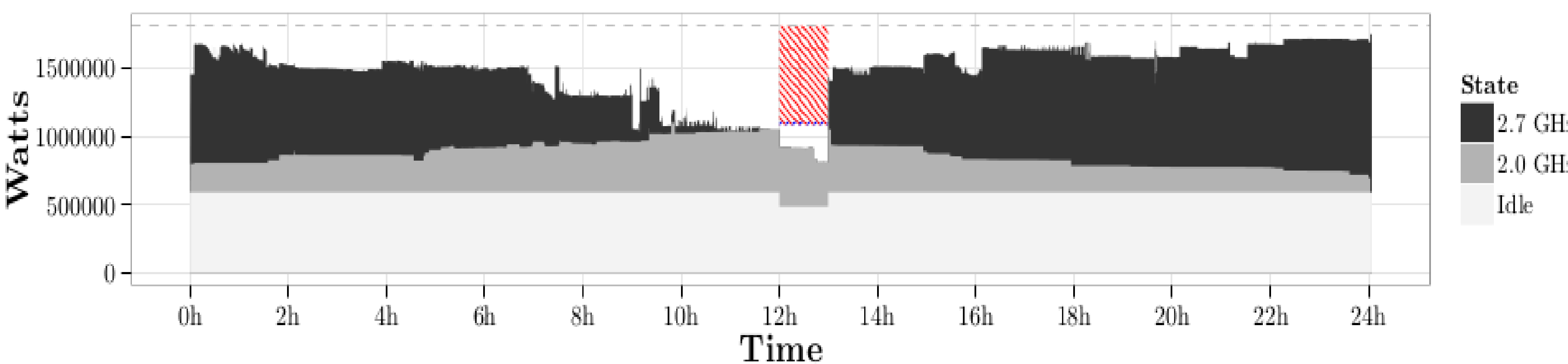
- Reductions through DVFS, idle and shut-down nodes (if power-save mode activated)
- Considering core level power consumption



Slurm User Group presentation, Sep 2015: http://slurm.schedmd.com/SLUG15/Power_Adaptive_final.pdf

DVFS Power adaptive scheduling study





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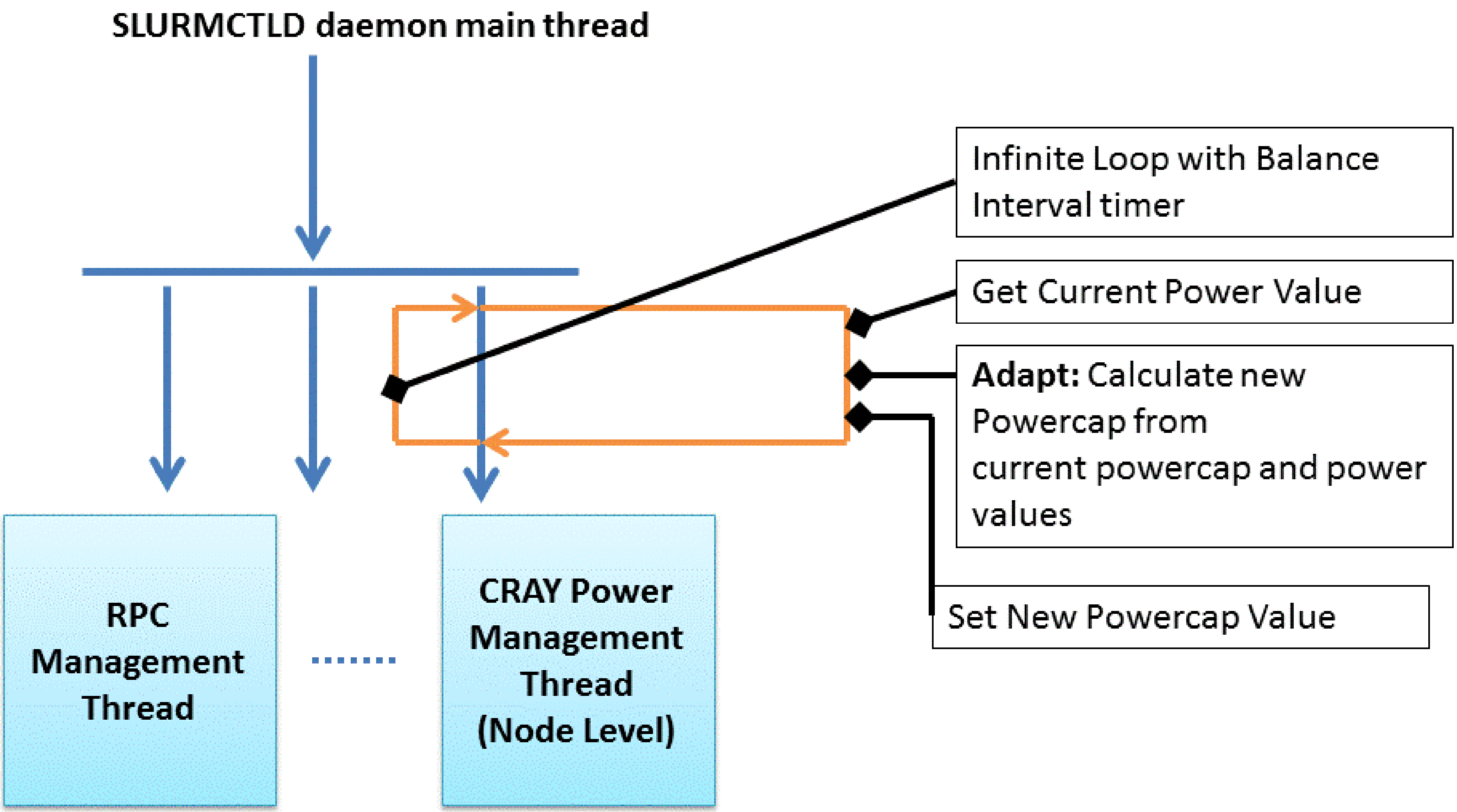
Second iteration

