Mobile Cloud Computing

Concepts, applications and beyond

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Who am I

• Head of Mobile & Cloud Lab, Institute of Computer Science, University of Tartu, Estonia

http://mc.cs.ut.ee
Estonia pop: 1,300,000

TARTU
Pop: 100,000
Academic excellence since 1632
Main Research Activities

The research at the Mobile & Cloud Lab contributes to the following fields:

- **Cloud Computing**
  The research goal is to study the migration of enterprise applications to the cloud and to study their performance on the cloud.

- **Scientific Computing on the Cloud**
  The research goal is to study the migration of scientific computing applications to the cloud and to reduce these applications and a

- **Mobile Computing**
  The research deals with developing mobile applications for various platforms and devices (e.g. Android, iOS, Windows Phone 7 etc).

- **Mobile Cloud**
  The goal of the research is to investigate how to efficiently utilize cloud resources within the mobile applications (aka mobile cloud.

- **Mobile Web Services**
  This research theme deals with the invocation, provisioning, discovery and integration of web services from smart phones, in develop

- **Internet of Things**
  The goal of this research is to overcome the challenges of cyber-physical systems in the Internet of Things. The challenges include: efficiency, trustworthiness etc.
Outline

• Mobile computing
• Cloud computing
• Mobile Cloud Binding Models
  – Task delegation
    • Internet of Things (IoT)
  – Code offloading
• Conclusions and Future work
# Mobile – The Seventh Mass Media Channel

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country or region</th>
<th>Number of mobile phones</th>
<th>Population</th>
<th>Phones per 100 citizens</th>
<th>Data evaluation date</th>
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[Tomi T Ahonen]
Advances in Mobile Technologies

• Embedded Hardware
  – Camera, Wifi, sensors such as accelerometer, magnetic field, etc.

• Higher data transmission and ubiquitous access to Internet
  – 3G, 4G, 5G and Wifi

• Marketing models of applications
  – Apple Store
  – Android Market – Google Play
Popular consumer mobile applications

• Location-based services (LBSs)
  – Deliver services to users based on his location
• Mobile social networking
  – Most popular social networking platforms have apps for mobiles
• Mobile instant messaging (MIM)
  – Skype for mobiles, WhatsApp
• Mobile payment & Mobile commerce
  – Near field communication (NFC) payment
Popular consumer mobile applications - continued

- Context-aware services
  - Context means person's interests, history, environment, connections, preferences etc.
  - Proactively serve up the most appropriate content, product or service
- It is also possible to make the mobile a service provider
  - Mobile web service provisioning [Srirama et al, ICIW 2006; Srirama and Paniagua, MS 2013; Liyanage et al, MS 2015]
  - Challenges in security, scalability, discovery and middleware are studied [Srirama, PhD 2008]
  - Mobile Social Network in Proximity [Chang et al, ICSOC 2012; PMC 2014]
However, we still have not achieved

• Longer battery life
  – Battery lasts only for 1-2 hours for continuous computing

• Same quality of experience as on desktops
  – Weaker CPU and memory
  – Storage capacity

• Still it is a good idea to take the support of external resources
  – For building resource intensive mobile applications
What is Cloud Computing?

• Computing as a utility
  – Utility services e.g. water, electricity, gas etc
  – Consumers pay based on their usage

  1969 – Leonard Kleinrock, ARPANET project
  “As of now, computer networks are still in their infancy, but as they grow up and become sophisticated, we will probably see the spread of ‘computer utilities’, which, like present electric and telephone utilities, will service individual homes and offices across the country”

• Cloud Computing characteristics
  – Illusion of infinite resources
  – No up-front cost
  – Fine-grained billing (e.g. hourly)
Cloud Computing - Services

• Software as a Service – SaaS
  – A way to access applications hosted on the web through your web browser

• Platform as a Service – PaaS
  – Provides a computing platform and a solution stack (e.g. LAMP) as a service

• Infrastructure as a Service – IaaS
  – Use of commodity computers, distributed across Internet, to perform parallel processing, distributed storage, indexing and mining of data
  – Virtualization
Cloud Computing - Themes

• Massively scalable
• On-demand & dynamic
• Only use what you need - Elastic
  – No upfront commitments, use on short term basis
• Accessible via Internet, location independent
• Transparent
  – Complexity concealed from users, virtualized, abstracted
• Service oriented
  – Easy to use SLAs

SLA – Service Level Agreement
Economics of Cloud Providers

• Cloud Computing providers bring a shift from high reliability/availability servers to commodity servers
  – At least one failure per day in large datacenter
• Why?
  – Significant economic incentives
    • much lower per-server cost
• Caveat: User software has to adapt to failures
  – Very hard problem!
• Solution: Replicate data and computation
  – This is how MapReduce & Distributed File System jump into the Cloud domain
Cloud Computing Progress

