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Energy-aware cloud computing

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ABSTRACT

Cloud computing, as a trending model for the information technology, provides unique features and opportunities including scalability, broad accessibility and dynamic provision of computing resources with limited capital investments. This paper presents the criteria, assets, and models for energy-aware cloud computing practices and envisions a market structure that addresses the impact of the quality and price of energy supply on the quality and cost of cloud computing services. Energy management practices for cloud providers at the macro and micro levels to improve the cost and reliability of cloud services are presented.

1. Introduction

The emerging cloud computing model facilitates access to computing resources for end users through the internet. Cloud computing is a model that enables on-demand access to the shared pool of customizable computing resources (e.g. servers, storage, networks, and applications) and services (Mell and Grance, 2011). These resources can be rapidly deployed with minimal management efforts and marginal interactions with the service providers. Providing dynamic computing resources in the cloud computing paradigm enables corporations to scale up/down the provided services, considering their clients' demand and the cost of the leveraged resources that contribute to the operational cost of the information technology (IT) facilities. The scalability of the cloud services enables smaller businesses to benefit from different categories of expensive computing-intensive services that were once exclusively available to large enterprises. Cloud computing remedies the IT barriers, especially for small and medium-sized enterprises, and provides efficient and economical IT solutions as the cloud providers develop tools and skills to exclusively focus on handling the computational and IT challenges. With marvelous effects of cloud computing on the IT industry, large enterprises such as Google, Amazon, and Microsoft endeavor to establish more powerful, reliable, and economically efficient cloud computing platforms.

The backbone of cloud computing is data centers. Cloud computing is achieved by establishing distributed data centers that consume a significant volume of energy. Data centers leverage advanced energy management solutions to achieve the targeted computing reliability and economic efficiency. This paper presents the envisioned market structure for energy-aware cloud computing that incorporates energy management strategies at multiple physical layers. The structure of this paper is as follows: Section 2 details the structure of cloud computing, including the various categories and layers of cloud computing, as well as different types of provided services. Section 3 surveys the impact of cloud computing on the quality and cost of the provided services in different sectors, the price of cloud computing services, and the notion of a cloud computing market. Section 4 explores energy management strategies at the macro level, including the interdependence of the cloud computing market and the wholesale electricity market. Energy management practices at the micro level, including the energy management practices in the data centers, are discussed in Section 5. Section 6 concludes.

2. Structure of cloud computing

The clouds are divided into four major models with distinct operational schemes: the public cloud, private cloud, hybrid cloud, and community cloud. In public clouds, the cloud computing resources are available to the public at the cost of lower security and privacy for the end users. Such models are not utilized by enterprises with high reliability and security requirements. In private clouds, the cloud computing resources are exclusively available to a single organization where the highest degree of control over performance, reliability, and security is offered to the end users at considerable operational cost. In this model, end users benefit from most features of cloud computing. In the hybrid cloud model, private IT resources dedicated to an enterprise are integrated with the public cloud. In this architecture, public and private infrastructure systems operate independently and communicate over the encrypted connections. This architecture enables the companies to store the protected data on private clouds while leveraging the computational resources in the public cloud to run applications that rely on

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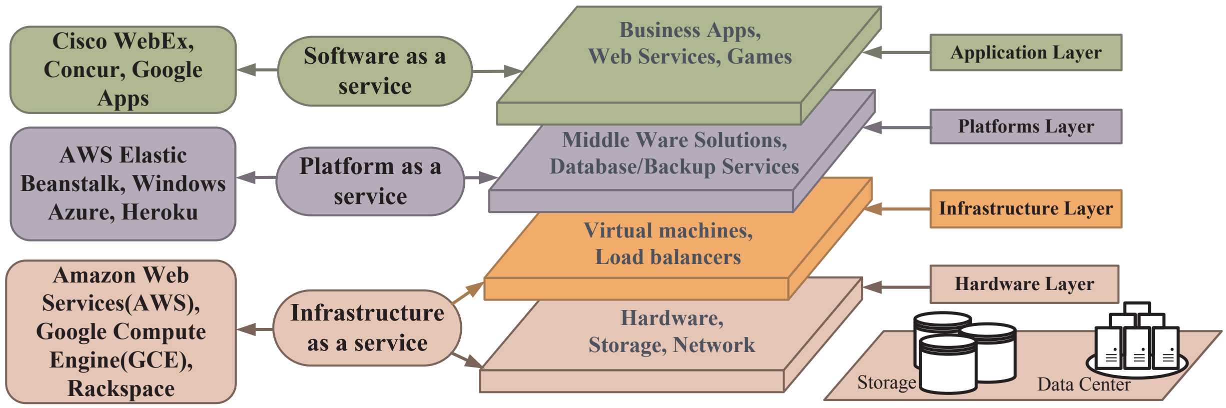

