Motivating Co-ordination of Power Management Solutions in Data Centers

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I. Introduction

Power and cooling are emerging to be key challenges in data center environments. A recent IDC report estimated the worldwide spending on enterprise power and cooling to be more than $30 billion and likely to even surpass spending on new server hardware. Server rated power consumptions have increased by nearly 10X over the past ten years. This has led to increased spending on cooling and power delivery equipment. A 30,000 square feet 10MW data center can need up to five million dollars of cooling infrastructure; similarly, power delivery beyond 60 Amps per rack can pose fundamental issues. The increased power also has implications on electricity costs, with many data centers reporting millions of dollars for annual usage. From an environmental point of view, the Department of Energy's 2007 estimate of 59 billion KWhrs spent in U.S. servers and data centers translates to several million tons of coal consumption and greenhouse gas emission per year. The U.S. Congress recently passed Public Law 109-431, directing the Environmental Protection Agency (EPA) to study enterprise energy use, and several industry consortiums such as the GreenGrid have been formed to address these issues. In addition, power and cooling can also impact compaction and reliability.

II. Power Management in Data Centers

In response to the increased importance of this area, there has been a large body of recent work on enterprise power management. Given the multifaceted nature of the problem, the solutions have correspondingly focused on different dimensions. For example, some studies have focused on average power reduction for lower electricity costs while others have examined peak power management for lower air conditioning and power delivery costs. Previous studies can also be categorized based on (1) the approaches used (e.g., local resource management, distributed resource scheduling, virtual machine migration), (2) the options used to control power (e.g., processor voltage scaling, component sleep states, turning systems off), (3) the specific levels of implementation – chip, server, cluster, or data center level – hardware, software, or firmware, and (4) the objectives and constraints of the optimization problem – for example, do we allow performance loss? Do we allow occasional violations in power budgets?

III. Co-ordination of Power Management Solutions

While a lot of previous solutions such as outlined so far individually address aspects of the enterprise power and cooling problem in isolation, combining these solutions has the potential for synergistic interactions and can better address the dynamic and diverse nature of workloads and systems in future enterprises. However, this requires a carefully-designed coordination architecture. The full or partial overlap in the objective functions and the use of the same or interrelated knobs for power control across the different solutions, often at different time granularities, makes this a hard problem. In the absence of such coordination, however, the individual solutions are likely to interfere with one another, in unpredictable, and potentially dangerous, ways.

Several open questions exist for the design of a coordinated architecture. How should the overall architecture be designed for individual controllers to interact with each other to ensure correctness, stability, and efficiency? How do we combine tracking, capping, and optimization solutions? How do we address the lack of visibility into other controllers and minimize the need to exchange global information? Furthermore, given such a coordinated scenario, there are several implications on the design of the solution. Are all solutions equally important? Does the coordinated architecture allow for functionality of one controller to be subsumed in another controller to enable an overall simpler design? Do the policies and mechanisms at the individual levels need to be revisited in the context of their interactions with other controllers? How sensitive are the answers to the above questions to the nature of the applications and systems considered?

We make two key contributions. First, we motivate and evaluate a preliminary co-ordination architecture for peak and average power management across hardware and software for complex enterprise environments. Our work builds on a control-theoretic approach to unify solutions for tracking, capping, and optimization problems, with minimal interfaces across controllers. Second, using our proposed architecture, we address questions around the trade-offs with different architectures, implementations, workloads, and system design choices.