1-1-2016

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Recommended Citation

Rabah, Sleiman; Belqasmi, Fatna; Mizouni, Rabeb; and Dssouli, Rachida, "An Elastic Hybrid Sensing Platform: Architecture and Research Challenges" (2016). *All Works*. 439.
https://zuscholars.zu.ac.ae/works/439

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 94 (2016) 113 – 120

Procedia Computer Science

The 13th International Conference on Mobile Systems and Pervasive Computing (MobiSPC 2016)

An Elastic Hybrid Sensing Platform: Architecture and Research Challenges

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Abstract

The dynamic provisioning of hybrid sensing services that integrates both WSN and MPS is a promising, yet challenging concept. It does not only widen the spatial sensing coverage, but it also enables different types of sensing nodes to collaboratively perform sensing tasks and complement each other. Furthermore, it allows for the provisioning of a new category of services that was not possible to implement in pure WSN or MPS networks. Offering a hybrid sensing platform as a service results in several benefits including, but no limited to, efficient sharing and dynamic management of sensing nodes, diversification and reuse of sensing services, as well as combination of many sensing paradigms to enable data to be collected from different sources. However, many challenges need to be resolved before such architecture can be feasible. Currently, the deployment of sensing applications and services is a costly and complex process, which also lacks automation. This paper motivates the need for hybrid sensing, sketches an early architecture, and identifies the research issues with few hints on how to solve them. We argue that a sensing platform that reuses the virtualization and cloud computing concepts will help in addressing many of these challenges, and overcome the limitations of today's deployment practices.

Peer-review under responsibility of the Conference Program Chairs

Keywords: WSNs, Mobile Phone Sensing, Integration, Dynamic Provisioning

1. Introduction

Wireless sensor networks (WSNs) have been widely used for implementing large and small scale sensing infrastructures, as means to collect data about our surroundings physical world in many application areas (such as health, environmental monitoring, agriculture, etc.). With the help of sink and gateway nodes, sensor nodes in WSNs collaborate together to perform well defined sensing tasks, process, and communicate the collected data. The sink, or a base station, is a WSN node that allows the communication between sensor nodes and the outside world. It collects data from sensor nodes, on which it performs simple processing before it forwards it to the interested devices. WSNs have been initially designed to be used for a specific domain and perform a single task and cannot be easily reused

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Peer-review under responsibility of the Conference Program Chairs
doi:10.1016/j.procs.2016.08.019

to run new applications. This results in costly and redundant deployments. On the other hand, mobile phone sensing (MPS) is an emerging people-centric paradigm that incorporates the concept of "human-as-a-sensor" [7]. Recent mobile phones that are equipped with built-in sensors and carried by people (crowd) are used to collect data about their surrounding environment [8].

Although WSNs' deployments have been successfully used to collect real-time information, the static nature of the WSN nodes limits the capabilities of the sensing applications as additional deployment of sensor nodes is required for more spatial coverage. Integrating WSNs and MPS does not only results in a highly flexible and large-scale collaborative computing-enabled sensing infrastructure and benefits from the advanced sensing capabilities of mobile phones, but also from the mobility of nodes that results in extended spatial coverage where traditional static sensors are difficult to deploy. Moreover, MPS brings several advantages to sensing applications. First, the human factor in MPS, also known as participatory sensing, has additional benefits since the users can directly enhance the sensing service functionality by controlling the service or by providing manual information input (that is, human sensing). For example, by typing text (e.g, personal opinion, current sensation), taking images, recording audio/video. Second, the large number of mobile phones owned and operated by people and that have an increasing processing power can be used to perform the same sensing tasks as a WSN, without requiring the acquisition of new sensing hardware nor significant deployment effort and cost. MPS can also take advantage of the participatory sensing paradigm which adds a social aspect (community sensing) to the sensing process.

