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Managing mobile cloud computing considering objective and subjective perspectives

Marcelo Antonio Marotta [a], Leonardo Roveda Faganello [a], Matias Artur Klafke Schimuneck [a], Lisandro Zambenedetti Granville [a], Juergen Rochol [a], Cristiano Bonato Both [b,*]

[a] Institute of Informatics – Federal University of Rio Grande do Sul Av. Bento Gonçalves, 9500 – Porto Alegre, RS - Brazil
[b] Federal University of Health Sciences of Porto Alegre, Brazil Av. Independência, 2293 – Santa Cruz do Sul - RS / Brasil

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ABSTRACT

Mobile Cloud Computing enables mobile devices to augment constrained resources such as processing, storage, and battery autonomy by using the cloud infrastructure. As the network is a key element in integrating mobile devices to the cloud, a proper management of the mobile cloud computing environment is necessary. Such a management must take into account two main perspectives: administrator's and end-user's perspectives. The administrator is usually concerned with a more objective perspective based on Quality of Service parameters, such as throughput, delay, and jitter. On the other hand, the end-user has a more subjective perspective, observing his/her Quality of Experience when using a mobile cloud application or service. In this article, we introduce a management model and architecture for mobile cloud computing, exploiting both objective and subjective perspectives. As a proof of concept, we prototyped the architecture in a management system called CoLisEU, which allowed us to investigate this architecture and we discuss the benefits of the combined objective and subjective perspectives in our management architecture.

1. Introduction

Mobile Cloud Computing (MCC) is the paradigm that integrates mobile devices and cloud computing. MCC allows the augmentation of mobile devices' constrained resources, such as processing, storage, and battery autonomy by using cloud services [1]. Counting on augmented resources, mobile devices can execute more sophisticated versions of key applications and services, such as mobile learning, e-commerce, and healthcare [2]. This is possible because tasks in MCC are partially performed in mobile devices and partially computed in the cloud. The network that interconnects mobile devices and the cloud largely impacts the proper execution of MCC applications and services. Besides, this network also allows MCC to perform a second augmentation, now in terms of coverage, extending the cloud towards the edge of the network, where the mobile devices and End-users lie [3]. In this article, we address the important issue of managing the MCC environment, focusing on the networking aspects. Such a management must take into account two main perspectives: the network Administrator's perspective and the End-user's perspective.

The Administrator is usually concerned with Quality of Service (QoS) parameters (*e.g.,* throughput, delay, and jitter [4]), which provide an *objective* view about the quality of the network. By observing QoS-related measurements, the Administrator can tune the operation of underlying

* Corresponding author. Tel.: +55 5193080875.
E-mail addresses: mamarotta@inf.ufrgs.br (M.A. Marotta), lrfaganello@inf.ufrgs.br (L.R. Faganello), makschimuneck@inf.ufrgs.br (M.A.K. Schimuneck), granville@inf.ufrgs.br (L.Z. Granville), juergen@inf.ufrgs.br (J. Rochol), cbboth@ufcspa.edu.br, cbboth@inf.ufrgs.br (C.B. Both).

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infrastructures, including wireless infrastructure, backhaul, backbone, provider infrastructure, and cloud infrastructure [1]. The End-user, in turn, tends to neglect QoS parameters and focus instead on his/her experience when using an MCC application or service. This experience can be measured by observing Quality of Experience (QoE) parameters, such as satisfaction level with application navigation, response time, and cloud ubiquity [5]. Since each End-user has a personal experience, QoE parameters provide a *subjective* view about MCC applications and services. Although different to the objective view obtained from QoS observation, the subjective, QoE-based observation of MCC is also important because it is directly related to the applications and services consumed by the End-user.

The combined observation of QoS and QoE parameters are fundamental to the management of MCC. However, such management is still underexploited by the research community. Some preliminary investigations point out that QoS and QoE can serve as guiding paradigms [6,7] for improving MCC management [8]. Other investigations focus on proposing architectural models for MCC management that are centered on the End-user [9,10] or on cloud applications [2], but neglect QoE parameters. Therefore, there is a need for concrete architectural models that explicitly take into account both QoS and QoE together.

