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Performance evaluation of remote display access for mobile cloud computing

Youming Lin [a,b], Teemu Kämäräinen [a,*], Mario Di Francesco [a], Antti Ylä-Jääski [a]

[a] Department of Computer Science, Aalto University School of Science, Finland
[b] Centre for Strategic Infocomm Technologies, Singapore

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ABSTRACT

Mobile applications are increasingly exploiting cloud computing to overcome the resource limitations of mobile devices. To this end, the most computationally expensive tasks are offloaded to the cloud and the mobile application simply interacts with a remote service through a network connection. One way to establish such a connection is given by remote display access, in which a mobile device just operates as a thin client by relaying the input events to a server and updating the screen based on the content received. In this article, we specifically address remote display access as a means for mobile cloud computing, with focus on its power consumption at mobile devices. Different from most of the existing literature, we take an experimental approach based on real user sessions employing different remote access protocols and types of applications, including gaming. Through several experiments, we characterize the impact of the different protocols and their features on power consumption and network utilization. We conclude our analysis with considerations on usability and user experience.

1. Introduction

Mobile devices such as smartphones and tablets have become very popular, and an increasing amount of people are nowadays using them not only for entertainment but also for several other activities. However, despite the advances in hardware manufacturing and wireless communication technologies, mobile devices are still much more resource-constrained than desktop computers and workstations. The fundamental restriction of smartphones and tablets is represented by their battery, which provides a limited amount of energy before it needs to be recharged, thus significantly hindering utilization on the move [1].

In order to overcome the resource constraints of mobile devices, several solutions have been proposed. One of the most important is represented by *offloading* computational and storage resources to the cloud [2,3]. With this approach, the mobile device runs only part of an application, namely, the components which are less resource-intensive. The rest of the application is deployed in the cloud and is accessed through a wireless network connection. One of the major challenges in offloading applications to the cloud is represented by the overhead in coordinating the different components and accessing the data of interest. Such an overhead may be significant, not only as network traffic, but also in terms of power consumption [4,5].

A different option is given by *remote display access* [6]. With this approach, mobile devices use a thin software client and connect to a remote display server running an operating system as well as one or more applications. The thin client displays the graphical user interface of the remote applications on the mobile device and relays all input events to the server. The server then processes the inputs and sends the changes in the content to be displayed back to the client. When the server is virtualized and runs in a data center, remote display access actually corresponds to an extreme case of *mobile cloud computing*, where the mobile device only processes input/output operations, while most of the computations are handled by the remote system [7,8].

In contrast with approaches specifically targeted to mobile cloud computing, most of the solutions for remote display access were originally designed for the reference scenario represented by personal computers. In that context, clients are static, with a wired connection to the Internet, and have plenty of resources. Some solutions have been specifically designed for remote access with mobile devices [9,10]; however, they are not usually available to the end users, or they cannot easily be integrated into the existing infrastructure. As a consequence, the vast majority of remote access protocols available for mobile devices are still those designed for personal computers. Even though some application-specific solutions such as [11] were

* Corresponding author.
E-mail addresses: lin.ym@csit.gov.sg (Y. Lin), teemu.kamarainen@aalto.fi (T. Kämäräinen), mario.di.francesco@aalto.fi (M. Di Francesco), antti.yla-jaaski@aalto.fi (A. Ylä-Jääski).

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proposed, they have not been evaluated as general means for mobile cloud computing.

In this article, we characterize the power consumption of mobile cloud computing realized through remote display technologies. Specifically, we analyze the performance of widely-used remote access protocols, including Virtual Network Connection (VNC), Remote Desktop Protocol (RDP) and GamingAnywhere. We perform several experiments involving realistic usage scenarios under different wireless communication technologies, *i.e*., WiFi and Long Term Evolution (LTE). Moreover, we characterize the power consumption and bandwidth utilization of the different solutions considered and relate them to the protocol features. Finally, we provide some considerations on aspects related to usability and user experience.

The remainder of the article is organized as follows. Section 2 discusses the related work, while Section 3 introduces the relevant background about remote access protocols and energy profiling of mobile devices. Section 4 presents the experimental setup and Section 5 discusses the obtained results. Finally, Section 6 concludes the article.

2. Related work

In the following, we discuss the most relevant solutions proposed in the existing literature for virtual networking and mobile computing. In detail, we first overview the major results about performance evaluation of remote access protocols, then focus on solutions specifically targeted to cloud environments and mobile devices. For clarity, we group the related work in different subsections accordingly.

