Applications and Trends in Mobile Cloud Computing

C. Costea
[*] Tech Univ Cluj Napoca, North Univ Center Baia Mare / Electrical Department,
Baia Mare, Romania, ccostea@ubm.ro

***Abstract*—Mobile devices are facing several challenges like frequent disconnections and limited resources like processor power, available memory, energy consumption. Mobile cloud computing can improve user experiences by executing applications on resource providers external to the mobile device. In this paper, we discuss recent mobile application models related to cloud computing technologies.**

I. Introduction

Despite of recent development of mobile hardware, the primary constraints for mobile computing are still limited energy and wireless bandwidth. Cloud computing has been recognized as the next generation's computing infrastructure and now mobility and cloud computing are colliding.

According to NIST (National Institute of Standards and Technology, USA), "*Cloud Computing is a model for enabling convenient, on-demand network access to a shared pool of configurable resources (e.g. networks, servers, storage, applications and services) that can rapidly be provisioned and released with minimal management effort or service provider interaction.*"

Cloud computing can be viewed as a collection of services, often described as a stack of services built on top of one another. Three distinct models within Cloud Computing are Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service(IaaS).

SaaS is defined as "*…software that is deployed over the internet… With SaaS, a provider licenses an application to customers either as a service on demand, through a subscription, in a "pay-as-you-go" model, or (increasingly) at no charge when there is opportunity to generate revenue from streams other than the user, such as from advertisement.*.". SaaS applications are designed for end-users, delivered over the web.

PaaS can be defined as a computing platform for the creation of software, delivered over the web; is the set of tools and services designed to make coding and deploying web applications quick and efficient.

IaaS refer to the way of delivering Cloud Computing infrastructure – servers, storage, network or operating systems – as an on-demand service. Rather than purchasing servers, software, datacenter space or network equipment, clients instead buy those resources as a fully outsourced service on demand.

Often a mobile application support thin client interactions with web services. Therefore, a mobile device could execute a resource-intensive task on a distant high-performance compute server.

For battery powered devices, the energy can be also an important criterion when considering moving computing to other machine, a critical aspect being the trade-off between energy consumed by computation and the energy consumed by communication.

The Mobile Cloud Computing Forum consider MCC as "*an infrastructure where both the data storage and the data processing happen outside of the mobile device*" [9].

II. Steps to Implementing MCC

There were more directions of defining the mobile cloud: data storage and processing outside the mobile device vs. Distributed and mobile computing infrastructure. However, there is a third direction by combining the first: Cloud computing, extended by mobility and new ad hoc infrastructure.

A. Ad-hoc Mobile Cloud

Marinelli [14] introduce Hyrax, a platform derived from Hadoop that supports cloud computing on Android smartphones. Client applications can execute computing jobs on networks of smartphones and heterogeneous networks of phones and servers.

B. Offloading

Offloading is a technique to increase the mobile systems' capabilities by migrating computation to other machines – servers or more resourceful computers. Few enablers for offloading are suggested in [23]: (a) wireless networks and mobile agents and (b) virtualization and cloud computing.

A computation offloading scheme, presented in [25], is based on partitioning of a program into a client unit and server distributed units by a compiler-based tool.

A number of parameters such as bandwidths, server speeds, available memory, server loads or the amounts of data exchanged between servers and mobile device are considered in [25] to develop algorithms for offloading decisions, to save energy or to improve performance.

In [13] is presented the middleware Mobile Augmentation Cloud Services (MACS), where Application logic is structured from multiple Android services which can be offloaded into the cloud.

C. Weblets

Weblets are autonomous functional software entities, platform independent and can be executed transparently on different computing infrastructures including mobile devices or migrate between different cloud nodes.

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An elasticity manager component decides on migration, instantiation and migration of the weblets. This processes are transparent to the running application[29].

D. Cloudlets

Satyanarayanan introduced [20] the notion of cloudlet. It can be viewed as a “data center in a box,” residing nearby and cache user data from an originated cloud, to local access and thereby reducing latency. When finished, the user data can be returned to the initial cloud. A cloudlet only contains copies of user data or code that is not available elsewhere.

