An Ubiquitous Service-Oriented Architecture for Urban Sensing

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Abstract. In the transformation from traditional to smart cities, there is an increasing trend around the world towards intelligent dynamic infrastructures that provide citizens with new services that can improve their quality of life and fulfill the criteria of energy efficiency and sustainability. In the light of this, an important challenge is how to enable citizens and cities to promote the sensing of data with regard to a number of different factors. This paper outlines the early stages of our research which is concerned with an ubiquitous service-oriented architecture for urban sensing called UrboSenti. The proposed approach differs from other sensing plat-forms since it provides a set of services to collect data from several sources and assists in the development of new sensing applications. In addition, our model encompasses all the sensing activities, ranging from the collection of data to the generation of reports about events in the city.

Keywords: Urban Sensing, Smart Cities, Service-oriented architecture, Ubiquitous.

1 Introduction

The urbanization of cities has been increasing dramatically in the last few years and it is expected that this migration of people to urban areas will continue [4]. For this reason, the question of how to meet the goals set by this socioeconomic development and thus ensure the residents' quality of life, has become a complex matter. The concept of Smart Cities is a response to this challenge [14].

According to [12], Smart Cities are urban systems that use Information and Communication Technologies (ICT) to provide an infrastructure and public services within a more interactive, accessible and efficient city. The authors point out that the predictions of a further rise in the urban population (about 70% by

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2050) has led to the emergence of the concept of Smart Cities. As a result, it is not only necessary to provide new types of services to assist in the organization of the city and the welfare of its residents, but also to offer sustainable alternatives, which can reduce the consumption of natural energy resources, and the emission of harmful gases in the atmosphere, by the use of renewable energy.

As can be seen, the concept of Smart Cities involves different areas. The final report of the "European Smart Cities" project [10] suggests that there are six factors that should be taken into account in this context: economics, governance, people, mobility, natural resources and quality of life. In all of these, it is clear that technology plays an important role as a tool-based means of arriving at solutions for inherently complex urban scenarios.

In view of this, researchers are raising important questions about how to foster citizen participation and community involvement to achieve a better interaction with the urban ecosystem. Among these initiatives, social urban sensing applications are a promising way to bring the computational world and community closer together.

In this paper, we outline the early stages of our research on an Ubiquitous Service-Oriented Architecture for Urban Sensing called UrboSenti. Our approach differs from other sensing solutions by providing a set of distributed services to collect data from several sources and assisting in the development of new sensing applications. Moreover, our model combines social sensing with traditional sensing and encompasses all the sensing activities, ranging from the collection of data to obtaining a high-level view of events in the city.

In summary, this paper adopts a seminal approach to urban sensing by employing an innovative ubiquitous service-based architecture. In addition to being original, it signals the way that further research can be carried out in this area.

This paper is structured as follows: The next section provides an overview of related work; Section 3 describes the motivational scenario and raises some of the current computational challenges; Section 4 describes the proposed architecture, and, finally, in Section 5 some conclusions are reached, together with recommendations for future research.

2 Related Work

In the literature, there are a number of key studies in urban sensing area.

In AnonySense [15,5], there is a framework for opportunistic and participatory sensing with a strong emphasis on privacy. This adopts a polling model for task dis-tribution to anonymize the location of the mobile device within the infrastructure. Furthermore, tasks are written by means of a domain-specific language called AnonyTL, which makes use of predicates based on the context of the mobile device, such as location and whether the device is moving or not.

Medusa [13] is a programming framework that provides a programming language and a distributed runtime system with a focus on crowd-sensing. This seeks to provide a common platform to carry out any kind of task supported by smartphone sensors. Medusa achieves this by employing a programming language based on XML, called Med-Script. It also specifies the workflow of sensing tasks that will be performed in smartphones (workers) that are coordinated with cloud services.

PRISM [7] provides a mobile phone sensing platform that can facilitate the development of large-scale sensing applications. PRISM seeks to address some issues of security, privacy and scalability, together with concerns about controlling the resource access in smartphones.

MobiSens [16] is concerned with the design, implementation and evaluation of a flexible platform for mobile sensing. It can be used on an individual scale (e.g. monitoring the falls of elderly people) or with community and public scales (e.g. collecting data from participants to infer collective behavior). Furthermore, MobiSens seeks to meet some of the common requirements made by these types of applications, such as privacy, energy optimization, interaction between the server and mobile client and recognition, segmentation and annotation activities.

