Minimizing Energy Cost for Green Cloud Data Centers by Using ESDs

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***Abstract*—In this paper, we study the issue of minimizing the total energy cost for green cloud data centers with time varying and location varying electricity prices and supply of renewable energy. Given the budget of energy cost, schedule the requests, servers, and power usage of different sources, such that the total cost can be minimized. We formulate the problem during the whole period of time as an MILP problem. We use Cplex to solve the problem. Experiment shows that our method can significantly reduce total cost after using ESDs.**

***Index Terms*—Green Scheduling, Data Center, Renewable Energy, Energy Storage Devices, Carbon Emissions**

I. Introduction

The high energy consumption of cloud data centers has aroused great concern on environmental implications, because most of electricity is generated by burning fossil fuels. In view of this, some Internet operators like Google and Yahoo try to build their own solar or wind farm. On the one hand, the total carbon emissions can be reduced by using renewable energy; on the other hand, the self-generated renewable energy is usually much more cheaper than that from the power grid.

In this paper, we study the problem of how to dispatch the users' requests to each data center so that the total cost can be minimized. Different from [1], we assume each data center has its own power plant with wind turbines and solar panels, as can be seen in Figure 1. We consider using ESDs to store the intermittent renewable energy, so that both the energy cost and carbon emissions can be reduced. We also use ESDs to store energy from grid when its price is low, and discharge when its price is high. However, it is hard to decide how much to charge energy of each type into ESDs and how much to discharge from ESDs in each time slot. It depends on the supply of renewable sources, delay time of requests, and electricity prices in different locations. Our problem is formulated as an MILP problem, and solved using Cplex. For each data center in each time slot, our solution determines: 1) the number of requests dispatched to each data center. 2) the usage of each type of energy, including charging and discharging, and that directly power data centers. 3) the number of active servers. Experiments show our method using ESDs to store energy can significantly reduce total energy cost.

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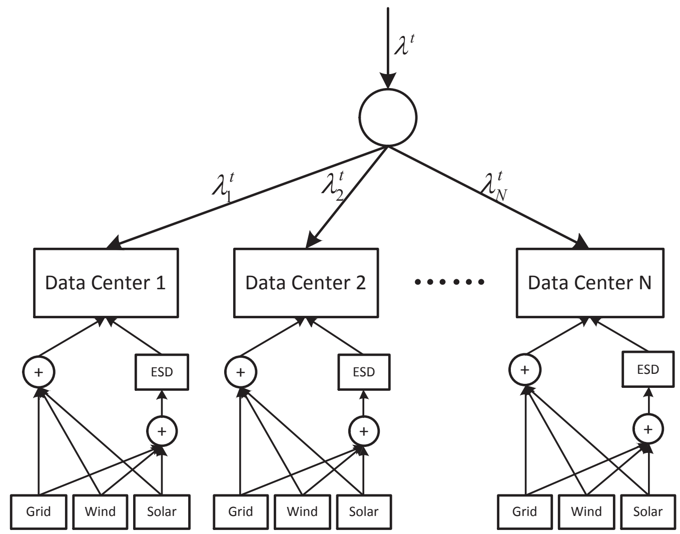

Fig. 1. Architecture of green scheduler

II. Problem Formulation and Solution

Suppose there are N data centers, the running period of our scheduler is T time slots, for each slot t, $t \in \{1, 2, ..., T\}$. Let Qw_i^t, Qs_i^t, and Qg_i^t denote the price of wind, solar and grid energy for data center i in time slot t, Sw_i^t, Ss_i^t, and Sg_i^t denote the actual usage of each type of energy, respectively. The objective function is to minimized total energy cost C, represented as (1). The actual usage of each type of energy can be further decomposed into the energy to directly power data centers, denoted as Pw_i^t, Ps_i^t, Pg_i^t, respectively, and the energy to charge into ESDs, denoted as Rw_i^t, Rs_i^t, and Rg_i^t, respectively. The usage of energy should be within the upper bound of its supply, denoted as $Sw_{i,max}^t$, $Ss_{i,max}^t$, $Sg_{i,max}^t$, respectively, so we have (2)$\sim$(4).

For each time slot t, let λ^t denote the number of users' requests. Let λ_i^t denote the number of requests dispatched to data center i, it should be within the processing capacity of active servers in this data center. Thus, we have (5)$\sim$(7), where $\mathbb{N}$ denote natural number, x_i^t denotes the number of active servers with service rate μ_i (requests per second), and M_i denotes the maximum number of servers of data center i. The QoS in our model is the average response time of requests, which is composed of the transmission delay from scheduler to data center, waiting time, and processing time. Let $R_{i,max}$

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denote the constraint of QoS, d_i denote the transmission time from the scheduler to data center i, so we have (8) using M/M/n queuing model.