E. Other implementations

Because today’s smartphones typically use a different instruction set architecture (ARM) than desktop and server machines (x86), MAUI [3] needs the ability to execute the same program on different CPU architectures, preferably without access to the program source code.

In [29] a type of migration occurs when a cloud provider migrates a VM from one physical cloud node to another, e.g., for load balancing.

With CloneCloud [2] it is possible to clone the entire mobile device environment on a remote server. Applications can restarted on or migrated to the remote machine when the device is running low on resources. The partitioning mechanism in CloneCloud aims to modify an application executable by deciding where to execute methods in the code. An optimizer will pick which application methods will migrate to the clone from the mobile device, minimizing the cost of the partitioned application.

Another platform for mobile cloud computing is Sonora presented in [17]. Sonora addresses dynamic adaptation and failure recovery.

III. Cloud Robotics as MCC Application

Among typical applications of Mobile Cloud Computing we can meet: speech-to-text applications, voice recognition and translation, mobile augmented reality (AR), Body Sensor Networks, autonomous driving, optical character recognition, face detection or mobile sensing.

Conventional data management is normally developed with a relational database, but the sensor data size is greatly expanding and the demand for complex queries and data analysis processing is rising. It is important for the sensor data management systems to be able to handle various data scales and some researches are oriented to cloud computing as the platform because of its support for NoSQL storage, scalability and distributed computing ability.

Recently, in robotics, the notions of cloud computing have been introduced by Kuffner of Carnegie Mellon University and Google, and are known as “cloud robotics”. Robots can improve their capabilities via clouds in: 3D vision, planning, speech recognition, language translation. Kuffner envisions a future when robots will feed data into a "knowledge database," where they’ll share their interactions with the world and learn about new objects, places, and behaviors.

The technologies of web services and service-oriented architecture (SOA) have been applied to robotic technologies in three ways. One is the utilization of computational resources for enhancing the abilities of robots on cloud servers, other refer to knowledge sharing and the exchange of semantic information; and third, since robotic services and robotic components are considered services in SOA, they can cooperate with each other if they are organized appropriately [11].

Accordint to Kazuhito Yokoi, head of the Humanoid Research Group at Japan’s National Institute of Advanced Industrial science and technology, “the next generation of robots needs to understand not only the environment they are in but also what objects exist and how to operate them,”[5].

In [18] are presented a conceptual design for a service robot system supported by cloud computed services. The mobile robot will act as service provider and consumer. Services will be published into a common service repository, thus making them discoverable by other remote services. A service could correspond to a skill learned by the robot, which would be published in the cloud and be usable by other robotic agents. The robot can rely on the cloud to obtain new services, downloading requested skill from cloud repository; this dynamic behavior can be similar to an app-store for robots, like in case of smartphones.

Scientists at NASA developed small helper robots powered by Android. Called SPHERES (Synchronized Position Hold, Engage, Reorient, Experimental Satellites), these volleyball sized helpers are capable of flying around the International Space Station, thanks to its tiny CO2 thrusters. A Samsung Nexus S is attached to each and due to its low-power computer and camera, it is transformed into a ‘Smart SPHERE.’

The robotic devices can download data that aids their mission. By example, the PerceptOR program’s goal is to improve the ability of unmanned ground vehicles (UGVs) to navigate autonomously; the robot will download Google Maps images of the terrain in which it operate and then image processing is used to attempt to find navigable routes through terrain.

RoboEarth is an European project led by the Eindhoven University of Technology, in the Netherlands, to develop a “World Wide Web for robots”, a giant database where robots can share information about objects, environments, and tasks [27]. The goal of the RoboEarth project is to build up huge common knowledge bases for robotic systems, which will allow them to reliably identify objects, improve their actions over time and adapt their navigation strategies for unknown environments, which they were not explicitly planned for at design time. “Rather than programming robots to handle every potential situation, the Internet of Things could create an environment in which the objects themselves inform robots of their purpose and usage…the fields of robotics and IoT need to define common standards for knowledge storage, representation and communication [27].”