Algorithm: CRAY Power Plugin



Slurm User Group presentation, Sep 2015:
http://slurm.schedmd.com/SLUG15/Power_mgmt.pdf

Algorithm: Adaptive Power Management

Current Powercap = 160W, What would be new Powercap Value?

- lower_threshold = 92 % → 160 * 92 /100 = 147.2
- upper_threshold = 96 % → 160 * 96 /100 = 153.6

} Threshold Calculation

- decrease_rate = 20 % → 160 *(100-20) /100) = 128
- increase_rate = 10 % → 160 *(100+10)/100) = 176

} Rate Of Change

Sr No	Current Power	Threshold Calculation	New Powercap Calculation
1	140	140 < 147.2	128
2	160	160 > 153.6	176
3	150	between	150

Other possibilities and Complete details of algorithm explained in http://slurm.schedmd.com/power_mgmt.html

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CRAY vs DVFS Power Management in SLURM

Behaviour	(2nd iteration) CRAY	(1st iteration) DVFS
Power Calculation	**Real** power values	Theoretical power values
Powercapping Functionality	**Separate Task** to adapt PowerCap Frequently	**Scheduler** to adapt PowerCap
Powercap Guarantee	**Yes** real values and hardware powercap mechanism	**No** since based only on theoretical values
Power Congestion	When large number of application running, power congestion may be increased	Scheduler **reduces Power Congestion** by increasing Waiting time of the Jobs
Adaptive Behavior	**Dynamic Power Allocation** Unused Power shared with other jobs	Static power allocation Unused power not calculated/shared
Architecture	Only Cray platforms	All Linux platforms
Respecting application needs	System adaptation regardless application needs	Scheduler driven considering DVFS (min-max) given by job

Third iteration

New Approach based on Intel RAPL

Resolving Powercap guarantee Issue:

- **RAPL ensures hardware powercap guarantee** → Run cluster within the power budget

Resolving theoretical values inaccuracies:

- **RAPL provides a good estimate of socket power consumption** → Adapt layouts regularly to reflect real values

Resolving System Utilization Issue:

- **Adapt power based on real power consumption** (capture the application behavior) → Allow more jobs to take advantage of the un-used power

RAPL Mechanism on Intel CPUs

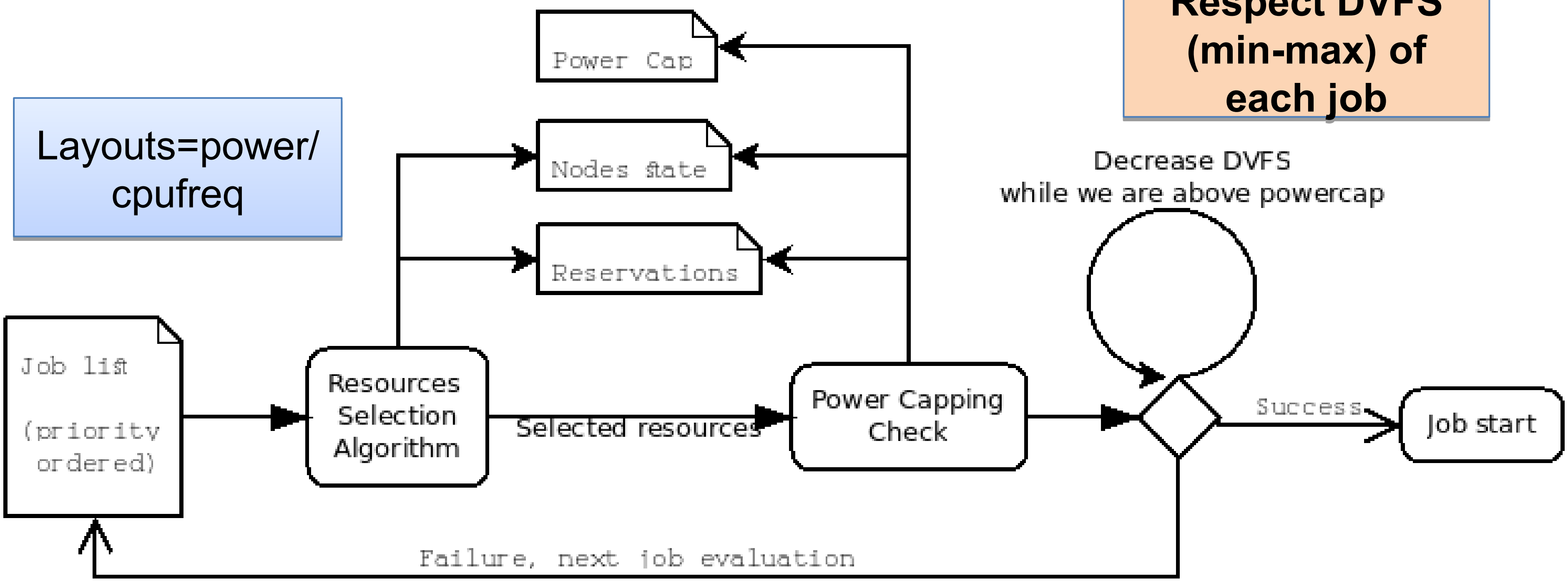
- **RAPL** (Running Average Power Limit) are register interfaces for keeping the processors in a particular user-specified **power envelope**
- Interfaces can estimate current energy usage based on a software model data collected represent energy in Joules
- **Linux** supports an **MSR driver** and access to the register can be made through **/dev/cpu/*/msr** with priviledged read permissions
- Access MSR features by external library **LibMSR** (developed by LLNL)

