**Paper: Parasol and GreenSwitch: Managing Datacenters Powered by Renewable Energy**

**Reviewer: Ye Xu**

**A SHORT SUMMARY OF THE PAPER:**

This paper mainly presents the following aspects:

1. It quantified, based on the real datacenter experimental evaluations, the tradeoffs of building a solar and/or wind powered datacenter in the future. Specifically, it discussed the space requirements and the capital cost of these technologies.
2. It demonstrated Parasol, a solar powered micro datacenter. The authors introduced the infrastructure, hardware, software components of Parasol, with quite a few details.
3. It also presented GreenSwitch, the core part of the system to manage workload and energy source. The authors explained in detail how GreenSwitch works, and how to mathematically model each part of the system, as well as the objectives.
4. Finally, the paper gave a couple of experimental results and evaluations. In particular, the authors argued that some of the results and evaluations would be overlooked if a pure simulation or simple prototype would otherwise be used.

**STRENTH AND CONTRIBUTIONS OF THE PAPER:**

This paper has three key contributions:

1. Rather than pure simulation, or a simple prototype, this paper was based on a real physical data center, which was built by themselves. In the process of building up all of the hardware and software systems for the datacenter, the authors were able to make the mathematical model of the system as well as the optimization problem more accurate, including additional sensor and actuator limitations, the minimum battery capacity required during discharge and so forth. More importantly, a couple of experimental results and evaluations would otherwise be overlooked without a real physical plant. For example, the authors argued that GreenSwitch was unable to prevent a slight increase of the peak grid power throughout the day by using batteries and/or solar energy, as its control of the grid draw (done through a limit on current) is not accurate enough. This effect would not be seen under simulation or with a simple prototype that does not include a real grid-tie.
2. The solver of GreenSwitch was mainly based on linear programming. Linear programming is a well-developed area, and the algorithms are available to solve various problems. Because of this general technique, as well as the whole GreenSwitch architecture, future researchers are able to reuse this system without significant modification; only the configurer part and the mathematical modeling of specific optimization problems are needed to be changed. The authors also claimed in the end of the paper that they are currently working on making GreenSwitch publically available.
3. This paper really aimed to solve a practical problem, a.k.a, how to save cost. Since the recent growth in data center caused quite a few environmental and social issues, many companies invested their money to build “green” data centers. But very few, in any, of them paid attention to the management or scheduling of workload and energy source to make high benefit out of this investment. Via GreenSwitch, the authors made a positive prediction of huge electricity cost reduction, and the capital cost in setting up “green” data centers could be amortized in an average of 5 to 8 years from this benefit.

In general, the structure of the paper was clear; the overall technical explanations were easy to understand. However, the paper seems to be unclear regarding to certain details of the technical part. Also, the novelty in terms of research seems to be weak, as would be discussed below.

**WEAKNESS OF THE PAPER:**

1. The whole parasol system is clearly a cyber-physical system (CPS). CPS is a recent growing topic facing quite a few research challenges. This paper, however, didn’t talk anything related to these challenges when building up the system as well as designing GreenSwitch. For example, before equation 3, the authors said “When it is deferrable, the offered load can be delayed within T”. But the authors didn’t mention how to estimate the little “t”. It is true that deferring a job in a later time within its deadline is a typical real time scheduling problem. However, estimation of the period of the periodical task and the average or worst case execution running time can be difficult, depending on a couple of issues, including different data inputs, different CPU power, cache and memory. Things would be more difficult for aperiodical tasks. As a matter of fact, dealing with uncertainty is one of major research challenges in CPS. Not to mention other issues like real time scheduling and fault tolerance. The authors did mention how to predict the power consumption next cycle, at page 6; I think the prediction of period and running time of a deferrable workload might also be the responsibility of the predictor. Therefore, it would be improved if the authors had talked a little bit about cyber physical system issues.
2. The authors claimed that “Given the flexibility to delay loads, GreenSwitch can produce integrated workload and energy source schedules that even more significantly lower electricity costs.” However, it seems unclear what the boundary of “non-deferrable” and “deferrable” workload is. Finding boundary is hard, especially for CPS. It might be the case that at this epoch this workload is deferrable, at another epoch it becomes non-deferrable, due to, for example, some emergent requirement. GreenSwitch itself is clearly a periodical system that runs “every 15 minutes”. Does it require manual modification of deferrable/non-deferrable, or GreenSwitch takes care of it? Or how to define these two terms per se? The paper failed to make it very clear.
3. As for the novelty of the paper, it seems a little bit of weak in terms of research contribution. The reason for this is that normally, in a research paper, it typically takes care of a specific issue, and solves it. This paper, however, put everything altogether and solved everything. But very few among these were new. Linear optimization algorithms, energy resource allocation, workload scheduling, etc, are all very well developed. In particular, linear programming (LP) served as the core algorithm of this paper, which was nothing new at all, although it might be enough to solve the workload and energy management for this particular problem.

In conclusion, this paper took advantage of a well-known technique to solve a practical problem in recent hot topic of “green” data center in both industrial and academic areas. It did raise research interests in the area of scheduling workload and resources in “green” data centers, although the technique and the algorithm used was nothing new. This paper might be improved if the authors mentioned some issues regarding to CPS in general, with which I think they were dealing during their implementations of both physical and cyber part of the system.