The RoboEarth Cloud Engine is a platform as a service (PaaS) framework for robots. Each robot connected to the RoboEarth Cloud Engine will have a system level clone on the cloud giving them the ability to move their heavy computation into the cloud. In addition, the system clones are tightly (high bandwidth) interconnected providing a useful platform for multi-robot deployments.

ASORO (A-Star Social Robotics Laboratory) from a Singapore researchers group tries built a cloud computing infrastructure that allows robots to generate 3-D maps of their environments much faster than they could with their onboard computers.

The DAvinCi framework combines the distributed ROS architecture, the open source Hadoop Distributed File System (HDFS) and the Hadoop Map/Reduce Framework [1].

IV. MOBILE AGENTS AND MOBILE CLOUD

A mobile agent is a process that can transport its state from one environment to another (included code and data), capable of communications and autonomous actions in its new environment.

Zhang proposed in [29] MABOCCF (Mobile Agent Based Open Cloud Computing Federation): user task is encapsulated in a mobile agent who runs in a MAP (Mobile Agent Place) container; the mobile agent can decides when to migrate to another MAP either on same CCSP (Cloud Computing Service Providers) or another if resources on particular MAP become scarce.

In [12] authors focused on cloud interoperability and portability issues by using XMPP protocol for discovering the nearby clouds and providing information to agents (i.e. next version technology). Agents are interoperable by default as per FIPA (Foundation of Intelligent Physical Agent), and keeping attributes like workload per service on each machine, distance between the clouds or services available on each cloud, can take decisions to fix problems.

V. TEST APPLICATION

The first steps of our experiments realized in our laboratory have been oriented to study the scalability and interfacing possibilities between more agents, using the JADE framework on Windows/Linux and Android device.

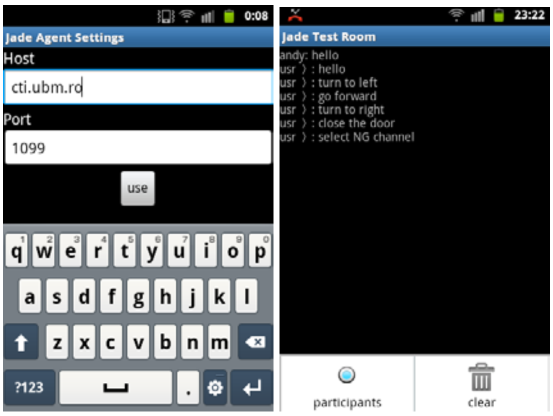

Figure 1. Android application - Jade agent connection

A second group of experiment aimed the mobility of JADE agents, using five machines in the local area network; the average time of itinerary (11 hops) being under 700 ms. The mobile agent can failed contacting next hop, but can try to another without serious errors; unfortunately, it has no information if the remote host is overloaded.

Figure 1 show an Android test application based on communication of agents situated on desktop application, Android emulators and real mobile device (Samsung Galaxy Gio S5660, Android 2.2 Froyo); each agent is registered in a proper container situated in the middleware, running in our tests on a virtual Linux system situated on a distance machine.

This agent middleware use ACL (Agent Communication Language) concept and support proper user ontologies; these can be very useful in both machine-machine and human-machine interactions; we try to suggest the possibility to select different levels of communications ("turn to left" vs. "close the door"), in a possible robotics application.

VI. CONCLUSIONS

Mobile Cloud Computing depends on cloud interoperability, but both are in the first stages and no standard exists. Some features like computation offloading and scalability of cloud services can be achieved by using mobile agents, therefore code mobility could be an important chapter in the next decade.

An issue can be the decisions of migrating agents, because the energy cost (especially in battery power device with wireless communication) can be important.

It would be useful to determine the moment when it is preferable to offload some job to remote servers and when to perform the job locally.

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