Techniques and tools for measuring energy efficiency of scientific software applications

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1 Introduction

As both High Performance Computing (HPC) and High Throughput Computing (HTC) are sensitive to the rise of energy costs, energy-efficiency has become a primary concern in scientific fields such as High Energy Physics (HEP).
We have performed several physical and software-based measurements of workloads from CERN running on ARM and Intel architectures, to compare their power consumption and performance. We leverage several profiling tools to extract different aspects of the experiments, including hardware usage and software characteristics.
We present an overview of the tools and techniques used to perform HPC power measurements. In addition we compare results of power efficiency in HPC between ARM and Intel architectures. Such results were obtained levearaging the tools and techniques described.

2 Energy model

Several components contribute for power consumption in HPC. It is vital to grasp how and where energy is consumed in a HPC system. The Figure 1 summarizes the high and low level components that should be taken into account when studying energy consumption of HTC systems.

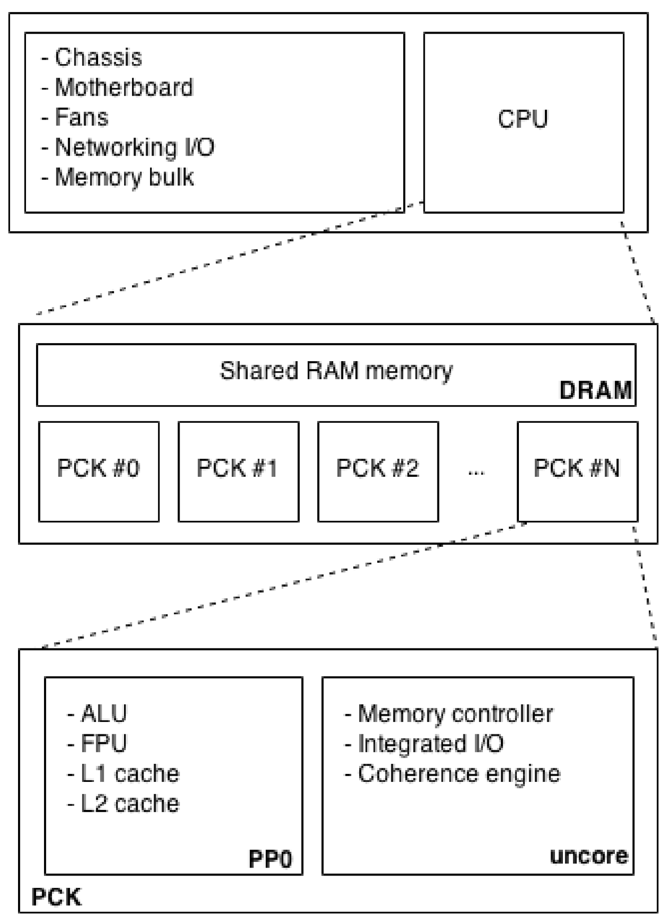


Figure 1: System's components which contribute for power consumption in HPC

According to our measurements, the power consumption quota of each component varies depending on the system's configuration (see Figure X).

3 Techniques and tools overview

- **External measurement tools** It consists of non-invasive clamp meters or electrical plugin power monitors. The external monitoring tools account for energy drained by the whole system or coarse-grained set of components.
- **On-chip measurement tools** It consists of monitoring chips embeeded on the system's SOC to perform fine grained and low resolution measurements. These monitoring chips usually support power measurements on RAM and CPU level (see Figure 1).
  Intel supports this since its Sandy Bridge models through Running Average Power Limiting (RAPL) technology. Other alternatives, such as the Texas Instrument TI231 power monitor, allow integration of monitoring chips in any architecture.
- **Software Based** It consists of software applications that predict energy consumed by the system based on energy consumption models. The software can also rely on physical measurements, which increases measurement accuracy .

4 IgProf

Software can help to understand how and where energy is consumed in a fine grained scale. For instance, IgProf is a tool for measuring and analysing the applications' memory and performance characteristics.
IgProf was recently ported to AArch64 and extended with an energy profiling module, which obtains energy measurements from the RAPL interface through the PAPI library. Therefore, it is possible to know how much energy is spent on each function of the application running, which is important for software fine-grained tuning.

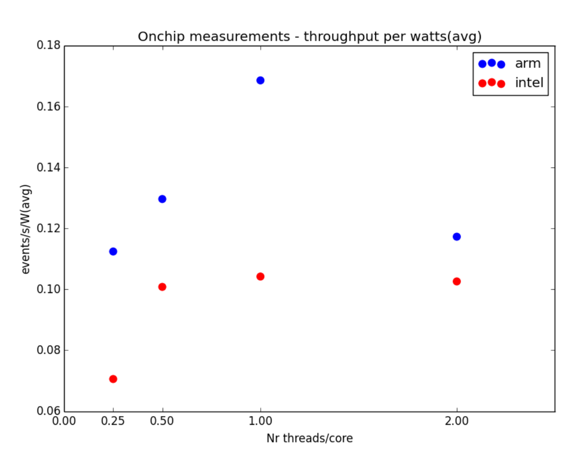
5 Energy consumption measurements

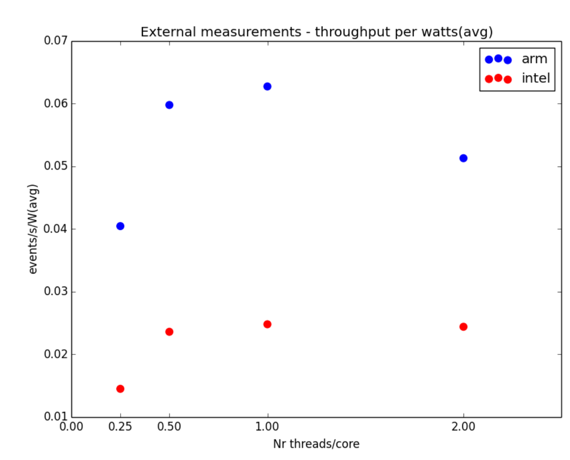
We have performed onchip and external measurements of workloads from CERN running on ARM and Intel architectures. The results presented below were obtained by running a typical CERN workload for an average of 30 minutes.

Machine's specifications

XeonPhi
- **CPU** big, 32 cores.
- **Memory** some teras
- **Notes** Machine on a rack , ect..

ODROID
- **CPU** not bg, 4 cores.
- **Memory** few gigas





5.1 Onchip monitors

The XeonPhi machine has support to the Intel's RAPL technology. Therefore, it was possible to measure the power consumed on package (PCK), core (PP0) and memory (DRAM) level (see Figure 1).
The ODROID machine has a TI INA231 monitoring chip embeeded. This chip allows power monitoring of the CPUs and memory. The results are shown in the Figure 2A.

5.2 External physical measurements

Both XeonPhi and ODROID machines have an external power monitoring tool for measuring the amount of power consumed by the whole system. The results are shown on Figure 2B. In addition, it is possible to see on Figure 3 the ratio between the different components and compare it with the overall energy consumed during the tasks.