Fig. 1. Structure of cloud computing.

the stored data. Such practices enhance the privacy and security of the data, as the data exposure to public domains is minimized. Furthermore, this architecture enables private corporations to leverage the resources of the public cloud once their computing workloads exceed the computation capacity of the private cloud. Consequently, extra computing capacity could be acquired when such resources are needed. In community cloud architecture, the cloud computing services with their corresponding costs are mutually shared among several organizations with common apprehensions, privacy, and security requirements within a community. Example of such organizations include banks and trading firms such as NYSE Capital Markets Community; government organizations such as organizations in the State of California that share the computing infrastructure on the cloud to manage state residents' data; and the healthcare community cloud such as the QTS healthcare community cloud (HCC), which is designed to meet the unique needs of the healthcare industry.

The structure of cloud computing is presented in the following four layers: (1) the hardware layer, (2) the infrastructure layer, (3) the platform layer, and (4) the application layer. Fig. 1 shows the layers of the cloud computing structure along with the cloud computing services provided at each layer.

The *application layer* rests on the top of the cloud computing architecture. The application layer is the most visible layer for end users and contains the cloud's actual applications such as Google Apps, email, calendaring, and office tools (e.g. Microsoft Office 365). The *platform layer* is where the programming-language-level interface is supplied in forms of operating systems and application frameworks to facilitate application deployment in cloud environments. The *infrastructure layer* is where virtualization technologies are employed to assign the required computing and storage resources dynamically. Examples of virtualization technologies include Xen (Xen, 2018), KVM (Kernal Based Virtual Machine, 2018) and VMware (VMWare ESX Server, 2018). The *hardware layer* is established at data centers that consist of different physical components such as servers, routers, switches, as well as electricity and cooling infrastructure. Such assets are managed and controlled by energy management systems. This architecture is perceived as a service-oriented model where each layer provides services to the above layer. In this perception, the services provided in cloud computing paradigm are categorized into three types: *Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS)*. In IaaS, the computing resources, storage, and networking capabilities of service providers are offered to customers through a web-based graphical user interface. These services enable customers to leverage the required infrastructure for IT operation management. Amazon EC2, GoGrid, and Flexiscale are examples of IaaS providers. In PaaS, a platform is provided to allow customers to develop, execute, and manage applications without dealing with the complexities of building and maintaining the infrastructure associated with the development environments. Examples include Google App Engine and Microsoft Windows Azure. SaaS is a software licensing and delivery model in which the service providers host, manage, and offer the applications to customers over the internet at any time on a pay-for-use basis. SaaS eliminates the need for organizations to install and run applications on their own servers. Examples of SaaS providers include Rackspace, Hipchat, Trello, and Intercom.

3. Quality and cost of cloud computing services

In today's fast-paced world, different industries, businesses, and sectors require high standards of IT performance with an escalating burden of computing capabilities to enhance the quality of their services and products. As it is difficult and expensive for most businesses to build and maintain their own IT assets, they outsource such requirements to cloud providers that handle their considerable computing needs. The automotive, energy, manufacturing, education, entertainment, transportation, and healthcare sectors, as well as financial and insurance companies, are among the businesses that have embraced cloud computing for their day-to-day operation. Shop Direct, one of the UK's largest online retailers, adopts a hybrid cloud model to increase flexibility and reduce the response time to deliver more than 48 million products a year. Marriot International shifted toward cloud computing in today's internet era to meet the needs of travelers. Energy companies such as Shell Oil are using cloud services to manage and analyze the massive volume of geographical data granted from an installed base of sensors to detect and extract oil. Another important application of cloud computing is smart power grids. The smart grid is a combination of power networks with intelligent entities that cooperate, communicate, and interact with each other to effectively deliver electricity to consumers. Achieving these objectives requires advanced technology for supporting mutual communication between the electric utilities and customers and processing real-time data for effective energy management strategies. Cloud computing provides the required computation asset for managing and processing the data collected from millions of smart meters in secure, reliable, and scalable manner. Considering the trending tendency toward cloud computing in various sectors, the reliability, security, and economic efficiency of cloud computing have a considerable impact on the performance and objective measures in these sectors and consequently the social welfare. The vulnerability and risks associated with cloud computing services impact the quality and reliability of the cloud services that are provided for these sectors. As cloud technologies continue to mature, they share the same types of issues with in-house computing systems. However, any failure in the cloud computing services affects a larger population of users and has higher visibility compared to private in-house computing infrastructure systems. For instance, in November 2014 the Azure storage service was hit by a massive outage as a result of software updates for performance