Let E_i^t denote the amount of energy stored in ESDs of data center i during t, which should be within its capacity $E_{i,max}$, so we have (9). The discharged energy, denoted as D_i^t, should be no more than E_i^t, so we have (10). The amount of energy that can be charged into ESDs should not exceed its remained capacity, so we have (11). For each time slot, the energy stored in ESDs should be represented as (12). The energy to power data center i should equal the energy requirement of the requests dispatched to this data center, so we have (13), where P_i^t denotes the total power consumption of data center i in time slot t, which can be calculated like this [2]:

$$P_i^t = x_i^t \cdot [P_{idle} + (P_{peak} - P_{idle}) \cdot (\lambda_i^t/(x_i^t \cdot \mu_i))] \cdot \rho_i,$$

where ρ_i denotes the PUE of data center i. The formulation of our problem is in the following:

$$\textbf{Minimize:} \quad C = \sum_{t=1}^{T} \sum_{i=1}^{N} [Sw_i^t \cdot Qw_i^t + Ss_i^t \cdot Qs_i^t + Sg_i^t \cdot Qg_i^t] \quad (1)$$

$$\textbf{Subject to:} \quad 0 \le Sw_i^t = Rw_i^t + Pw_i^t \le Sw_{i,max}^t \quad (2)$$

$$0 \le Ss_i^t = Rs_i^t + Ps_i^t \le Ss_{i,max}^t \quad (3)$$

$$0 \le Sg_i^t = Rg_i^t + Pg_i^t \le Sg_{i,max}^t \quad (4)$$

$$\lambda^t = \sum_{i=1}^{N} \lambda_i^t, \;\; (\lambda_i^t \in \mathbb{N}, \; \forall i \in \{1, ..., N\}) \quad (5)$$

$$0 \le \lambda_i^t \le x_i^t \cdot \mu_i \quad (6)$$

$$0 \le x_i^t \le M_i, \quad (7)$$

$$\frac{1}{\mu_i x_i^t - \lambda_i^t} + \frac{1}{\mu_i} + d_i < R_{i,max}. \quad (8)$$

$$0 \le E_i^t \le E_{i,max}, \quad (9)$$

$$0 \le D_i^t \le E_i^t \quad (10)$$

$$0 \le Rw_i^t + Rs_i^t + Rg_i^t \le E_{i,max} - E_i^t \quad (11)$$

$$E_i^{t+1} = E_i^t - D_i^t + (Rw_i^t + Rs_i^t + Rg_i^t) \quad (12)$$

$$Pw_i^t + Ps_i^t + Pg_i^t + D_i^t = P_i^t \quad (13)$$

From the above modelings, our problem is formulated as a MILP problem during the whole period of time. Thus, we can solve it using *Cplex* solver, an efficient tool for MILP problem.

III. Performance Evaluation

Our simulation is based on traces from real world. We use the same climate data, fluctuating electricity prices, and statistical requests as [3]. The time duration is from June 1st to June 30st in 2014. We assume there are 50K BP-MSX-120 solar panels and 1000 NE-3000 wind turbines to power each data center. The QoS constraint is 1 second for all data centers. The investment of wind turbine and solar panel is fixed, so we only need to consider the operation cost for solar and wind, which is 10$/MWH for all data centers [4]. The maximum energy supply from grid is 5 times of the maximum power of this data center. We use similar parameters for our 4 data centers like that in [5], as can be seen in Table I.

TABLE I
Parameters of Internet Data Centers

i	μ_i	M_i	d_i	P^i_{peak}	P^i_{idle}	ρ_i
1	1.75	4500	0.20	140	84	1.3
2	1.50	5000	0.25	90	54	1.5
3	1.25	6000	0.10	34	20.4	1.7
4	2.00	4000	0.15	150	90	1.3

Let the unit capacity of ESD be denoted as *Uhour*, which equals to the total energy of the data center running in peak power for one hour. We have:

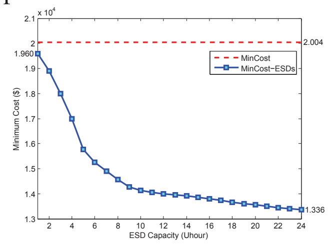

Fig. 2. Comparison of Minimum Cost

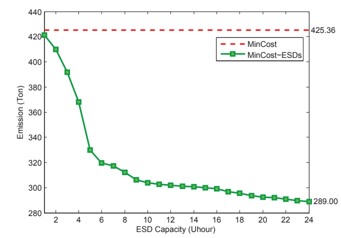

Fig. 3. Comparison of Emissions

Figure 2 compares the minimum cost of that using ESDs and that without using ESDs. Using ESDs can significantly reduce total cost, reaching to more than 30% when ESD is very large (like 24 *Uhours*). To show the greenness of data centers after using ESDs, we calculate carbon emissions using method in [3]. In minimizing energy cost, the carbon emissions can also be greatly reduced after using ESDs, as can be seen in Figure 3. ESDs will always store as much renewable energy as possible, and it also stores cheap energy from grid and discharge when necessary. From the two Figures, we found that larger ESDs will always brings more reduction in energy cost and carbon emissions. The reduction of cost and emissions become smaller after the capacity of ESDs reaches a certain threshold, because ESDs have enough capacity to store sufficient cheap energy to meet users' requirement in energy.

IV. Conclusion

We propose a new scheduling architecture for green cloud data center, based on which we study the problem of minimizing total energy cost. We consider using ESDs to store as much renewable energy as possible due to its low price and carbon emissions, and we also use ESDs to store energy from grid, such that the energy cost can be minimized by leveraging its fluctuating prices. Experiments show that our scheduler using ESDs can significantly reduce energy cost for green cloud data centers. Lager ESDs will always bring more reduction in both cost and emissions.

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