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Mobile crowdsensing as a service: A platform for applications on top of sensing Clouds

Giovanni Merlino[a,b], Stamatis Arkoulis[c], Salvatore Distefano[d,e,*], Chrysa Papagianni[c], Antonio Puliafito[a], Symeon Papavassiliou[c]

[a] Dip. di Ingegneria (DICIEAMA), Università di Messina, Italy

[b] Dip. di Ingegneria (DIEEI), Università di Catania, Italy

[c] School of Electrical and Computer Engineering, National Technical University of Athens, Greece

[d] Social and Urban Computing Group, Higher Institute of Information Technology and Information Systems (ITIS), Kazan Federal University, Russia

[e] Dip. di Elettronica, Informazione e Bioingegneria (DEIB), Politecnico di Milano, Italy

HIGHLIGHTS

- Emulation of deployment comparing (i) prototype of MCSaaS and (ii) current practices.
- Modeling of MCSaaS paradigm by Petri nets and evaluation against conventional MCS.
- Description of architectural elements of the platform and their interactions.
- MCSaaS platform for mass deployment of MCS apps, and their elastic user base adaptation.
- Mobile crowdsensing as a service paradigm for MCS apps design and deployment.

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ABSTRACT

Consumer-centric mobile devices, such as smartphones, are an emerging category of devices at the edge of the Internet. Leveraging volunteers and their mobiles as a (sensing) data collection outlet is known as Mobile Crowd Sensing (MCS) and poses interesting challenges, with particular regard to the management of sensing resource contributors, dealing with their subscription, random and unpredictable join and leave, and node churn.

To facilitate and expedite the (commercial) exploitation of this trend, in this paper we propose to adopt a service-oriented approach to cope with MCS application deployment into a sensing Cloud infrastructure, decoupling the MCS application domain from the infrastructure one. To this purpose we provide the building blocks for implementing such a novel take on MCS, which from a Cloud layering perspective can be identified as a platform service, i.e., an MCS as a service (MCSaaS). A prototype implementation that serves as a blueprint and a proof-of-concept of the proposed framework is presented, while an evaluation of the effectiveness of the MCSaaS paradigm has been provided using suitable mobility-related use cases for a validation of the concept, as well as a modeling approach through the adoption of generalized stochastic Petri nets.

1. Introduction and motivations

Current trends, with specific regard to cyber physical systems and Internet of Things (IoT), suggest that one of the most interesting thrusts towards pervasive services comes from opportunistic and participatory sensing paradigms, such as Mobile Crowd Sensing (MCS). MCS leverages the pervasiveness of smartphones and other portable devices, enabling users and community groups to collectively share data from onboard sensing resources so as to measure phenomena of common interest, exploiting social dynamics. The contributor has also the possibility to augment raw data with context as metadata. This community-driven sensing trend is brought about by machine interactions at different levels, including data communications, collection, processing and mining. Commencing crowd-sourcing and sensing duties from mobiles, involving device owners as volunteering participants, potentially renders end users both contributors and consumers of large volumes of (curated) data.

* Corresponding author at: Dip. di Elettronica, Informazione e Bioingegneria (DEIB), Politecnico di Milano, Italy.

E-mail addresses: gmerlino@unime.it, giovanni.merlino@dieei.unict.it (G. Merlino), stark@cn.ntua.gr (S. Arkoulis), s_distefano@it.kfu.ru, salvatore.distefano@polimi.it (S. Distefano), chrisap@noc.ntua.gr (C. Papagianni), apuliafito@unime.it (A. Puliafito), papavass@mail.ntua.gr (S. Papavassiliou).

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However, there are several key issues that need to be addressed for the MCS paradigm to experience widespread adoption [1,2]. Firstly, a unified architecture for supporting MCS applications is required to enable reusability of software components, facilitating shorter time to market cycles. Existing MCS applications are built as stand-alone ones, while common challenges, e.g., related to resource engagement, get independently revisited each time, or are not addressed at all. The heterogeneity of mobile Operating Systems (OS) and sensor hardware further amplifies the problem. As a result sensing and processing activities usually result in carrying out similar tasks (i) within a single device (contributing node) for different MCS applications, resulting in energy starvation and (ii) across multiple, neighboring devices, leading to spikes in bandwidth usage and processing requirements at the back end. Both cases highlight a non-scalable deployment model.

Furthermore, MCS applications rely on every single contributor for local deployment duties. While most MCS apps require a critical mass of contributors to be deemed useful, app adoption is bounded by the rate at which users keep track of, and install, newly introduced ones. A substantially low rate as, according to recent reports, e.g., in 2014 nearly 80% of the 1.2 million apps available at the Apple App Store had hardly any downloads at all.[1] Providing resources on a volunteer basis is one of the foremost limitations to the large scale exploitation of the MCS paradigm, as it naturally bears constraints related to contribution churn. In terms of MCS applications this sets the need for "marketing" strategies aimed at increasing the number of subscriptions, stimulating, retaining and rewarding potential contributors through incentives. However, even if the enrollment activities (or even mechanisms, such as credit-reward systems) may be highly effective, the subscription process is usually characterized by long and smooth dynamics. Therefore a significant time delay may be experienced before getting a significant stream of sensing data. This issue may strongly confine the scope of the MCS paradigm to a shortlist of applications featuring broad, long-established supporting communities of potential contributors.