Algorithm: DVFS - RAPL Power Adaptive Scheduling (1)

1) Usual steps of DVFS power Adaptive Scheduling

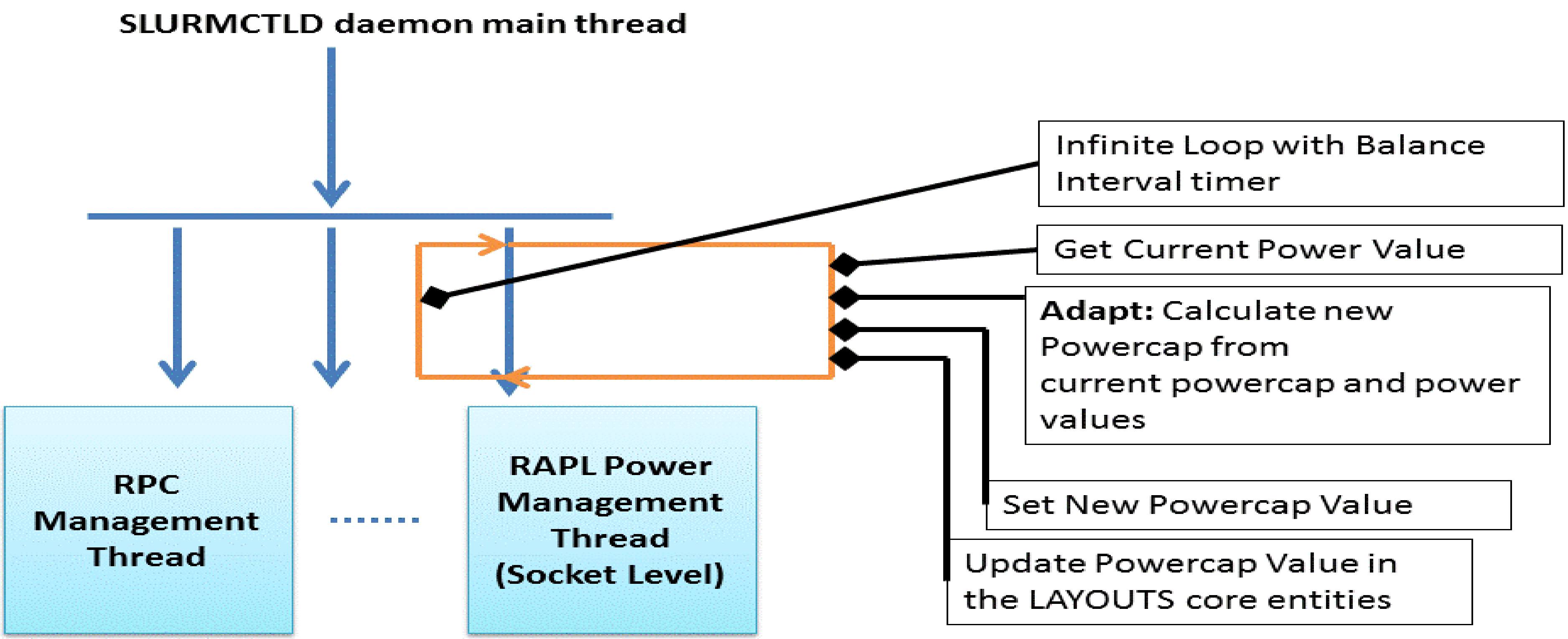
Respect DVFS (min-max) of each job

Layouts=power/cpufreq

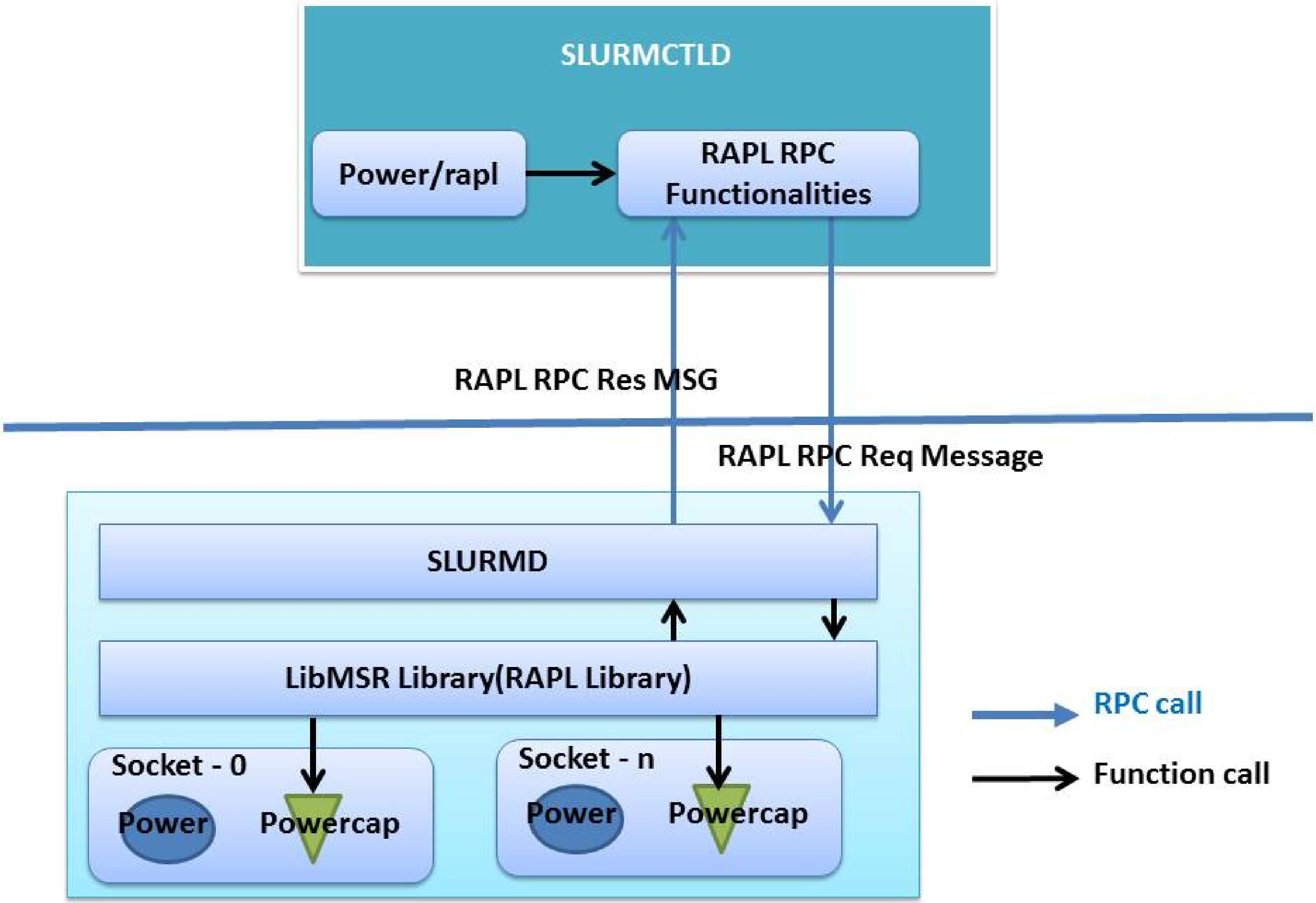


Algorithm: DVFS - RAPL Power Adaptive Scheduling (2)

2) Layouts framework keep the new updated power information
3) A RAPL Power plugin sets the RAPL powercap based on the layouts power info and adapts the powercap as needed
4) The updated power kept on layouts for the new jobs



High Level Architecture



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Power Management in SLURM

Behaviour	CRAY	DVFS	RAPL
Power Calculation			**Real** power values
Powercapping Functionality			Both a **Separate Task** and the **Scheduler** to adapt PowerCap Frequently
Powercap Guarantee			**Yes** real values and hardware powercap mechanism
Power Congestion			Scheduler **reduces Power Congestion** by increasing Waiting time of the Jobs
Adaptive Behavior			**Dynamic Power Allocation** Unused Power shared with other jobs
Architecture			All Linux platforms
Respecting application needs			Respect application needs based on prediction

