Universidade Federal do Ceará

Departamento de Computação

Mestrado e Doutorado em Ciência da Computação

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Applying Smart Decisions, Adaptive Monitoring and Mobility Support for Enhancing Offloading Systems

Fortaleza, Ceará
2016

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Tese submetida à Coordenação do Programa de Pós-graduação em Ciência da Computação da Universidade Federal do Ceará como parte dos requisitos para obtenção do grau de Doutor em Ciência da Computação.

Orientador: Prof. Dr. José Neuman de Souza

Co-Orientadores: Prof. Dr. Fernando Antonio Mota Trinta e Dr. Masum Z. Hasan

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Dados Internacionais de Catalogação na Publicação
Universidade Federal do Ceará
Biblioteca Universitária
Gerada automaticamente pelo módulo Catalog, mediante os dados fornecidos pelo(a) autor(a)

R268a Rego, Paulo Antonio Leal.
Applying smart decisions, adaptive monitoring and mobility support for enhancing offloading systems / Paulo Antonio Leal Rego. – 2016.
115 f. : il. color.

Tese (doutorado) – Universidade Federal do Ceará, Centro de Ciências, Programa de Pós-Graduação em Ciência da Computação , Fortaleza, 2016.
Orientação: Prof. Dr. José Neuman de Souza.
Coorientação: Prof. Dr. Fernando Antonio Mota Trinta.

1. Mobile cloud computing. 2. Tomada de decisão de offloading. 3. Mobilidade. 4. Monitoramento adaptativo. I. Título.

CDD 005

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Aprovado em 02 de dezembro de 2016.

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This work is dedicated to my wife Marcia, my parents Joaquim and Maria Celia, and my siblings Pedro and Vanessa. All I have and will accomplish are only possible due to your love and endless support.

Acknowledgements

This thesis becomes reality with the kind support and help of many individuals. I would like to extend my sincere thanks to all of them.

Foremost, my parents, **Joaquim e Maria Celia**, for the encouragement I had to study and for the love and support at all times of my life. My siblings, **Pedro e Vanessa**, for the unconditional support and partnership. My wife **Marcia**, who is ALWAYS by my side when I need, helped me a lot throughout my years of study. This accomplishment would not have been possible without them.

My advisor, **Prof. Dr. José N. de Souza** for the continuous support throughout my academic life, from undergrad to my Ph.D. study and research. His guidance and friendship helped me in all the time of research and writing of this thesis. My co-advisors, **Prof. Dr. Fernando Trinta** and **Dr. Masum Z. Hasan** for their guidance during the development of this study and for all conversations we had. Thank you all for believing in my potential and for all ideas you gave me.

I would like to thank the **Federal University of Ceará (UFC)** for showing me how to be a student, a professor, and a researcher. The university has given me the opportunity to grow as a person, student and professional. Thanks to all the people who are part of this university, especially my colleagues from the **Quixadá campus**, for the amazing work environment and friendship. I also would like to thank my professors and colleagues from **DC/MDCC**, **GREat**, and other UFC research groups. Thanks for the collaboration and stimulating research environment. It is always a pleasure working with you.

My internship at Cisco System in the US was a unique experience. Thanks, **CNPq**, **Cisco Systems**, and **UFC** for the opportunity. Thanks to all members of the **Cisco CVG team**, your friendship and help were incredible. You all are highly professional and capable.

Last, but not least, I would like to thank **all my friends** who somehow encouraged me to pursue my goals.

"Persistence is the shortest path to success."
(Charles Chaplin)

Resumo

O hardware de dispositivos móveis tem evoluído nos últimos anos, ao ponto de alguns aparelhos conseguirem alcançar o mesmo desempenho de instâncias de máquinas virtuais. No entanto, apesar dos avanços tecnológicos na capacidade dos smartphones e redes sem fio, a maioria dos dispositivos ainda são computacionalmente limitados se comparados com um computador desktop ou um notebook, e eles enfrentam muitos desafios, principalmente para executar aplicações que requerem computação intensiva. O paradigma *mobile cloud computing* (MCC) estuda formas de estender os recursos computacionais e energéticos dos dispositivos móveis, através da utilização de técnicas de *offloading*. Nesse contexto, esta tese investiga alguns dos desafios identificados na área de MCC, tais como: a decisão de quando e onde fazer *offloading*, a decisão de quais métricas devem ser monitoradas pelo sistema de *offloading*, e o suporte à mobilidade dos usuários em ambientes híbridos, compostos por *cloudlets* e instâncias de nuvens públicas. Diante de tais desafios, esta tese foca no desenvolvimento de um *framework* que permita que aplicações móveis façam *offloading* dinâmico de métodos em um ambiente com múltiplos *cloudlets* e nuvem pública. O *framework* desenvolvido utiliza técnicas de aprendizagem de máquina e redes definidas por software para melhorar a decisão de *offloading*, realizar monitoramento adaptativo e suportar a mobilidade dos usuários. Diversos experimentos foram realizados para avaliar a solução proposta e os resultados mostram que a abordagem desenvolvida para a tomada de decisão é leve e que o serviço de monitoramento adaptativo proposto pode ser utilizado para reduzir o consumo de energia de dispositivos móveis. Além disso, os resultados mostram que a solução proposta pode lidar com diferentes cenários de mobilidade e pode realizar *offloading* em diferentes servidores remotos de forma transparente para o usuário.