From a different perspective, another significant trend moves IoT towards service-oriented and Cloud computing paradigms [3–5]. In this view, the Cloud is not just a technology to support the archiving of sensed data coming from pervasive IoT infrastructure, but also a model and a paradigm to adopt in the management of the underlying resources and things.

Following this IoT-Cloud research trajectory, in this paper, a novel platform for opportunistic (mass) exploitation of contributed resources for MCS apps is presented to get more insights as to whether the MCS paradigm may indeed be applied at large-scale in the IoT context. The proposed approach overcomes several of the aforementioned hurdles, by facilitating what is essentially the most difficult endeavor for prospective MCS entrepreneurs, i.e., offering a level playground, with homogeneous access to wildly different underlying ecosystems. To this end, we identify two classes of concerns with regard to (unassisted) dissemination of MCS apps; (i) *infrastructure*-related, mostly focused on mechanisms to enroll and manage voluntarily contributing nodes, as well as to abstract sensing resources and enable uniform access, and (ii) *application*-related, mainly devoted to mechanisms for interfacing with enabled infrastructure, asking for the required sensing resources and, once obtained, deploying the MCS app onto the resource-hosting nodes. This way we are able to decouple infrastructure resources (*supply*) from application requirements (*demand*) as in Cloud contexts, making development, deployment and operation fully independent.

[1] https://www.adjust.com/assets/downloads/AppleAppStore_Report2014.pdf.

For delivering this novel MCS approach, the Sensing and Actuation as a Service (SAaaS) framework, proposed in [6], is adopted as the lower-level (infrastructure domain) enabler. SAaaS is based on the service-oriented (and Cloud-inspired) approach of elastically providing (virtual) sensing and actuation resources on demand, gathered from underlying (contributed) physical nodes. The study at hand extends and adapts the SAaaS paradigm for enabling rapid MCS app deployment and streamlining their operation, actually providing an *MCS as a Service* (MCSaaS) platform.

There are a number of advantages in dealing with MCS from the (SA)aaS angle. Virtualizing and customizing sensing resources, starting from the capabilities provided by the SAaaS model, allows for concurrent exploitation of pools of devices by several platform/application providers. Delivering MCSaaS may further simplify the provisioning of sensing and processing activities within a device or across a pool of devices. Moreover, decoupling the MCS application from the infrastructure promotes the roles of a sensing infrastructure provider that enrolls and manages contributing node(s), below, and of a platform provider on top of that, acting as a broker between (i) the former and (ii) the MCS application provider, enabling the latter to focus on the application and leave concerns and enforcement about requirements (type of resources, availability, etc.) to the platform.

In this paper we provide a high level overview of the proposed MCSaaS approach complemented by a description of the distinct architectural elements and their interactions. Moreover we highlight the benefits of the proposed framework as opposed to the conventional MCS approach, by means of (i) a prototype implementation of the MCSaaS framework under the guise of the MobiCSOS stack and the emulation of a real-world application deployment; and by (ii) modeling with generalized stochastic Petri nets (GSPN) [7].

The main contributions of this work can be therefore identified in:

- a novel (Cloud-based) service-oriented paradigm for MCS, i.e., MCSaaS;
- a reference architecture for the MCSaaS stack;
- a prototype MCSaaS implementation, i.e., MobiCSOS, developing basic mechanisms, such as churn management, that serves as a proof of concept for the proposed approach;
- a preliminary evaluation of the MCSaaS potential on Android mobiles, based on simple real-world scenario and a larger-scale analytical model.

The remainder of the paper is organized as follows. Section 2 provides an overview of related work. Section 3 focuses on the overall MCS scenario, characterizing and motivating the MCSaaS approach we propose, while Section 4 presents the infrastructure elements. Section 5 deals with the main features of the MCSaaS platform, Section 6 addresses the problem of application setup and deployment, while Section 7 focuses on the implementation details of MobiCSOS. The MCSaaS-assisted deployment of MCS apps, with regards to urban mobility use cases, are discussed in Section 8, with some numerical evaluation based both on an emulated scenario and on a GSPN model, while conclusions are drawn in Section 9.

2. Preliminary concepts and related work

2.1. Mobile crowd-sensing

MCS [1] is an emerging trend, lying at the intersection of volunteer and crowd-based computing, IoT, and sensing paradigms. It refers to a broad range of community-powered sensing approaches belonging to either *participatory* [8] and/or *opportunistic* [9] categories, aiming at involving large population of contributors [2,10].