Towards a Better Understanding of Ubiquitous Cloud Computing

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ABSTRACT
Ubiquitous Cloud Computing has been recently proposed as a new hybrid computing model. This paradigm has two aspects: (a) Making use of cloud services to realize context-awareness (especially for mobile phones) and (b) Introducing a new and hybrid computing model. Likewise, this paper mainly involves two subjects: To deeply investigate previous cloud services that have been utilized to design context-aware systems, and to propose an open architecture for the “Ubiquitous Cloud Computing” paradigm. The aim of this article is to technically discuss mutual trends of ubiquitous and cloud computing, to foster the dissemination of state-of-the-art research in this area, and to present future research directions.

KEYWORDS
Cloud Computing, Context-Awareness, Ubiquitous Computing

INTRODUCTION
Ubiquitous computing, which is considered as the third era of computing (Abowd, 2016; Krumm, 2016; Weiser & Brown, 1997), seeks ubiquitous provisioning of services to users (Satyanarayanan, 2001). Context is an essential concept in ubiquitous computing, which is defined as “any information that can be used to characterize the situation of an entity” (Dey, Abowd, & Salber, 2001). Context-aware applications, which are usually resided on smart mobile phones, are considered as the building blocks of the ubiquitous computing paradigm (Vahdat–Nejad, Zamanifar, & Nematbakhsh, 2013). These kinds of applications make use of relevant contextual information to provide personalized services to users. Generally, a context-aware application supports several functionalities including context acquisition, modeling, reasoning, and service management (Vahdat–Nejad, 2014), which result in generating massive programs. In spite of recent improvements in hardware technology of smart phones, they suffer from energy, computational and memory limitations comparing with high speed multiple-core laptops and personal computers. However, a major part of context-aware applications that are resided on mobile phones should provide real-time services according to the current situation of the user and environment (Bertolli, Buono, Mencagli, & Vanneschi, 2009). These remarks introduce a paradox that should be resolved before realizing the perspective of ubiquitous computing. In other words, the limited-resource mobile applications have limitations in gathering the contextual information, processing them, and acting in real-time.

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Cloud computing has emerged as a new computing model, in which resources can be provided as general services to users, anywhere and on any device (Q. Zhang, Cheng, & Boutaba, 2010). As a result, ubiquitous and on-demand provisioning of services have become an important characteristic of cloud computing. Companies, universities and research centers use cloud computing to acquire virtual resources and improve scalability of applications (Da Cunha Rodrigues et al., 2016; Saurez, Gupta, Mayer, & Ramachandran, 2017). Cloud has previously helped the users and organizations to utilize various resources by a low operational cost (Poorejbari, Vahdat-Nejad, & Mansoor, 2017); Therefore, it can play the role of a supporter for ubiquitous applications. In fact, it seems that cloud computing technology can be exploited to resolve deficiencies of current approaches to realize ubiquitous computing (Shirvani & Vahdat-Nejad, 2016). However, the major part of ubiquitous computing research has been performed independently and separately from cloud computing.

The main contributions of this paper are twofold:

- Firstly, the paper aims to answer whether cloud computing could help to realize ubiquitous computing. In particular, which functionalities of a typical ubiquitous computing system (i.e. context-aware system) could be accomplished by cloud computing. Previously, a few pieces of research have utilized cloud computing services to develop context-aware systems (Grønli, Ghinea, & Younas, 2014; Xiao, Hui, Savolainen, & Ylä-Jääski, 2011). The first contribution of this paper is to investigate these papers for the desired functionalities of a context-aware system that they accomplish by using cloud services. After discussing these functionalities, the question could be answered. An extensive framework is proposed for this purpose. This framework consists of three main dimensions, as the main tasks of a context-aware system, including context acquisition, context processing, and context API and application development. In context acquisition, related papers are reviewed with respect to the cloud usage in context information collection. In context processing, the use of cloud is investigated in processing and making contextual information more operational. Context aggregation, context modeling and context reasoning are different context processing methods. The third dimension includes three parameters of context dissemination, privacy protection and service management. The position of cloud in each of these parameters is investigated, in detail. This helps in understanding the real advantages of cloud computing in current ubiquitous computing systems;

- Although cloud computing and ubiquitous computing have been proposed and formalized individually and separately, they have some mutual features and targets. For example, both of them pursue ubiquitous provisioning of services to the users in an anywhere/anytime manner. As a result, a new computing model, which is referred to as “Ubiquitous Cloud Computing” (UCC), has been recently proposed (Egami, Matsumoto, & Nakamura, 2011; Lomotey & Deters, 2014; Van der Merwe et al., 2010); However, this concept is still vague and in needs of formalization. Specifically, the position of UCC regarding Mobile Cloud Computing (MCC) should be clarified. The other contribution of the paper is to formalize this computing paradigm and propose an open architecture for it. This architecture could illuminate the path of research in this new computing model.

This paper is organized as follows. Section 2 presents related papers that use cloud for performing one or more functional requirements of a context-aware system. In the third section, projects are reviewed with respect to the use of cloud in context acquisition. Section 4 deals with how cloud is used in context processing and relevant parameters. The fifth section investigates the use of cloud in providing supporting platform for context-aware application development. Finally, section 6 discusses the conclusion remarks and open research areas.
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