Palavras-chaves: *mobile cloud computing*. tomada de decisão de *offloading*. mobilidade. monitoramento adaptativo.

Abstract

The hardware of mobile devices has evolved, and a few device models can even reach the performance of virtual machine instances. Nevertheless, despite technological advances in the capacity of smartphones and wireless technologies, most devices are still computationally limited compared to a desktop computer or a notebook, and they face many challenges to execute applications that require heavy computation. The mobile cloud computing (MCC) paradigm studies how to extend computational resources and the energy of mobile devices through the use of offloading techniques. In this context, this thesis investigates some of the challenges identified in the mobile cloud computing area. Among these challenges, we can mention: the decision of when and where to perform offloading, the decision of which metrics must be monitored by the offloading system, and also the support for user's mobility in a hybrid environment composed of cloudlets and public cloud instances. Given these challenges, this thesis focuses on the development of a framework that allows mobile applications to dynamically perform offloading of methods in a hybrid environment. The developed framework leverages machine learning and software-defined networking techniques to improve offloading decisions, to perform adaptive monitoring, and to support users' mobility. Several experiments were conducted to evaluate the proposed solution, and results show that our offloading decision approach is a lightweight process and the proposed adaptive monitoring service can be used to reduce the energy consumption of mobile devices. Moreover, the results show that the proposed solution supports the most variate mobility scenarios and performs offloading to different remote servers transparently to the user.

Key-words: mobile cloud computing. offloading decision. mobility. adaptive monitoring.

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List of abbreviations and acronyms

ADSL	Asymmetric Digital Subscriber Line
AMQP	Advanced Message Queuing Protocol
API	Application Programming Interface
APNS	Apple Push Notification Services
C2	CloudCell
CMX	Connected Mobile Experiences
CSR	Cloud Service Router
DAG	Directed Acyclic Graph
DSM	Distributed Shared Memory
DVFS	Dynamic Voltage and Frequency Scaling
FPS	Frames Per Second
GCM	Google Cloud Messaging
GPS	Global Positioning System
GRE	Generic Routing Encapsulation
HTTP	Hypertext Transfer Protocol
IaaS	Infrastructure as a Service
IDE	Integrated Development Environment
ILP	Integer Linear Programming
IPC	Inter-process communication
IPsec	Internet Protocol Security
JSON	JavaScript Object Notation
LAN	Local Area Network
MAN	Metropolitan Area Network

MCC	Mobile Cloud Computing
MI	Million Instructions
MIPS	Million Instructions Per Second
MPLS	Multiprotocol Label Switching
MPNS	Microsoft Push Notification Service
MSE	Mobility Services Engine
NVGRE	Network Virtualization using Generic Routing Encapsulation
OSGi	Open Service Gateway Initiative
PaaS	Platform as a Service
PM	Physical Machine
P2P	Peer-to-Peer
RDP	Remote Desktop Protocol
REE	Remote Execution Environment
REST	Representational State Transfer
RPC	Remote Procedure Call
SaaS	Software as a Service
SHA-1	Secure Hash Algorithm 1
SLA	Service Level Agreement
SL4A	Scripting Layer for Android
SLC	Seamless Cloud
SOA	Service-oriented Architecture
VCPU	Virtual CPU
VM	Virtual Machine
VMM	Virtual Machine Monitor
VNC	Virtual Network Computing
VPN	Virtual Private Network

VXLAN	Virtual Extensible LAN
WAN	Wide Area Network
WLAN	Wireless Local Area Network
XML	Extensible Markup Language
XMPP	Extensible Messaging and Presence Protocol

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