Computers and Electronics in Agriculture 135 (2017) 96–107

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

# Sensing-cloud: Leveraging the benefits for agricultural applications

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ARTICLE INFO

*Article history:*
Received 16 July 2016
Received in revised form 27 January 2017
Accepted 31 January 2017
Available online 10 February 2017

*Keywords:*
Sensor-cloud
Virtualization
System model of sensor-cloud
Sensor-cloud for agricultural applications

ABSTRACT

The advent of the sensor-cloud framework empowers the traditional wireless sensor networks (WSNs) in terms of dynamic operation, management, storage, and security. In recent times, the sensor-cloud framework is applied to various real-world applications. In this paper, we highlight the benefits of using sensor-cloud framework for the efficient addressing of various agricultural problems. We address the specific challenges associated with designing a sensor-cloud system for agricultural applications. We also mathematically characterize the virtualization technique underlying the proposed sensor-cloud framework by considering the specific challenges. Furthermore, the energy optimization framework and duty scheduling to conserve energy in the sensor-cloud framework is presented. The existing works on sensor-cloud computing for agriculture does not specifically define the specific components associated with it. We categorize the distinct features of the proposed model and evaluated its applicability using various metrics. Simulation-based results show the justification for choosing the framework for agricultural applications.

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## 1. Introduction

In precision agriculture, WSNs are used to address different problems (e.g. Ojha et al., 2015; ur Rehman et al., 2014; Barcelo-Ordinas et al., 2013; Burrell et al., 2004). Some of the existing works in this domain with WSN applications are categorized into irrigation management (Nikolidakis et al., 2015; Lichtenberg et al., 2015; Reche et al., 2015; Greenwood et al., 2010; Gutiérrez et al., 2014; Moghaddam et al., 2010), precision agriculture (Chen et al., 2015; López et al., 2011; Díaz et al., 2011; Park et al., 2011; Riquelme et al., 2009), farmland monitoring (Corke et al., 2010; Voulodimos et al., 2010), greenhouse gases monitoring (Mao et al., 2012; Yang et al., 2013; Malaver et al., 2015), agricultural production process management (Dong et al., 2013; Díaz et al., 2011), optimization of plant growth (Hwang et al., 2010), and security and intrusion detection in fields (Roy et al., 2015; Garcia-Sanchez et al., 2011). However, these WSN-based applications primarily target serving single application only, on which WSN is deployed by the users only at their specific interest area. Consequently, only the users (generally the user organization) has access to the data, and, thereby, they are in sole charge of the maintenance of the network. Third party access to this information is generally not enabled in this framework. Alternatively, data sharing may happen between organizations with exchange of money.

In recent times, the sensor-cloud framework has become very popular in various application domains. Compared to traditional WSNs, sensor-cloud provides numerous advantages. The science behind cloud computing empowers the distributed WSNs for enhanced storage and information processing capability. The integrated framework also creates a virtualized platform of sensors, which facilitates efficient and real-time information sharing among multiple users. The virtualization technique also enables dynamic resource management, which, in turn, increases resource utilization. Due to the abstraction of computing resources and efficient access control techniques, the overall architecture also provides information security. All these features the sensor-cloud framework suitable for real-time decision support in multi-user, multi-application scenarios.

The initial works in sensor-cloud focused on defining the infrastructure and its components (Yuriyama and Kushida, 2010). Over the recent years, the concept of sensor-cloud and its architecture has matured (Alamri et al., 2013). In one of the initial works, the concept of physical sensor and its services virtualization was proposed by Evensen and Meling (2009). Later, Ibbotson et al. (2010) presented a semantically rich service oriented architecture (SOA), which focuses on simplification of sensor service discovery. Recently, Misra et al. (2014a) presented a theoretical model of sensor-cloud, which mathematically formulates the underlying

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http://dx.doi.org/10.1016/j.compag.2017.01.026
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virtualization technique involved in this technology. The authors promoted the concept of Sensor-as-a-Service (Se-aaS) (Misra et al., 2014a) and showed the benefits of the architecture in terms of cost effectiveness, lifetime of sensor nodes, and fault-tolerance. Madria et al. (2014) present an architecture for sensor-cloud which define the different part of the protocol stack and interconnections with physical sensors as well as users. In this work, the authors envision the sensor-cloud protocol stack comprised of three vertical layers – *sensor-centric*, *middleware*, and the *client-centric*. The Agriculture Sensor-Cloud Infrastructure (ASCI) (Kim et al., 2014) shows how various agricultural services can be offered via the sensor-cloud platform. The ASCI framework also devises a layered architecture, which shows the integration of various deployed sensors with different services. Krintz et al. (2016) proposes an open source, cloud-based agricultural analytics service named SmartFarm. This platform integrates various different technologies such as satellite imagery, weather predictions, and existing data sets with on-farm sensors. One major objective of this platform is to provide a cost-effective platform for data analytics ensuring data privacy.