Experiments

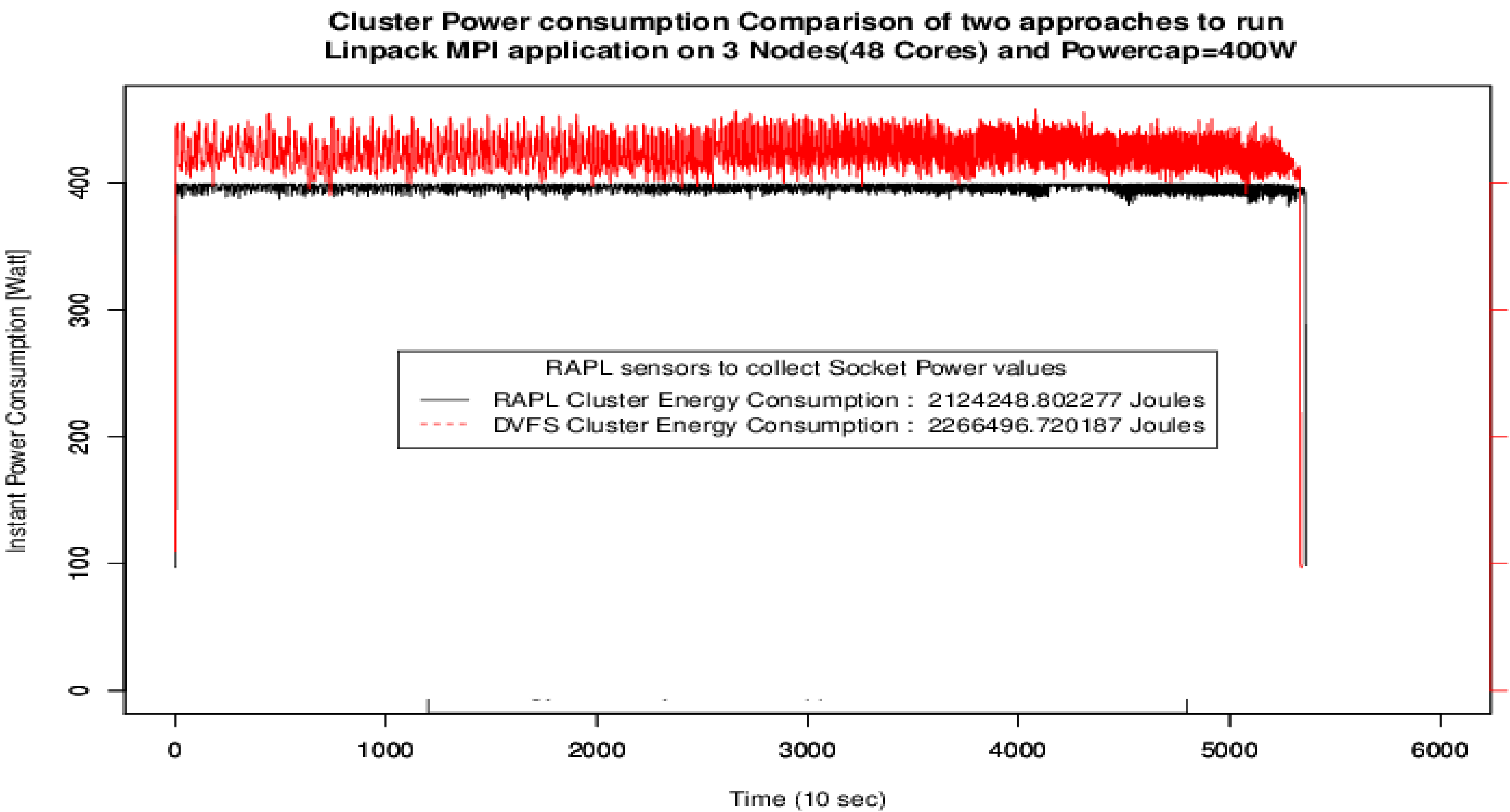
Experimental Evaluation

- **Cluster Configuration**
  - Intel Sandy Bridge Processor with RAPL, DVFS support
  - 3 nodes(2 sockets/node, 8 cores/socket and 65GB) cluster
  - Cluster's powercap range is 400-1200 Watts
  - balance_interval=10, cap_watts=700, decrease_rate=20, increase_rate=10, lower_threshold=90, upper_threshold=96
- **Experiment – I**
  - Ensuring hardware Powercap by running HPLinpack application
- **Experiment - II**
  - System Utilization Experiment with lightESP benchmark workload
- **Demo**

Experiment I - Powercap Guarantee

- sbatch –N3 –exclusive --cpu-freq=2400000 ./HPLinpack.sh
- less **HPLinpack.sh**
  - #!/bin/sh
    #SBATCH -o ./hpl.out
    srun --cpu-freq=2400000 -n 48 ./xhpl
- less **HPL.dat**
  - 282256 Ns **// More than 90% Memory was allocated**
  - 1 # of NBs
  - 192 NBs
  - 0 PMAP process mapping (0=Row-,1=Column-major)
  - 1 # of process grids (P x Q)
  - 8 Ps
  - 6 Qs **// P*Q = 48 tasks to run on 48 Cores**