2.1. Performance of remote display protocols

The performance of different remote display protocols was evaluated in [6,12,13]. Specifically, the authors performed several experiments on a real testbed under varying workloads corresponding to web-browsing and multimedia-oriented user activities. To this end, the evaluation exploited a *slow-motion* benchmarking technique, *i.e*., modified application benchmarks in which the activities affecting display updates are separated by adding artificial delays. Slow-motion benchmarking allows to accurately measure the impact between a single user-generated event at the client and its counterpart at the server. However, such an approach alters the actual interactions, possibly resulting in unexpected side-effects. Furthermore, it is based on synthetic application benchmarks rather than on the actual input from real users. In contrast, in this article we explicitly consider sessions by real users instead of relying on artificial benchmarks.

A performance study of user experience with thin clients was carried out in [14]. The authors recorded real remote display sessions using the Virtual Network Computing (VNC) protocol and involving interactive programs for image as well as document creation. The related traces were then used to perform extensive simulations in a wide range of network scenarios, characterized by different values of bandwidth and delay. As the work focused on user experience, the evaluation was limited to classify the user satisfaction based on the response time. The work in this article shares some similarities with [14], as we explicitly consider real use cases and adopt a record-replay strategy in our evaluation. In contrast, we perform experiments on a real testbed and specifically consider quantitative metrics (*i.e*., power consumption and network utilization) in our evaluation.

Finally, none of the solutions mentioned above considered scenarios involving virtualized servers nor mobile clients. Instead, we specifically evaluate remote display access as a means for mobile cloud computing. To this end, we perform measurements on a real testbed consisting of a mobile device and a virtualized server instance.

2.2. Cloud-based solutions

Offloading resources to the cloud has been the major focus for improving the performance and reducing the power consumption of mobile devices [4]. Some approaches have focused on techniques for automated and even dynamic offloading of mobile applications to the cloud. Among them, MAUI [2] is a platform which can evaluate the energy-cost tradeoff of applications running on top of the Microsoft .NET framework. Based on such an evaluation, MAUI automatically decides to execute part of an application in the cloud rather than on the mobile device. ThinkAir [15] uses a similar approach but targets Android devices and provides a finer granularity for offloading decisions. Different from those solutions, CloneCloud [3] enables offloading Android applications to the cloud without the need of special support by the application developer, who would otherwise need to annotate the application code to exploit the offloading platform. Due to the focus on computational and storage resources, the solutions for offloading mentioned above address computing aspects more than networking ones. As a consequence, they have been evaluated in use cases that are not very practical. In contrast, we consider realistic use cases and specifically address remote display scenarios.

Some research on offloading proposed running native mobile applications in the cloud and accessing them through a virtual network connection. Among them, the work in [16] evaluated PDF viewing and web browsing performed locally on a phone and remotely on a server running the X11 protocol over WiFi. The concept of *virtual smartphone* was introduced in [17], which also presented an architecture suitable to support the remote installation and execution of mobile applications. The approach in [17] relies on the VNC protocol for remote access, but it does not provide any characterization of the related resource utilization. In this article, instead, we characterize the power consumption and the bandwidth utilization of several remote display access protocols, including (but not limited to) VNC.

The concept of *virtualized screen* was introduced in [8], together with an architecture for thin-client mobile devices to perform screen rendering in the cloud. The proposed model targets complex graphic environments based on 3D rendering and takes a cross-layer approach which is both network and content-aware. Even though the architecture of the proposed system is described in detail, the solution in [8] is not evaluated in real-world scenarios. In contrast, we experimentally evaluate the power consumption of different remote display solutions available off-the-shelf under realistic use cases.

A cloud-based architecture for providing desktop services to thin clients was proposed in [18]. The authors outline the requirements for a smooth user experience at the clients and specifically consider issues related to scalability, resource allocation, and energy costs in a data center. The work takes a provider-centric perspective; it does not evaluate different remote desktop solutions and their impact on the power consumption of mobile devices. Indeed, we evaluate the performance of remote desktop access as a means for mobile cloud computing.

2.3. Mobile-friendly remote access

Solutions for remote display access have originally targeted personal computers [19]. Approaches suitable for mobile devices have been designed only recently. For instance, MobiDesk was proposed in [9] as an infrastructure for mobile virtual desktop computing. MobiDesk uses different techniques to provide display and network virtualization for both local and wide area networks, including session migration. However, this solution mainly targets mobile laptops and not devices such as smartphones or tablets which have significantly lower energy resources. In contrast, we specifically consider energy-constrained mobile devices in this article.

Smart VNC [10] is a solution built on top of VNC to improve the user experience in remote computing scenarios. The proposed