The work presented in this paper focuses on how to provide an elastic framework for hybrid sensing service provisioning. A hybrid service is a service that relies on both mobile phones and WSN infrastructures to collect data and achieve the sensing service goal. Service provisioning covers the whole life cycle of a service, which includes development, deployment and management of services. The framework elasticity refers to the ability to adapt the resources to the service's need. In other words, resources are allocated dynamically in order to satisfy the quality requirements of the sensing service. The aim is to integrate WSN and MPS paradigms in order to create a collaborative sensing environment where different kind of sensor nodes (static and mobile) can be used as source of information and to use the available nodes in an efficient way (i.e. the same set of nodes can be used to provision different sensing services). Such integration enables collected data from WSNs to be complemented with MPS data. Virtualization is a promising enabler for resource efficiency and platform elasticity. It allows physical computing resources to be divided (sliced) into several isolated logical (virtual) units so that they can be efficiently shared and used by multiple independent users/applications [9,6]. A Lot of work was done in the context of both WSN and MPS service provisioning. However, only few attempts were carried out regarding hybrid sensing. In this paper, we present a scenario that illustrates our vision for a hybrid sensing platform, and which also pinpoints the motivations behind. We also propose an early architecture for the platform and identify the related research challenges.

The remainder of this paper is organized as follows: in Section 2 we discuss a motivating scenario along with the derived requirements. Section 3 presents the related work. In Section 4 and 5 we describe the proposed overall framework architecture and detail the associated challenges. In Section 6 we conclude the paper and present some future research directions.

2. Motivation and Requirements

2.1. Motivating Scenario

In this scenario, a set of heterogeneous sensor nodes are used to provide two services: tracking of electrical vehicle charging stations, and charging stations' deployment planning.

Service 1: Electric Vehicle Charging Stations Tracking System Electric vehicles (EVs) are environment friendly, they are considered as an alternative to fuel-based cars, and they are being sold at an increasing rate in North America. However, harsh weather conditions during the winter, especially in Canada and the cold parts of the United States, have an impact on the life span of the car's battery. This makes the battery charge unpredictable and leaves the owners of EVs in doubt: How long will the battery last? Will it allow the driver to reach his final destination?

To help and assist EVs' owners while traveling, there is a need for a system that efficiently tracks the locations of EV charging stations (CSs) and assist owners with relevant and real-time information about weather, road, traffic conditions, and waiting time in the EV stations. In this first part of the scenario which is depicted in Figure 1, we consider an EV owner, John, who is planning to go on a long road trip for which he needs assistance. Using an application installed on his mobile phone, John can configure his trip and then get the locations and characteristics of the available CSs on his way. At the same time, he can also get the nearby services of interest where he can spend time while the car is charging. This information is collected form CSs, WSN deployment at that specific location or from people using their mobile phones.

While on the road, John can also receive real time notifications about the road condition, the CSs' condition, his EV battery status, and up-to-date recommendations in order to avoid battery drainage. As example, if the EV station John is planning to go to is crowded (i.e. the waiting time is too long) or/and a traffic jam is observed on one of the roads while the EV battery is low, the system re-computes an alternative route taking into consideration the remaining battery charge as well as the collected information about the road and weather conditions from different sources. The traffic and weather conditions can be monitored via WSN nodes and/or can be crowdsourced that is, collected by mobile phones carried by people (crowd) who are on the same way as John. The crowd can also report active construction sites via images or text. The WSN nodes used here can be running multiple concurrent tasks, including tasks for monitoring various weather-related aspects (e.g. air temperature, humidity level and quality, and wind speed). The information collected by the different nodes may be oh heterogeneous type and granularity.

Fig. 1. Motivating Scenario: Electric Vehicle Charging Stations

Service 2: Charging Station's Deployment Planning In a region where the infrastructure is already deployed, the municipalities wish to efficiently manage and optimize the usage of the CSs' infrastructure and predict the need for the installation of new ones. For example, they would like to know when and where additional CSs can be deployed to cope with the increased demand. To this end, information about daily usage of CSs need to be collected over a period of time. Existing WSN deployments already used for the first service can be re-used here. In addition, to have better prediction for potential CSs use, CSs collected information would be complemented by the information coming from the mobile phones of the drivers that are taking the roads of the area of interest. In fact, the mobility patterns of those drivers can give a better insight about the future use of these stations.