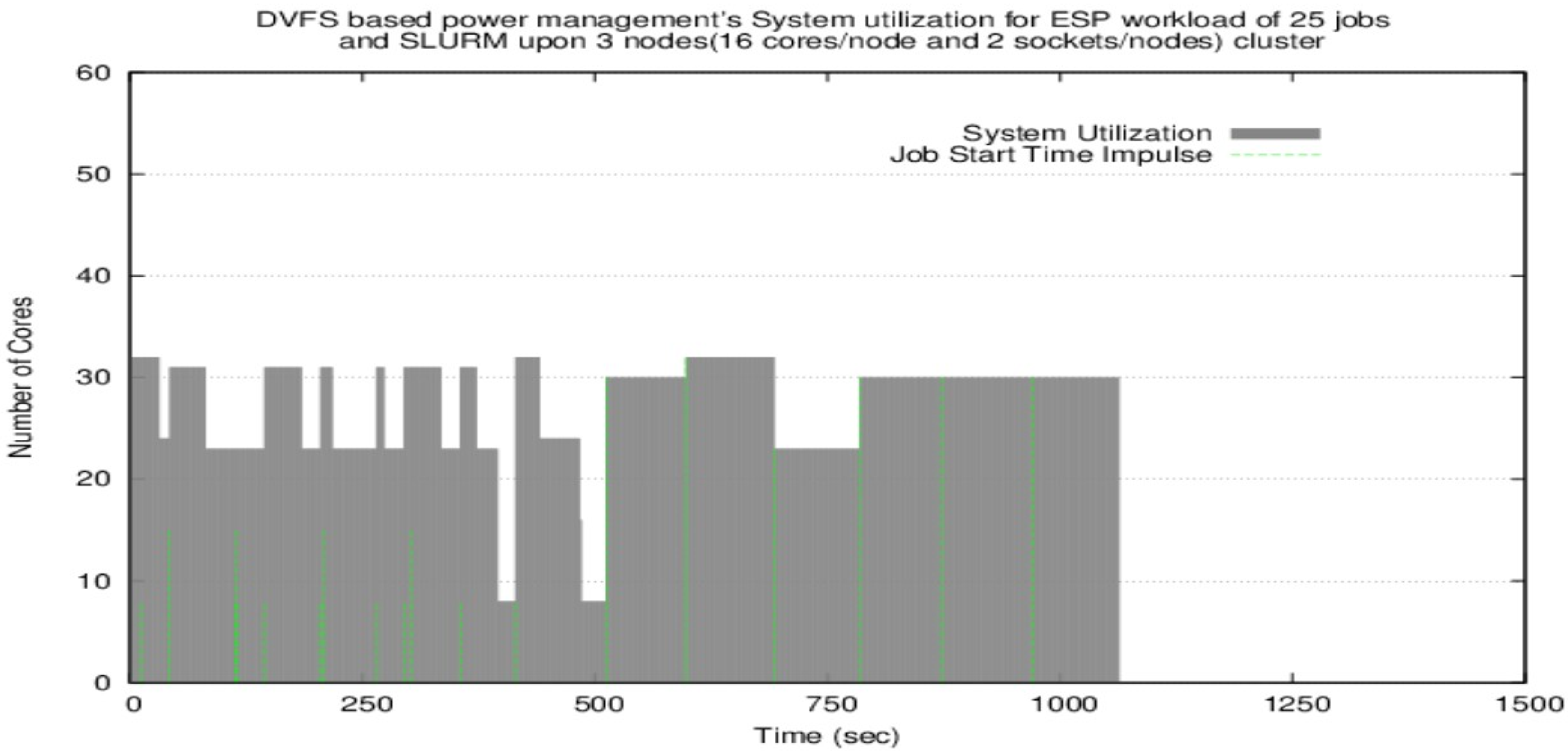
Cluster Powercap is Guaranteed by RAPL



Experiment II - System Utilization

- lightESP to run ESP workload (25 jobs) with serial linpack application
- PowerPlugin=**power/rapl**
- Layouts=**power/cpufreq**
- cgroups enabled
- **PowerParameters**=balance_interval=10,**cap_watts=700**,decrease_rate=40,increase_rate=10,lower_threshold=92,upper_threshold=96,recent_job=20

DVFS based approach



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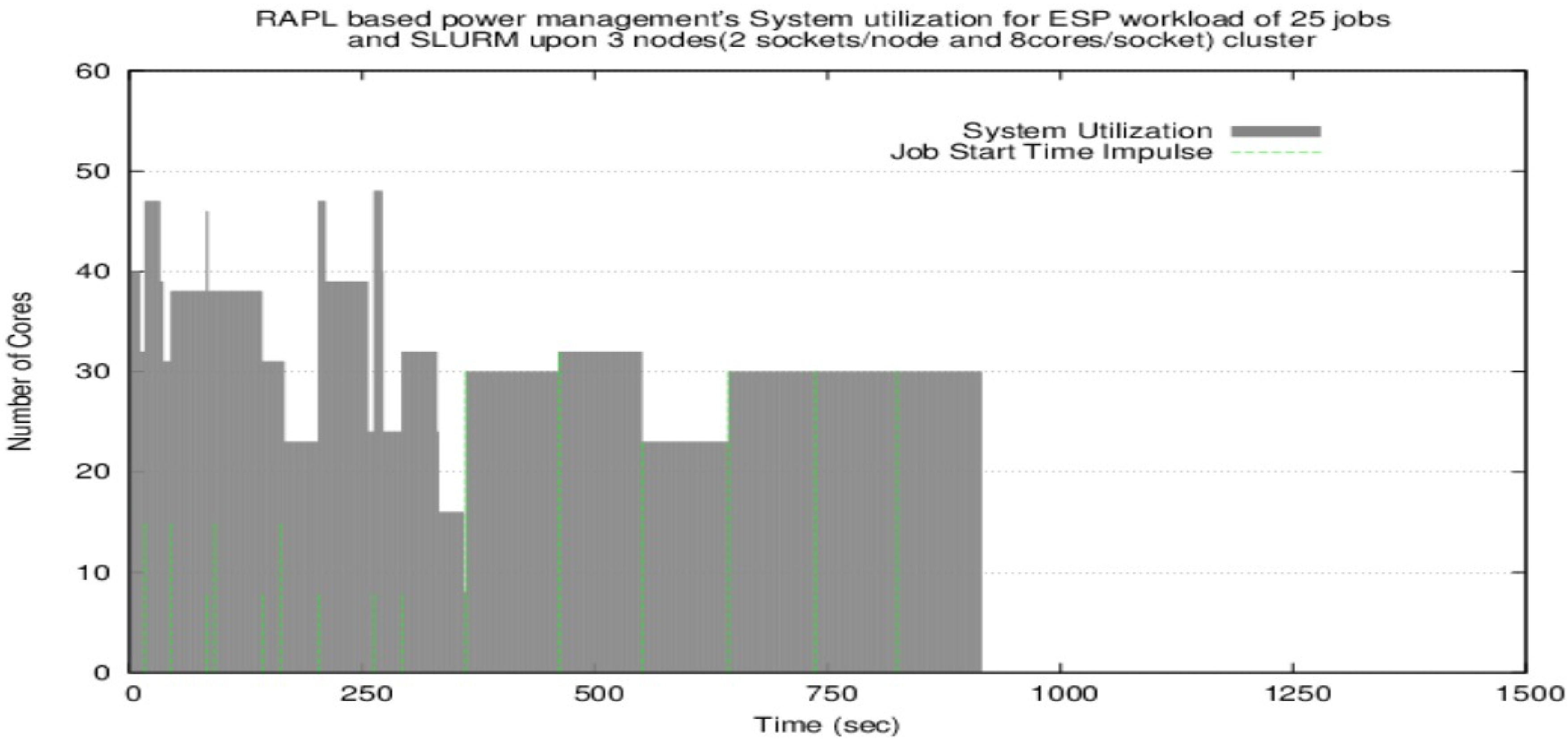
RAPL based approach