[Armando Fox, 2010]

[Diagram showing layers of computing: Web startups, CS researchers, Enterprise apps, eg email, Educators, scientific & high-performance computing (HPC)].
Mobile Cloud Applications

• Bring the cloud infrastructure to the proximity of the mobile user
• Mobile has significant advantage by going cloud-aware
  – Increased data storage capacity
  – Availability of unlimited processing power
  – PC-like functionality for mobile applications
  – Extended battery life (energy efficiency)
Mobile Cloud is the future

Report: Mobile cloud to grow beyond $11 billion in 2018
Written by CopperEgg // July 12, 2012 // No Comment // Cloud Performance

The proliferation of smartphones, tablets and other mobile devices is contributing to change in the private sector, as businesses continue to leverage these gadgets in an attempt to enhance efficiency and potentially gain a competitive advantage. According to a new report by Global Industry Analysts, the evolution of Mobility is also changing the cloud computing landscape, pushing the mobile cloud market to generate more than $11 billion in revenue by 2018.

Maribel Lopez, Contributor
1 track how mobile changes engagement and business strategies
+ Follow (87)

Verizon's Stratton: The Future Of IT Is Mobile And Cloud

+ Comment Now  + Follow Comments

9/8/2016  Satish Srirama
Mobile Cloud – Interpretation

• We should not see Mobile Cloud to be just a scenario where mobile is taking the help of a much powerful machine!!!
• We should not see cloud as just a pool of virtual machines

• Mobile Cloud based system should take advantage of some of the key intrinsic characteristics of cloud efficiently
  – Elasticity & AutoScaling
  – Utility computing models
  – Parallelization (e.g., using MapReduce)
Mobile cloud - Binding models

Task Delegation

[Flores and Srirama, JSS 2014]

Code Offloading

[Flores et al, IEEE Communications Mag 2015]
Task Delegation

• Follows traditional SOA model to invoke services
  – Similar to mobile Web service client

• Typical scenarios
  – Process intensive services
    • Face recognition, sensor mining etc.
  – Data Synchronization (SyncML, Funambol, Google Sync)
    • Calendar, contacts etc.

• Critical challenges were (~2010)
  – Cloud interoperability
  – Unavailability of standards and mobile platform specific API
Mobile Cloud Middleware

[Srirama and Paniagua, MS 2013]

[Warren et al, IEEE PC 2014]

[Flores et al, MoMM 2011; Flores and Srirama, JSS 2014]
MCM – enables

- Interoperability between different Cloud Services (IaaS, SaaS, PaaS) and Providers (Amazon, Eucalyptus, etc)
- Provides an abstraction layer on top of API
- Composition of different Cloud Services
- Asynchronous communication between the device and MCM
- Means to parallelize the tasks and take advantage of Cloud’s intrinsic characteristics
MCM - Scalability

Load Balancer

[Flores & Srirama, JSS 2014]
CroudSTag – Scenario

• CroudSTag takes the pictures/videos from the cloud and tries to recognize people
  – Pictures/Videos are actually taken by the phone
  – Processes the videos
  – Recognizes people using facial recognition technologies
• Reports the user a list of people recognized in the pictures
• The user decides whether to add them or not to the social group
• The people selected by the user receive a message in facebook inviting them to join the social group

[Srirama et al, PCS 2011; SOCA 2012]
CroudSTag [Srirama et al, PCS 2011; SOCA 2012]

- Cloud services used
  - Media storage on Amazon S3
  - Processing videos on Elastic MapReduce
  - face.com to recognize people on facebook
  - Starting social group on facebook
Other applications

• **Zompopo** [Srirama et al, NGMAST 2011]
  – Intelligent calendar, by mining accelerometer sensor data

• **Bakabs** [Paniagua et al, iiWAS-2011]
  – Managing the Cloud resources from mobile

• **Sensor data analysis**
  – Human activity recognition
  – Context aware gaming
  – **MapReduce based sensor data analysis** [Paniagua et al, MobiWIS 2012]

• **SPiCa: A Social Private Cloud Computing Application Framework** [Chang et al, MUM 2014]
Adaptive Workflow Mediation Framework for IoT [Chang et al, PMC 2014]

- Task delegation is a reality!!!
  - Cloud providers also support different platforms
- Mobile Host allows invocation of services on smartphones
- So Peer-to-Peer (P2P) communication is possible
- Extended the Mobile Host to also support workflow execution [Chang et al, ICSOC 2012; MUM 2014]
  - To address challenges of discovery and quality of service (QoS) [Srirama et al, MW4SOC 2007]
  - Tasks can move between mobile and middleware
  - Very handy in the IoT context
Internet of Things (IoT)

“*The Internet of Things allows people and things to be connected *Anytime, Anyplace, with Anything and Anyone, ideally using *Any path/network and Any service.”* [European Research Cluster on IoT]

- More connected devices than people
- Cisco believes the market size will be $19$ trillion by 2025

Source: Cisco IBSG, April 2011
IoT - Scenarios

- Environment Protection
- Smart Home

[Image of refrigerator with RFID tagged ice cream and cheese packet]

[Kip Compton]
[Perera et al, TETT 2014]
Internet of Things – Challenges

How to provide energy efficient services?