2.2. Requirements

We classify the requirements for a hybrid sensing platform into three categories as follows:

1. Service and Resource Management: Service and resource management covers three key requirements.
   (a) Dynamic service management: the framework should enable on demand creation, deployment, and management of sensing services, which can be deployed on a subset of available sensing nodes that may span multiple domains.
   (b) Node and service publication and discovery: the framework should provide a mechanism (including protocols, algorithm, etc.) for publication and discovery of information about sensing nodes and services. This will allow existing resources having specific characteristics (such as location, sensing and processing capabilities, etc.) to be dynamically discovered, selected and used to create and deploy hybrid sensing services.
   (c) Scalability and elasticity: the framework should support efficient resource usage and allow for dynamic scalability and elasticity. Resources' assignment to applications should depend on the applications' need, and should be updated following the needs fluctuations. This will allow the sensing infrastructure to be shared by a wide range of heterogeneous applications and services.

2. Business model: participating sensing nodes can be owned by different types of owners and the collected data may be used by different parties to develop new attractive sensing services. Therefore, the hybrid sensing framework should not be tied to a specific WSN, mobile, or service provisioning business model. The underlying business model should be open and flexible enough to support different business roles and actors. In addition, the model should clearly state how to regulate, for instance, the data ownership, the hardware and network usage of the sensing nodes (and charging stations in the scenario) as well as access to/and deployment of new services.
3. Data management: As described in the motivating scenario section, the trip planning application uses information collected from various WSN nodes and mobile phones. Different sensing applications and services may need to integrate data originated from different sources that do not necessary have similar characteristics. For instance, sensors in CSs can be more accurate than mobile phones' sensors. This leads to three main requirements.

   (a) Information modeling: data collected from different sources may have heterogeneous types, granularity, and format. The framework should provide a common information model for describing functional and non-functional aspects related to the data collected from different participating entities (e.g. WSN nodes, mobile phones, user profiles, etc.) in a formal and expressive manner. Such model would facilitate data sharing and reuse by different applications.
   (b) Data collection and dissemination: This requirement covers two aspects: data exchange and data reliability/quality. Regarding data exchange, the framework should allow the applications to access the data via a standardized interfaces. The communication between the platform and the data sources is covered by the heterogeneity requirement discussed next. Concerning reliability, collected data may have different levels of accuracy and quality. Data collected by municipality sensors are for instance more reliable than data entered manually by users (e.g. report of active constructions in the scenario). The framework should provide a mechanism to assess data integrity and rate its reliability.
   (c) Heterogeneity: The framework should support data collection from (and therefore communication with) various sources, including WSN nodes and mobile phones. These sources may have heterogeneous sensing capabilities, operating systems, and communicating interfaces. The framework should not depend on any specific WSN/Mobile operating system. It should support interoperability between different types of networks and application domains as well as interfacing several networks together such as WSN, WiFi, cellular, Internet, etc. Ideally, any technological change should not have an impact on the overall operation of the system.

3. Literature Review

In the literature, a lot of work has been done to provision WSNs and to provision MPS services. Thus, many of the requirements discussed in the previous section are not new and have been tackled from the perspective of WSN or MPS, but not in a hybrid environment. For instance, the authors in [7] proposed a generic participatory sensing framework which tackles data management and heterogeneity by providing a set of application-specific and independent dataset models, for different sources. In addition, scalability and elasticity have been tackled in [10] where the authors introduce the concept of sensing as a service (S^2aaS) in which sensing services are provisioned through smart phones with the help of a cloud platform. Similarly, when provisioning WSN, most of the applications need to accommodate the requirements of various types of devices and sensing services[13]. The authors in [6] address the challenge related to service and resource management, however, for a different context. Their proposed cloud-based architecture decouples the applications and services from the hosting WSN and incorporates cloud computing's PaaS and IaaS into WSN in order to enable efficient management and usage of resources and services. Another framework is proposed in [11] that tackles heterogeneity in WSN. It allows for creating personalized smart environments based on users' needs. As mentioned previously, despite its increasing importance, only few solutions have been proposed for the integration of both WSN and MPS. Ruan et al.[2] introduced a collaborative sensing paradigm that involves wireless sensors (static nodes) and mobile phone participants. They proposed a framework that enables the integration and deployment of wireless sensor nodes in mobile phone assisted environment using different communication standards. However, their work mainly focuses on the sensing quality and availability of the involved sensing nodes while aiming at minimizing the cost of sensor deployment. Huang et al.[3] proposed a framework that uses peer-to-peer and