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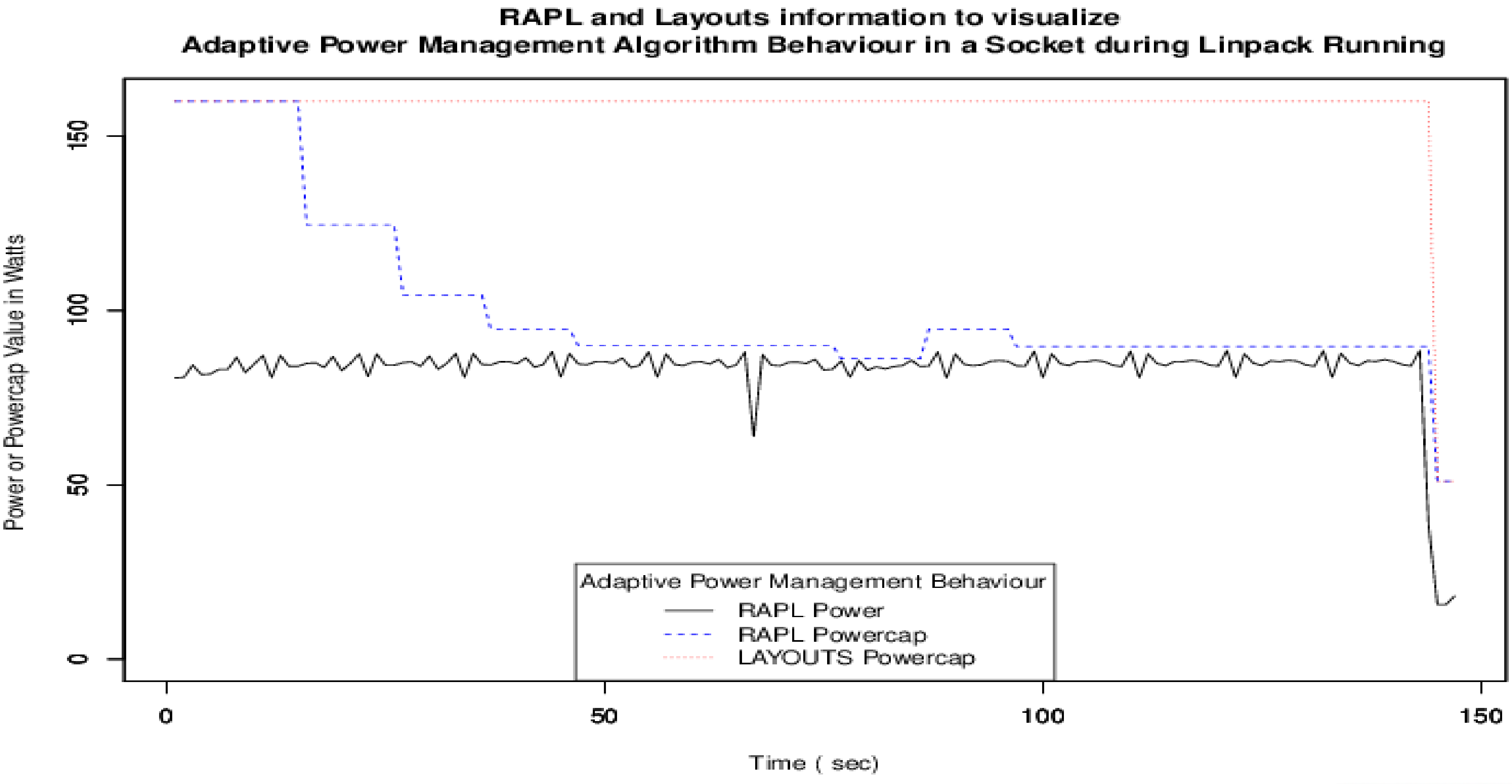
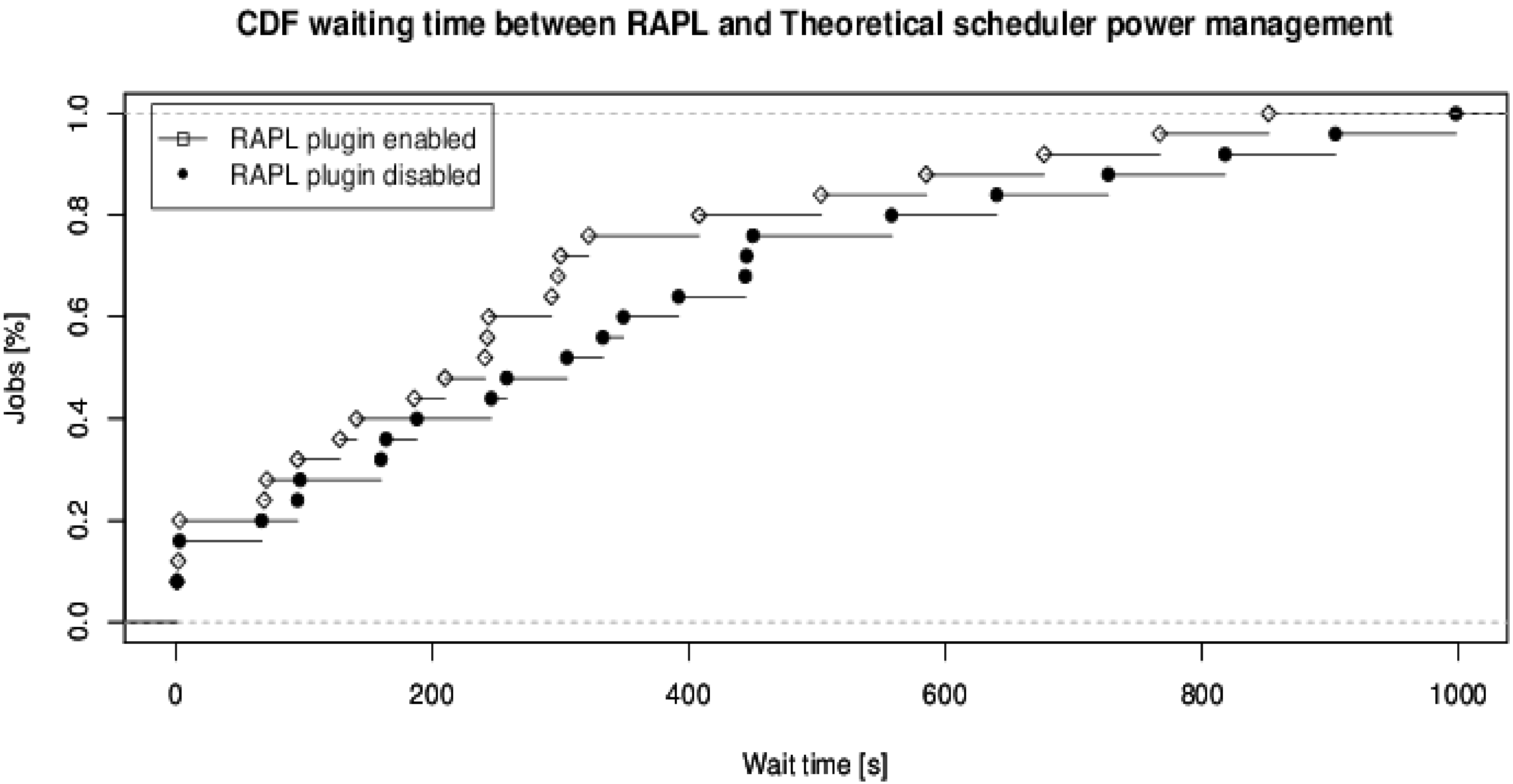
Algorithm Behavior: Based on RAPL Info's