### 1.1. Motivation

The sensor-cloud framework is strongly founded on the principle of virtualization. The cloud provides the facility for storage and retrieval of huge amount of sensed data. Using the virtualization concept, the service providers are empowered with the power of greater sensor utility, while maintaining information security. In this distributed framework, the sensor owner is responsible for the deployment of sensor nodes. The service provider takes care of the maintenance and deployment overhead for the deployed nodes. The end-users consume the sensed information through various services offered by the service providers. Thus, the users are relieved from the task of deployment, maintenance, redeployment, system up-gradation, and any such works.

In Fig. 1, we depict the structural comparison of the architecture for WSN and sensor-cloud. In this figure, we depict that WSNs are envisioned to work with single user and single application. On the other hand, sensor-cloud provides a framework supporting multiuser and multi-applications. The end-users subscribe to these various services which are running as applications in the framework. Unlike the traditional WSNs, in sensor-cloud we can construct different access levels which ensures information safety for different levels of users.

In agricultural applications, this framework is very helpful due to its cost effectiveness and minimal maintenance requirements. The end-user, typically a farmer, has no burden of deploying and maintaining the field sensors unlike what would happen if they had used the conventional WSNs. From the service providers point-of-view as well, the sensor-cloud framework provides enhanced benefits. Unlike WSNs, in sensor-cloud, the service provider is able to utilize the deployed sensors for multiple applications and services. In turn, the service providing organization is able to provide the services to more number of people. The distributed framework also guarantees certain amount of fault-tolerance for the services. This is of great help specifically for agricultural applications, where sensor nodes face harsh climatic conditions leading to fault-proneness of the nodes. Thus, the sensor-cloud framework has the potential for leveraging benefits for both the end-users and service providers.

### 1.2. Contributions

In this paper, we present a sensor-cloud architecture for the agricultural applications. We present a mathematical model of sensor-cloud virtualization specifically targeting agricultural applications. The mathematical model includes details on different components involved in virtualization. Using case studies, we point out the specific benefits of this new framework over the existing WSN-based framework. Simulation-based results are presented for both these frameworks. In the following, we list the major contributions of our work.

- We present the physical node virtualization model for agricultural applications. Mathematically, we justify the advantages of the sensor-cloud framework over the traditional WSN-based framework.
- We formulate the sensor node utilization model targeting any agricultural application. The theoretical model presented in this paper focuses on building up a virtual sensor configuration, which enhances node utilization.
- We present a model for providing cost effective agricultural computing services to large number of farmers.
- The theoretical model depicted in this paper is suitable for a multi-organization, multi-user, and multi-application scenario. This is a significant paradigm-shift from the typical agricultural applications.

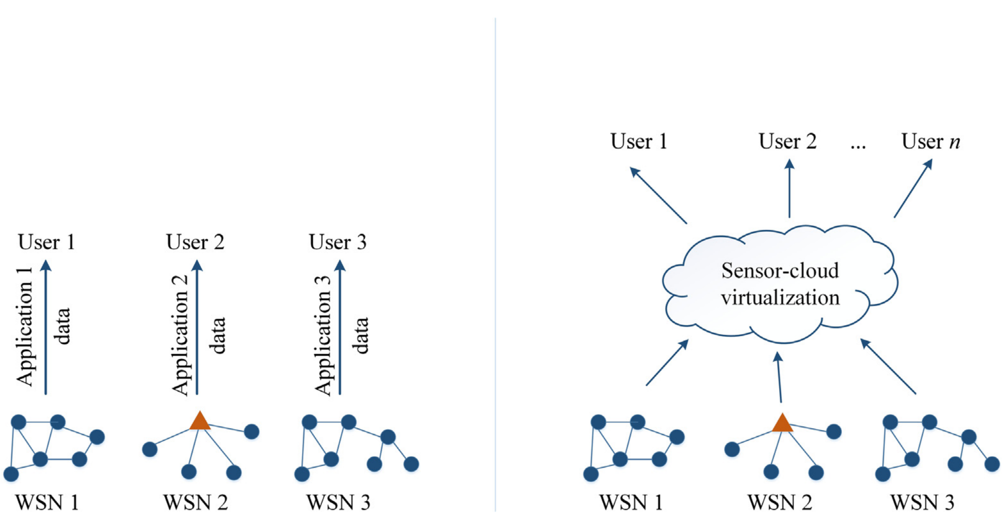


**Fig. 1.** Comparison of architectures: WSN vs sensor-cloud.

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