Table 1. Existing Hybrid Platforms: Comparison

	Requirements					
Related Work	Information modeling	Data Dissemination	Dynamic deployment of Services	Heterogeneity	Concurrent execution of services and elasticity	Different business models
Ruan et al. [2]	No	Partially	No	Yes	No	No
Huang et al. [3]	No	Yes	No	Yes	No	
Kroc et al. [1]	No	Yes	No	Yes	Partially	Yes
Villalonga et al. [4]	Yes	Yes	No	Yes	Yes	No

publish/subscribe approaches for building an overlay network composed of mobile and wireless sensing devices and enabling data exchange among them. Mobile clients in such a framework, can subscribe to sensing events of interest at a specific location to collect data which will be later disseminated by the concerned wireless sensors by means of notifications to subscribers. Although their framework support and enable data dissemination between heterogonous devices, their work mainly focuses on reducing communication overhead using efficient routing strategies. Krco et al.[1] advocates that wireless sensor networks should be interconnected with other networks such as mobile networks in order to enable a global collaboration and sensing paradigm. They proposed an architecture that is based on a horizontal approach that aims at decoupling sensor networks from end user services by introducing a broker and processing layers in between. Moreover, to enable an open business environment in which a sensing service can be used by multiple applications, they introduced a new business model with four distinct entities. Villalonga et al.[4] proposed a multi-layered information model to be used in, but not limited to, the SENSEI project[5]. The model introduces tree layers for describing raw sensor data, observation and measurements as well as context information. Although this model is flexible and facilitates information exchange by employing semantic annotations. However, it lacks support for describing sensor nodes related characteristics and capabilities. As shown in Table 1, the above papers meet some of the requirements we identified in the previous section. However, none of them consider the on-demand provisioning and dynamic deployment of hybrid sensing services nor enable resource management to cope with changing requirements (e.g. more resources). In order to address this challenge, our framework relies on the virtualization of resource (sensing nodes) to enable the dynamic deployment of several hybrid sensing services and the efficient use of physical sensing nodes- while taking into consideration the interoperability between mobile phones and wireless sensor networks.

4. Proposed Architecture

Figure 2 depicts the overall architecture we are proposing. It consists of a broker and three layers, namely: Application layer, Platform layer, and Infrastructure layer. The broker is a public repository (with access control policies) that stores information about existing sensing nodes and services. It allows sensing infrastructure providers/owners to publish the description of the sensing nodes they offer along with their availability, capabilities, and other characteristics (e.g. pricing). The advertised sensing nodes can be later selected and used to deploy new applications/services, or to scale-up existing ones.

The application layer represents the sensing applications that are provided as a service to end users. A sensing application can be composed of one or more sensing services (e.g. a same application may be providing both services described in the scenario in section 2.1), and can be consumed by end users using different types of client devices (e.g. cell phone, desktop).

The platform layer consists of the key building blocks that enable the dynamic provisioning of sensing services by service providers. It contains two main components: Service Management Engine (SME) and Data Management Engine (DME). The SME contains the necessary functions for enabling dynamic discovery, composition, deployment, and management of sensing services. It interacts with the broker in order to discover available resources of interest. Newly created services may also be published for reuse by other providers, depending on the service provider preferences. The SME is also responsible for testing the deployed services and monitoring their quality and usage. The DME supports the SME by providing data modeling, integration, and representation. It describes the collected data using a common model (i.e. data modeling), integrates the appropriate data, when needed, to support the requesting application/service (i.e. data integration), and represents the data in the appropriate format (e.g. XML, JSON) for the target application/service (i.e. data representation).

The main component in the infrastructure layer is the Resource Management Engine (RME), which insures the interaction between the platform layer and the actual sensing nodes. RME includes four functions and a local repository: 1) the sensor description and publication function describes the available sensing nodes under the control of the infrastructure provider. Some of these nodes may be private to the infrastructure and others may be made available for use by the platforms. Private nodes are published in the local sensor description repository, whereas sharable nodes are published into the broker. 2) The mapping and monitoring function is used to map sensing services/applications to the set of sensing nodes assigned to them, to monitor the usage and availability of these nodes, and to keep track of the amount of resources in use and the number of participating nodes in a given service/application; 3) the resource configuration function is responsible for activating, de-activating, and configuring both virtual and physical sensing nodes. Configuration includes, for instance, which sensing task to execute (e.g. sense temperature), for how long (e.g. one day), and with which frequency (e.g. every 5minutes); 4) the resource allocation and de-allocation (RA&D), which is the core function in the RME, coordinates the RME operation in providing elastic and on-demand allocation of resources. When a new service/application is created by the platform, the service deployment function in the platform layer sends a resource allocation request to the RA&D, with the list and characteristics of the sensing nodes that were selected for the service. The RA&D instructs the resource configuration function to configure the appropriate nodes, and the mapping function to store the mapping information and start the monitoring process. And depending on the monitoring output and the feedback from the platform layer, resources may be scaled up or down. After the deployment phase, continuous communication is kept between the RME and the platform for service management purposes. The sensing resources in this layer represents the different kind of sensing nodes such as static nodes, cameras, mobile phones as well as physical and virtual sensors (VS). The sensing resources interact with the layer above via the communication layer that is responsible for hiding the communication interface heterogeneity of these resources to the rest of the nodes in the architecture.