- Launched **serial linpack** on one node
- RAPL Hardware information gathered in **a socket** to visualize the algorithm



Jobs Waiting Time (CDF)



Ongoing Works

- First implementation of the code is finished, working to provide the new RAPL based Power plugin for the upcoming Slurm version 17.02
- Evaluating and improving the scalability of the approach, especially that of layouts framework
- More experiments to be done with real traces and applications to validate the new code
- Active within the Energy and Power aware Job Scheduling and Resource Management team of Energy Efficiency HPC working group (https://eehpcwg.llnl.gov/) to exchange with the community and see what are the real use cases/needs of powercapping

Thank you for your attention

Questions ?

Discussion
Power Adaptive Scheduling VS Power Plugin

- The Power adaptive scheduling and the Power Plugin logic (Cray) provide 2 different approaches for powercapping:
  - The first one is based on logical, **static power values** and theoretical calculations for altering scheduling to achieve a global power budget
  - the former one based on the physical, **real power values**, and an integration to a hardware mechanism that will adapt each nodes power consumption to align to a global power budget
- Disadvantages of each approach:
  - Power adaptive scheduling is based on **approximations** so result may not be optimal either in system utilization or final power consumption
  - PowerPlugin will change the node configuration of jobs **without respecting their needs** and depending on the executed application it will affect its turnaround time which may not be welcome
- **Our goal here is to take the best of the 2 worlds!**