In this article, we investigate the management of MCC through an architecture that considers both objective (QoS-based) and subjective (QoE-based) perspectives. In Section 2, we review MCC basic concepts, as well as the state-of-the-art on MCC management. Afterwards, we highlight five key requirements for managing the MCC environment. Next, a mapping of traditional management entities (*i.e.,* agent, gateway, and management application) to the MCC environment is introduced. In Section 3, we describe a management architecture that explicitly takes into account both QoS and QoE. As a proof of concept, in Section 4, we prototyped the proposed architecture in a management system called CoLisEU,[1] whose details are presented in the article as well. To evaluate our prototype, in Section 5, we analyze one thousand samples provided by End-users about their satisfaction using a wireless infrastructure to request cloud services. Finally, the benefits of the combined analysis of QoS and QoE in our MCC management architecture are summarized in the concluding section.

2. Mobile Cloud Computing

In this section, we present the components of an MCC infrastructure. Next, we present the state-of-the-art of the MCC management. Afterwards, we detail key management requirements considering the MCC environment.

2.1. MCC infrastructure

MCC enables the augmentation of computing resources of mobile devices in an environment composed of the following infrastructures: (*i*) *wireless infrastructure*, (*ii*) *backhaul*, (*iii*) *backbone*, (*iv*) *provider infrastructure*, and (*v*) *cloud infrastructure*. These components are depicted in Fig. 1. The *End-user*, through his/her *Mobile Device* establishes communication with a *Base Station* or an *Access Point*, requesting a resource (*e.g.,* storage or processing) augmentation from the cloud. This request may be based on different wireless technologies, such as LTE or WiFi. After reaching the *Base Station/Access Point*, the request is forwarded through the *Backhaul* to an Internet Service Provider (ISP).

The *Backbone* routes the request along different ISPs. When the request reaches the destination ISP, it accesses the *Provider Infrastructure*. This infrastructure is similar to the *Backhaul*, only with typically larger capacity links. The target Cloud then receives the request and allocates resources inside the *Cloud Infrastructure*. In the Cloud, virtual nodes communicate with one another through virtual links. These links are created by the Cloud administrators as an abstraction of the real network links with specific characteristics, such as capacity, routing protocol, and virtual node endpoints. Finally, the Cloud provides the requested resources, replying to the *Mobile Device* across the five infrastructures.

Each infrastructure presents different problems, such as intermittent wireless signal, insufficient coverage areas, traffic overhead, non-optimal service level agreements, and virtual link misconfiguration [11]. These problems may degrade both QoS and QoE. To try to avoid this degradation, MCC management must monitor each infrastructure to detect these problems. When problems are detected, MCC management reconfigures and tunes the internal components of the five infrastructures, in order to lead the network to a state that again satisfies the *End-user* expectations, thus keeping QoE at satisfactory levels.

2.2. MCC management

MCC extends from the *End-user* to the *Cloud Infrastructure*. Therefore it is important that the MCC management strategy takes into account the perspectives of both the *Administrator* and *End-user*. The *Administrator* has a more objective view of the managed network, typically observing QoS parameters to detect specific problems, such as link bottlenecks or network node inactivity [4]. However, solely relying on QoS parameters may cause Administrators to be unaware of whether the *End-user* expectations are fulfilled (*i.e.,* QoE). As opposed to Administrators, *End-users* have a more subjective perspective of the network, based on QoE. As such, aspects that escape the Administrator's objective analysis (*e.g.,* satisfaction level, network efficiency, and Cloud ubiquity), end up being confined to the End-user's point-of-view. That, however, is inadequate and QoE must be observed too. On the opposite side, QoE evaluation alone is not able to accurately point out specific problems in any of the five MCC infrastructures. We thus argue that MCC management must be based on a joint observation of both QoS and QoE.

In reviewing the state-of-the-art on the management of MCC, we divide the literature work into two groups: (*i*) works that combine the use of QoS and QoE and (*ii*) works that focus on architectural models for MCC management. The investigations from the first group indicate that the traditional QoS-based management alone is insufficient to guarantee *End-user's* satisfaction [6–8,12]. Meanwhile, management architectures (from the second group) do not consider QoE, as described in the surveys of Rahimi, Ren, and Liu [2], and

[1] CoLisEU: https://coliseu.rnp.br .