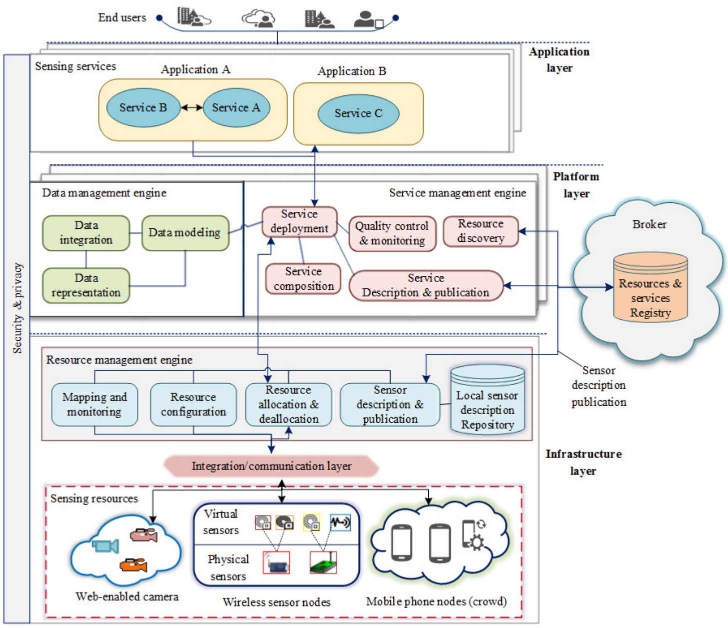

Fig. 2. Proposed Architecture

5. Research Challenges

The key research challenges associated to the hybrid sensing architecture are four folds, as discussed below:

5.1. Design and validation of a platform for hybrid sensing service provisioning

A framework for provisioning hybrid sensing services should allow for efficient creation and deployment of a diversified set of sensing services as well as for an automated and on-demand management and monitoring of such services. The framework should also enable concurrent execution of sensing services on the very same sensor node/network. Therefore, there is a need for a mechanism that allows the on-demand deployment of services based on a pre-defined set of requirements in an efficient manner. In this regard, virtualization which enables the cost-effective sharing of resources is considered as one key enabling and promising technique. Physical resources can be divided into several logical units (slices) enabling them to be shared and used by multiple independent users/applications. However, WSN virtualization is still a very challenging topic and many technical issues still need to be tackled. Examples include virtualizing different components of a sensor node (e.g. MAC and routing layers) and preventing different applications using the same set of sensor nodes from harming each other, dynamic activation and de-activation of sensing tasks on specific nodes[14].

Furthermore, the framework is intended to be used by various parties in order to gain on- demand access to sensing services. The challenge remains in making hybrid sensing services and applications available from any device while taking into consideration the interoperability between heterogeneous devices and networks (WSN, mobile, Internet, etc.). A sensing application that requires a mobile phone to talk to WSN nodes introduces new challenges including connectivity (i.e. how to connect the phone to the WSN? using wifi, blue-tooth, or other) and communication protocols (e.g. HTTP, UPDP, etc). Standardized communication and programmatic interfaces to be used should be carefully selected.

