Shadows on the Cloud: An energy-aware, profit maximizing resilience framework

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1 Introduction

Cloud Computing has emerged as an attractive platform for increasingly diverse compute- and data-intensive applications, as it allows for low-entry costs, on demand resource provisioning and reduced cost of maintaining internal IT infrastructure [1]. Recent studies predict annual growth rate of 17.7 percent by 2016, making cloud computing the fastest growing segment in the software industry.

As the demand for cloud computing accelerates, cloud service providers (CSPs) will be faced with the need to expand their underlying infrastructure to ensure the expected levels of performance, reliability and cost-effectiveness. The direct implication of large datacenters is increased propensity to failure.Failure is the norm rather than an exception at scale [2].

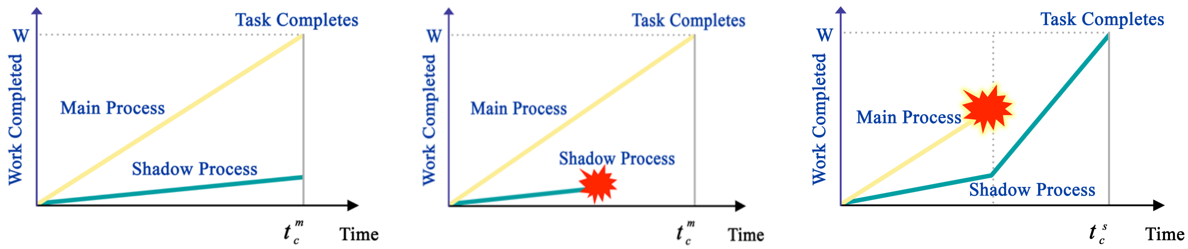
Service Level Agreements (SLAs) has become a critical aspect for a sustainable cloud computing business model. Failure to deliver the service as specified in the SLA subjects the CSP to lose of revenue. In addition, CSPs face rising energy costs of their large-scale datacenters. It is reported that energy costs alone mounts up to $30 billion worldwide [3]. This raises the question of how fault tolerance might impact power consumption and ultimately the expected profit of the CSPs.

Current fault tolerance approaches rely upon either time or hardware redundancy. The first approach requires the re-execution of the failed task, and can result in a significant delay subjecting CSPs to SLA penalties. The second approach runs multiple instances of the same task in parallel to hide failures. This solution, however, increases the energy consumption for a given service, which in turn might outweigh the profit gained by providing the service. The trade-off between profit and fault-tolerance calls for new frameworks to take both SLA requirements and energy awareness in dealing with failures.

In this paper, we address the above challenge and propose an energy-aware, SLA-based profit maximization framework, referred to as "Shadow Replication", for resilience in cloud computing [4]. Similar to the second approach above, Shadow Replication ensures successful task completion by concurrently running multiple instances. However, Shadow Replication executes the main instance of the task at the speed required to maximize profit and uses dynamic voltage and frequency scaling (DVFS) to slow down the replicas, thereby enabling a parameterized trade-off between response time and energy consumption. This allows CSPs to maximize the expected profit by accounting for income, potential penalties and energy cost.

2 Methodology

The basic tenet of Shadow Replication is to associate with each main process a suite of "shadows" whose size depends on the "criticality" of the application and its performance requirements, as defined by the SLA.



(a) No Failure (b) Shadow Process Failure (c) Main Process Failure

Fig. 1. Shadow replication for a single task and single replica

Formally, we define the Shadow Replication fault-tolerance model as follows:

- A main process, $P_m(W, \sigma_m)$, whose responsibility is to completes a task of size W at a speed of σ_m;
- A suite of shadow processes, $P_s(W, \sigma_b^s, \sigma_a^s)$ ($1 \leq s \leq \mathcal{S}$), where $\mathcal{S}$ is the size of the suite. The shadows execute on separate nodes, and start execution simultaneously with the main process at speed σ_b^s ($1 \leq s \leq \mathcal{S}$). Upon failure of the main process, all shadows switch their speeds to σ_a^s, with one shadow being designated as the new main process. This process continues until completion of the task.

To illustrate the behavior of Shadow Replication, we limit the number of shadows to a single process and consider the scenarios depicted in Figure 1, assuming at most one process failure. Figure 1(a) represents the case when neither the main nor the shadow fails. The main process, executing at a higher speed, completes the task at time t_c^m. At this time, the shadow process, progressing at a lower speed, stops execution immediately. If the shadow process fails (Figure 1(b)), it has no impact on the progress of the main process, which still completes the task at t_c^m. Figure 1(c) depicts the case when the main process fails while the shadow is in progress. After detecting the failure of the main process, the shadow begins execution at a higher speed, completing the task at time t_c^s. Given that the failure rate of an individual node is much lower than the aggregate system, it is very likely that the main process will complete its execution successfully, thereby achieving fault tolerance at a significantly reduced cost of energy consumed by the shadow. Even if the main process fails, its associated shadow process can still complete the task with minimal increased delay, thereby minimizing SLA penalty.

3 Conclusion

The main motivation of this work stems from the observation that, as systems become larger and more complex, the rate of failures is highly-likely to increase significantly. Hence, understanding the interplay between fault-tolerance, energy consumption and profit maximization is critical for the viability of Cloud Computing. To this end, we propose Shadow Replication as a novel energy-aware, reward-based computational model to achieve fault-tolerance and maximize the profit.

To assess the performance of the proposed fault-tolerance computational model, an extensive performance evaluation study is carried out. In this study, system properties that affect the profitability of fault tolerance methods, namely failure rate, targeted response time and static power, are identified. Our performance evaluation shows that in all cases, Shadow Replication outperforms existing fault tolerance methods.

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