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Tradeoff between energy and user experience for multimedia cloud computing ☆

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ABSTRACT

Cloud computing provides an effective approach to deliver multimedia services to end users with the desired user quality of experience (QoE). However, cloud-based multimedia applications require many of servers and consume huge energy. To reduce energy consumption, a multimedia service provider (MSP) should balance the energy and QoE. In this paper, a theoretic model is developed to explore the trade-off between energy consumption and QoE for multimedia cloud. Based on objective factor, a QoE quantifying model is proposed. Employing Lyapunov Optimization techniques, an optimal control framework is designed and analyzed to make energy and QoE decisions in MSPs. An approximate online algorithm (EUE-RP) is proposed with the explicitly provable performance upper bound. Extensive experiments have been conducted to verify the effectiveness of EUE-RP algorithm in the practical settings. The algorithm can guarantee desired QoE and reduce energy consumption, even without any information about the future fluctuation of user demands.

1. Introduction

Multimedia computing has emerged as a noteworthy technology to provide rich media services, such as video surveillance, real-time access of medical images and video, photo and video sharing. Multimedia applications and services typically require intensive computation and/or storage resources, which are burdens to devices of end users. Recently, cloud computing has been regarded as a promising infrastructure to provide desired resources and provisioning QoS for multimedia services. Multimedia cloud [1] is a specific cloud computing paradigm, focusing on how cloud can effectively support multimedia services. In the cloud-based multimedia system, users are able to process and store multimedia applications in the cloud and alleviate requirement of multimedia software installed in users' devices. The elastic and on-demand features of resource provisioning in cloud effectively meet the intensive resource demands of multimedia processing.

Multimedia cloud confronts new critical issues. In addition to a large of computational resources, another important factor for multimedia services is the stringent Quality of User Experience (QoE) requirement. Due to poor users' experience, users maybe resort to a competitor's services and affect their perception of the company's products and the company itself. QoE as perceived by users has the potential to become the guiding paradigm for managing quality in the cloud environment. Ensuring that the users' experience remains as good as it was before adoption will be one of the key factors in promoting new

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cloud services and migrations of existing ones [2]. Although multimedia QoE has been studied for a long time, there are open issues for which no answers is yet available, especially when considered in the cloud environment [2].

Multimedia applications always require a mass of servers and consume a great portion of energy in cloud computing. With the presence of unpredictable and burst application demands, the objectives of such a Multimedia Service Providers (MSP) are two-fold: (1) maximize the QoE of end users to improve its competitiveness in the market; (2) minimize power consumption of servers to reduce operation cost. There is a clear trade-off between the energy cost of computational resources and the achieved QoE of end users. Such trade-off is due to the fact that minimizing data center's energy cost is achieved essentially by turning off some servers, scaling down CPU clocks, or migrating some workload, which can all potentially lead to degrading the QoE offered by MSPs and consequently its income, considering the stochastic nature of workload. In this paper, our purpose is to provide guidelines for MSPs on how to minimize the power consumption while still guarantee QoE of users when processing user requests in order to improve their competitiveness in the market. Since the multimedia cloud application operates is randomly changing over time and the distribution of the underlying stochastic process is often unknown a priori, it is a challenge for MSPs to perform a desired trade-off.

In this paper, a theoretic model is developed to explore the trade-off between the energy consumption and the achieved QoE for cloud-based multimedia streaming application. The problem is formulated into an optimization problem of system energy consumption and user QoE. This paper aims to optimize the time average of the energy consumption and the achieved QoE of end users. By using the Lyapunov optimization framework [3], a new optimal online control framework is designed and analyzed to make all two decisions in MSPs. An approximate online algorithm, called EUE-RP, is proposed with the explicitly provable performance upper bound. The proposed algorithm also has low complexity by exploiting the structural properties of the optimal solution. Extensive experiments have been conducted to verify the effectiveness of our proposed EUE-RP algorithm in the practical settings. The algorithm can guarantee desired QoE and reduce energy consumption, even without any information about the future fluctuation of user demands.

The rest of this paper is organized as follows. Related work is reviewed in Section 2. Section 3 describes the system model. In Section 4, we develop a provably-efficient online resource provisioning algorithm to balance user experience and energy consumption. Experiment results are shown in Section 5 and finally, concluding remarks are offered in Section 6.

2. Related work

In this section, we review the existing related works from three perspectives: multimedia cloud service, energy-aware studies in multimedia cloud and studies of QoE.

2.1. Multimedia cloud service

Multimedia services have strong demands for cloud computing and cloud-based multimedia services have been widely studied in recent years. Nan et al. [4] proposed optimal resource allocation policies for multimedia cloud in both single class service case and multiple-class service case based on queuing model. In each case, the response time minimization problem and resource cost minimization problem is formulated and solved, respectively. Compared with this work, our paper focuses on how to assure the QoE of end users keeping at a reasonable level. Sujit and Wang [5] proposed an approach which enables multi-player games on mobile devices, called cloud mobile gaming. In cloud mobile gaming, the computation intensive tasks, like three-dimensional model rendering, are executed on cloud servers in response to the control commands from players, and the rendered frames are compressed and streamed to mobile devices as video streaming. Ref. [6] proposed a novel cloud multimedia streaming architecture, which provides dynamic adjustable streaming services. Considering mobile device resources, multimedia codec characteristics and the current network environment, a stream dispatcher is designed with the adaptable codec approach to calculate the most suitable segment for mobile devices in time. Aggarwal et al. [7] seeked to lower a provider's costs for real-time IPTV services through a virtualized IPTV architecture and through intelligent time-shifting of selected services.

2.2. Energy-aware studies in multimedia cloud

With more and more multimedia services on cloud, there is an upsurge of research interest in energy consumption for cloud-based multimedia services. Ren and van der Schaar [8] explored a cloud-based stream mining system, which the mobile devices send via wireless links unclassified media streams to the cloud for classification. In order to minimize the affine combination of classification cost and energy consumption at the cloud, an online algorithm is developed. The cloud operator can dynamically adjust its resource provisioning, and the mobile devices can adapt their transmission rates to the instantaneous channel conditions. Compared with this paper, our approach focuses on the study of the trade-off between QoE of user and the system energy consumption. Ghamkhari and Mohsenian-Rad [9] proposed a systematic approach to maximize green data center's profit. The model incorporates various other factors such as availability of local renewable power generation at data centers and the stochastic nature of data centers' workload. A novel optimization-based profit maximization strategy is proposed for data centers for two different cases, without and with behind-the-meter renewable generators. Xiao et al. [10] presented an energy-efficiency enhanced virtual machine (VM) scheduling policy, with the