Principles of Energy Efficiency in High Performance Computing*

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Abstract. High Performance Computing (HPC) is a key technology for modern researchers enabling scientific advances through simulation where experiments are either technically impossible or financially not feasible to conduct and theory is not applicable. However, the high degree of computational power available from today's supercomputers comes at the cost of large quantities of electrical energy being consumed.

This paper aims to give an overview of the current state of the art and future techniques to reduce the overall power consumption of HPC systems and sites. We believe that a holistic approach for monitoring and operation at all levels of a supercomputing site is necessary. Thus, we do not only concentrate on the possibility of improving the energy efficiency of the compute hardware itself, but also of site infrastructure components for power distribution and cooling. Since most of the energy consumed by supercomputers is converted into heat, we also outline possible technologies to re-use waste heat in order to increase the Power Usage Effectiveness (PUE) of the entire supercomputing site.

Keywords: High Performance Computing, Energy Efficiency, Power Usage Effectiveness, HPC, PUE.

1 Introduction

As of today, HPC sites and large data centres are among the biggest power consuming entities in the Information and Communication Technology (ICT) sector. According to a study conducted by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the power consumption of the German HPC sites and data centres has more than doubled since the year 2000 and amounted to 10.1 TWh[1] in 2008, which corresponded to

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[1] TWh: terawatt hour.

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the emission of 6.4 million tonnes of CO_2 [6] based on the German energy mix of that time.

Recently, Moore's law [12] has continued to show its validity: The number of transistors that can be put on a computer chip of constant die size has roughly doubled every 18 months. Manycore CPUs are omnipresent and in many cases supplemented by special purpose accelerators such as Graphics Processing Units (GPU) that feature similar levels of transistor density. Along with the growth of the number of transistors comes an increased demand of electrical power for the components. Thus, further increases in processing performance to support larger scientific simulations can only be achieved if the efficiency in terms of FLOPs[2] per Watt is increased significantly.

Although energy efficiency for ICT has been thoroughly discussed in the past, only very few HPC sites have implemented versatile power saving methods. Yet, many HPC sites operate systems with thousands of processing cores and the power consumption of the systems is getting more and more important as the number of processors increases. So far, the major drivers for energy efficient ICT have been mobile applications and commercial data centres, which were seeking longer battery runtimes and lower operating costs, respectively. Unfortunately, many of the developed energy saving technologies either do not scale to the size of HPC sites or are not applicable to HPC at all. For example, virtualisation technology has enabled data centres to increase the average usage of their servers notably, thus reducing the total amount of hardware components in use and the overall energy consumption. Yet, since HPC sites typically operate at more than 90% utilisation of their machines anyway, the use of virtualisation technologies is not a feasible way for supercomputing centres to reduce energy consumption.

In this paper, we provide an overview of the existing and future promising techniques to improve the energy efficiency of HPC sites and applications. We introduce key concepts of power awareness and efficiency for both the compute hardware as well as for the surrounding HPC site infrastructure. Therefore, the next section will outline the necessary tools for energy monitoring and control, section 3 will cover possible improvements of the HPC site infrastructure, and section 4 will outline the requirements for energy efficient system hardware and operation management software.

2 Tools for Energy Monitoring and Control

A preparatory step to improve the energy efficiency in HPC consists of the fine-grained assessment of the power consumption of the entire HPC system encompassing not only compute nodes, interconnect networks and storage devices, but also site infrastructure components for cooling, monitoring and power supply. Given a holistic view of the energy consumption over time, ineffective use of components can be spotted and subsequently improved.

An approach for this would be to sample the power consumption of all components at regular intervals and to store the resulting information into a central

[2] FLOPs: Floating-point operations per second.