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Towards energy management in Cloud federation: A survey in the perspective of future sustainable and cost-saving strategies

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A B S T R A C T

Nowadays, the increasing interest in Cloud computing is motivated by the possibility to promote a new economy of scale in different contexts. In addition, the emerging concept of Cloud federation allows providers to optimize the utilization of their resources establishing business partnerships. In this scenario, the massive exploitation of ICT solutions is increasing the energy consumption of providers, thus many researchers are currently investigating new energy management strategies. Nevertheless, balancing Quality of Service (QoS) with both energy sustainability and cost saving concepts is not trivial at all. The growing interest in this area has been highlighted by the increasing number of contributions that are appearing in literature. Currently, most of energy management strategies are specifically focused on independent Cloud providers, others are beginning to look at Cloud federation. In this paper, we present a survey that helps researchers to identify the future trends of energy management in Cloud federation. In particular, we select the major contributions dealing with energy sustainability and cost-saving strategies aimed at Cloud computing and federation and we present a taxonomy useful to analyze the current state-of-the-art. In the end, we highlight possible directions for future research efforts.

1. Introduction

Nowadays, there is an increasing interest regarding energy management in Cloud computing. The growing success of Cloud computing is mainly due to its better flexibility, reliability, and scalability than traditional information and communication technology (ICT) systems and the capability to satisfy the worldwide demand of highly specialized and customized services. In the context of ICT processes, the cost of energy is one of the major factors for determining the cost of services provided to users. Typically, such a cost is due to the management of the infrastructure and human resources. Data processing, storage, and transport imply the use of a set of devices that use electricity for various reasons. In fact, the cost of energy is typically due to ICT equipments, electrical equipments, and cooling equipments. In this context, if on one hand, we are observing an increasing globalization in supplying ICT services, on the other hand, there is an increment in the complexity of ICT systems to fulfil the requests of more customized solutions. The Digital Agenda for Europe (DAE) [1] has recently identified the priorities on digital technologies for years 2013–2014. In particular, priority No. 6 stresses the need to “accelerate Cloud computing through public sector buying power”. At the same time, the *National Energy Research Scientific Computing Center (NERSC)* at the U.S. Department of Energy (DOE) has tested the effectiveness of Cloud computing in terms of energy efficiency. Energy management is, in fact, one of the major keywords in the Cloud computing literature [2], including two main aspects that are

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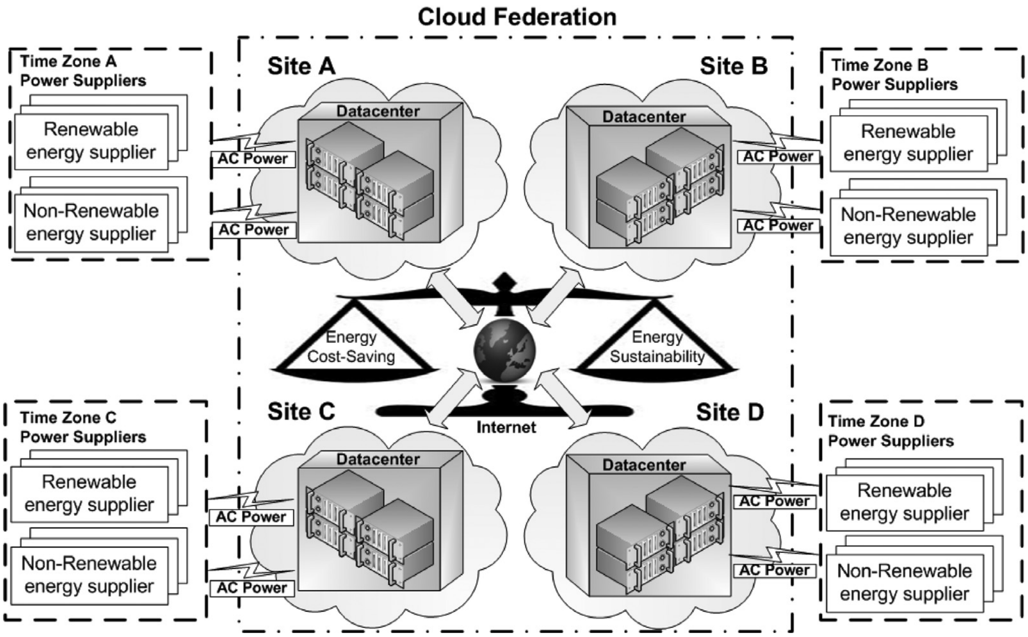

Fig. 1. Energy efficiency in the perspective of Cloud federation.

generally uncorrelated: energy costs-saving and energy sustainability. Another interesting aspect is the energy market (and the electrical energy market in particular) is becoming highly dynamic, both in terms of cost and quality of provisioning. The advent of the free market and the increasing widespread utilization of primary renewable energy sources along with the continuous necessity to balance the distribution in power grids is changing the way to provide energy. In the recent decade, new solutions for energy production have modified the dynamics of the market, leading to new forms of agreements between providers and consumers, in a way that is very different from the past. By now, the management policies of the electricity market have been developed according to the automated demand response (ADR) paradigm [3,4], where energy providers and consumers dynamically fix their production/management policies according to the current market conditions. As a consequence, it is possible to carry out a dynamic management of ICT services following the ADR principles. In this panorama, considering the ICT processes, the cost of energy is one of the major factors that has to be considered for pricing services offered to end-users. Data processing, storage, and transport imply the usage of a set of devices that consume electricity for different purposes. This energy consumption is typically due to power supply of ICT, electrical, and cooling equipments.

Currently, a wide variety of contributions are available in literature focusing on energy efficiency in Cloud computing. However, many existing surveys have tried to assess the energy management issues only focusing on data centers (DCs) needs, see [5–8]. Indeed, most of the analyzed scientific contributions focus on how to reduce the waste of energy in DCs and they are not specific to the Cloud. Considering Cloud computing, scientific contributions have regarded mainly solutions that are confined in the DC of an independent Cloud provider managed by a specific administrative domain of an organization. In this scenario, independent Clouds can be viewed as “isolated islands in the ocean of Cloud computing”. At the same time, there is an increasing number of scientific contributions oriented to Cloud federation. Differently from independent Clouds, a Cloud federation considers an ecosystem of different providers that are interconnected in a cooperative decentralized computing environment. Thus, activities and services are driven by specific agreements in an ubiquitous system. The increasing interest of both industrial and academic communities toward Cloud federation is opening to new business opportunities especially for small and medium enterprises. Cloud federation allows providers to optimize their ICT resources and services over a world-wide extended area taking advantages of dynamic and elastic management of physical resources, and even more taking into consideration the dynamic energy management strategies. Fig. 1 shows an example of Cloud federation including four providers interconnected through the Internet, powered by renewable and/or no renewable energy suppliers. In this case, the scale in the centre of Fig. 1 highlights how providers need to find the right trade-off between energy cost-saving and sustainability.

Differently from existing surveys, the main contribution of our paper is twofold: (1) providing the first survey focused on energy management in Cloud computing and federation; (2) highlighting the current research trends falling into energy sustainability and energy cost-saving strategies in Cloud federation. For a comprehensive assessment we collected and analyzed the main scientific contributions focusing on energy management in Cloud computing. Moreover, the survey was also thought gathering the published scientific contributions that will be useful to Cloud federation architects that need to plan in advance future energy sustainability and energy cost-saving strategies. To this end, by starting from the current state-of-the-art on Cloud