5.2. Resource management

Dynamic deployment of services relies on finding the best set of nodes whose capabilities comply with the service requirements. Thus, physical and virtual sensors' capabilities and characteristics should be described and published in a concise yet expressive way, so that they can be later discovered and selected based on several requirements. To this end, a dynamic publication and discovery mechanism that supports heterogeneous services/sensing nodes (WSN nodes and mobile phones) is needed. A standardized information model should be used to describe participating sensing nodes' functional and non-functional attributes. Such a model should enable efficient data dissemination and sharing. It should also enable service requesters to formulate their needs and requirements in terms of requested services and sensing nodes. Therefore, selecting the best set of nodes whose capabilities comply with service's requirements need to be performed in an optimal manner. This problem has been already tackled in WSN (deployment strategy) and in MSP (worker selection algorithms). In MPS-WSN, however, the nodes are not playing an identical role, yet, in most of the cases they are playing a complementary role. This results in a challenging nodes selection process. For instance, to satisfy the requirements of a given sensing services, what would be the percentage of WSN nodes and the percentage of MPS nodes and how this will affect the quality of the collected data. Selecting sensing nodes and services should be based on different criteria, depending on the application requirements (e.g. nodes location, data reliability, service characteristics, etc). Another challenge consists in tracking and adapting the amount of resources that are allocated to each service. This should be done dynamically so that resources that are no longer needed can be deallocated and made available to be used by other services. The concept of elasticity of resources and pay-per-use concepts offered by cloud computing can be employed. One potential enabler for solving the problem of nodes and services description and discovery is using semantic web.

5.3. Data management and service composition

WSN and MPS have different sensing models. In WSN data are directly collected from well-configured (and generally trusted) sensor nodes. Whereas in MPS, data are not only collected from mobile phone's sensors but also can be contributed by people (acting as human sensors). This results in data augmented with knowledge and having various dimensions such as social, contextual intelligence, etc. Furthermore, WSN and MPS nodes are owned by different parties and in this case data ownership becomes critical. Questions such as who is the actual owner of the data (the person who produced the data, network operator, the application that is collected the data?); what are the measures to ensure people's privacy and protect sensitive data; can the people-generated data be trusted? should be answered. There should be an automated data management and integration mechanism that allow the fusion of the data generated from different sources. Another issue relates to service composition and consists of identifying hybrid services that can provide the required information of interest. For instance, a composite service that is composed of two or more services (such as temperature, air quality, pollution level, etc.) can be dynamically created and deployed.

5.4. Secure the proposed platform

Another important challenge is securing the proposed framework due to the heterogeneity of supported networks and participating devices. Different security aspects and schemes related to WSN cannot be applied to MPS and vice versa. This is due to the fact that WSN and mobile phones provide different sources of information and employ different sets of hardware (more computational capabilities in mobile phones), protocols and software. Therefore, the same security techniques, approaches and schemes to ensure various security aspects such as privacy, preventing attacks and denial of service as well as data integrity and authenticity may not be used in a hybrid sensing environment that involves both WSN and MPS. Moreover, security requirements should be taken into account while creating and deploying sensing services in order to cope with potential threats and denial of service attacks.

5.5. Social Aspect

MPS is associated with many remaining unsolved issues and challenges due to its people-centric nature. These challenges have been already identified in the literature [12]. For example, among others, limited battery life, processing power, and expensive data plans as well as users' reputation and privacy. Another issue in participatory-based sensing relates to the privacy and confidentiality aspects with regard to users' collected data such as location, identity and personal information, as most of the collected data is geo-tagged and time-stamped. Integrating WSN and MPS will lead to the inheritance of those challenges making them also applicable to WSN-MPS. Therefore, the impact on the integration should be thoroughly studied.

6. Conclusion

Currently, sensing is mainly done through WSNs or MPS, and the provisioned applications and services are domain specific (i.e. either for WSN or for MPS). The integration of both WSN and MPS is a promising approach that is considered as a step further to enable the provisioning of hybrid sensing services that take advantages of both paradigms combined. This will lead to the creation of a new type of sensing services where data is collected from various and heterogeneous sources. On the other hand, the current process of sensing applications and services' infrastructure deployment is costly and complex. The non-sharing of the sensing infrastructure leads to redundant deployments (e.g. different WSN network for each application) and non-efficient use of resources (e.g. if the application for which a sensor node is deployed requires 50% of the node's resources, the other 50% is wasted because not used by other applications). In this paper, we proposed a multi-layer architecture for dynamic provisioning of hybrid sensing services. Our architecture integrates both WSN and mobile phone sensing paradigms. As future work, a prototype of the proposed architecture will be developed and validated.

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