How do we communicate automatically?

How to interact with ‘things’ directly?

[S chang et al, ICWS 2015]

[Chang et al, SCC 2015; Liyanage et al, MS 2015]

9/8/2016
Cloud-based IoT

Remote Cloud-based processing

Connectivity nodes & Embedded processing

Sensing and smart devices
Demo – IoT and Smart solutions Laboratory

Smart Home
Scenario: Disabled Person Trying to Avoid Crowd in Urban Areas

- Mobile Host and MCM enable moving tasks between mobile and the middleware.
Real-time IoT Service Discovery

[Chang et al, SCC 2015]
Discovery Workflow

- Workflow approach selection
- Fuzzy sets and Cost Performance Index
Mobile cloud - Binding models

Task Delegation

[Flores and Srirama, JSS 2014]

Code Offloading

[Flores et al, IEEE Communications Mag 2015]
Code Offloading

- Also known as Cyber-foraging [M. Satyanarayanan, 2001]
- Mobile devices offload some of their heavy work to stronger surrogate machines in the vicinity (Cloudlets)
- Major research challenges
  - What, when, where and how to offload?
Major Components

• Mobile
  – Code profiler
  – System profilers
  – Decision engine

• Cloud based surrogate platform
Some of the well known frameworks

- **MAUI**
  - Manual annotations [Cuervo et al., 2010]
- **CloneCloud**
  - Code profilers & Automated process [Chun et al., 2011]
- **ThinkAir**
  - Manual annotations and scalability [Kosta et al., 2012]
- **EMCO** [Flores and Srirama, MCS 2013] & etc.
  - Improved offloading by analysing the traces
- **mCloud** [Zhou et al, Cloud 2015; TSC 2016]
  - A context-aware offloading framework for heterogeneous mobile cloud

- **Work in controlled environments like nearby servers**
  - However, none can be adapted for real life applications
Challenges and technical problems

• Inaccurate code profiling
  – Code has non-deterministic behaviour during runtime
    • Based on factors such as input, type of device, execution environment, CPU, memory etc.
    – Some code cannot be profiled (e.g. REST)
• Integration complexity
  – Surrogate should have similar execution environment
• Dynamic configuration of the system
• Offloading scalability and offloading as a service
  – Should also consider about resource availability of Cloud

[Flores et al, IEEE Communications Mag 2015]
Applications that can benefit became limited with increase in device capacities
Multi-tenancy for code offloading

Auto-scaling becomes a challenge
Dynamic configuration

Vast resource allocation choices in the cloud ecosystem and the large diversity of smartphones make the context very variable.
Acceleration via pre-cached results
Conclusions

• Mobile has significant advantage by going cloud-aware
• Mobile Cloud based system should take advantage of some of the key intrinsic characteristics of cloud efficiently
• Task delegation is a reality!!!
• Code offloading still has significant distance to cover and has enough future research directions
  – However, applications that can benefit from code offloading are becoming limited
Current work – Fog Computing

- Public Cloud
  - Distanced Computational & Storage Offloading

- Private Cloud
  - Near-field Computational Offloading (another form of MEC)

- Cloudlet VM
  - Local Input VM
  - Proximity based Computational Offloading

- MEC
  - Collaborative Mobile Sensing

- D2D
  - Proximity-based Mobile Computing

- Fog Computing
  - Real-time Opportunistic Information Sharing
Other research interests

• Dynamic deployment and Auto-Scaling applications on the Cloud [Srirama et al, Cloud 2016]
  – Optimal Resource Provisioning for Auto-Scaling Enterprise Applications [Srirama and Ostovar, CloudCom 2014]

• Scientific Computing on the Cloud [Srirama et al, SPJ 2011]
  – Migrating Scientific Workflows to the Cloud [Srirama and Viil, HPCC 2014]
  – Adapting Computing Problems to Cloud computing frameworks like MapReduce and BSP [Srirama et al, FGCS 2012] [Kromonov et al & Jakovits and Srirama, HPCS 2014]
THANK YOU FOR YOUR ATTENTION

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