Pogo [2] proposes a middleware infrastructure for mobile phone sensing to facilitate the construction and testing of large-scale sensing applications. Furthermore, Pogo enables the granularity of resources to be controlled at user-level to protect the privacy of volunteers. It uses the XMPP protocol to disseminate data sets.

Micro-blog [9] is responsible for the design and implementation of an application, that can allow smartphone equipped users to generate and share multimedia content data called microblogs. This kind of data can be browsed or queried through Internet map services so that different information can be obtained about stored data.

MetroSense [8] is an architecture for large-scale urban sense services that adopts an approach of opportunistic sensing networks. It takes advantage of its interaction with mobile devices and provides coordination between mobile and static people-centric sensors. On the basis of this analysis, it can be noted that all the studies examined are involved with the area of urban sensing. However, most of them only perform sensing by means of mobile phones (smartphones), and fail to carry out this task with a mix of different source, such as mobile and fixed devices. The only work that addresses other devices is MetroSense, but unlike our approach, this does not consider data from social networks.

AnonySense has a large overhead arising from the use of the pull-model. This ensures more privacy for the device than the push-model, but does not scale very well in large-scale applications. Nonetheless, the process of anonymizing data used by AnonySense and PRISM is a desirable characteristic for crowd-sensing applications that need to publish public data in an anonymous way; however, it is not suitable for all types of systems such as healthcare and personal sensing services. In our work, these issues are not intrinsically bound to the core of the platform. Instead, we provide a set of services for this purpose so that the developer can use it when required.

Moreover, most of the works support both opportunistic and participatory sensing, as is the case with our approach (the exceptions are Medusa and Micro-blog that only address participatory sensing, and in contrast, MetroSense that only supports opportunistic sensing). However, only AnonySene and MetroSense consider the use of Delay-Tolerant Networks (DTNs) as a paradigm for situations where the infrastructure is not available. In our platform, support will be provided for both opportunistic and participatory sensing with the use of several communications paradigms, including DTN.

Furthermore, a key area where our approach differs from all the others is the usage of Service-Oriented Architecture (SOA) to design the services and components. This provides more flexibility for integration than the other current solutions, by reducing the complexity of the proposed platform and leveraging the reusability of the existing services to find new solutions rather than trying to re-invent the wheel. Finally, it should be highlighted that all the works focus on gathering sensing data. However, none of them is concerned about providing a complete solution for collecting and analyzing data or giving people feedback. It is our belief that we are filling this gap by providing a platform that covers all these stages.

3 Application Scenario

Our research has been driven by the problem-scenario that is shown in Fig. 1. This scenario includes a city with several data sources that are being used for sensing. Human-carried, fixed or vehicle-mounted sensors are applied for obtaining sensing maps of transits, air quality, noise levels, temperature, CO2 concentration, etc. Moreover, data from social networks are used in conjunction with sensors data to provide a holistic view of the city.

The scenario in the diagram considers an urban sensing ecosystem where the following computational challenges have to be addressed: (i) heterogeneous devices (both fixed and mobile) are used to collect data and access the resulting processed information. (ii) context-aware and adaptation mechanisms are needed to support the application adaptation; (iii) a large amount of data is continuously being generated and collected throughout the city. This requires high processing power, with data preferably being processed in real time; (iv) uncertainty about whether the collected data require data fusion and analytics techniques to generated useful and correct information for decision-making and to allow it to be exported to other systems; (v) the infrastructure for communications is not always available. This require an alternative means of inter-device communication, like ad-hoc networks or delay tolerant networks; (vi) data security of the collected data and privacy for the citizens and devices used by sensing; (vii) the possibility of reusing the software components so that new sensing applications can be deployed. The computational challenges listed above are based on findings from researchers such as [4,1,11,6,3]. They observed an increasing demand for new ubiquitous and pervasive solutions to provide better services for citizens in a Smart City.

With this in mind, we argue that an ubiquitous service-oriented architecture could provide a set of components and services that can meet all the challenges (i to vii) mentioned earlier. In the next section, we will state our views about this architecture.

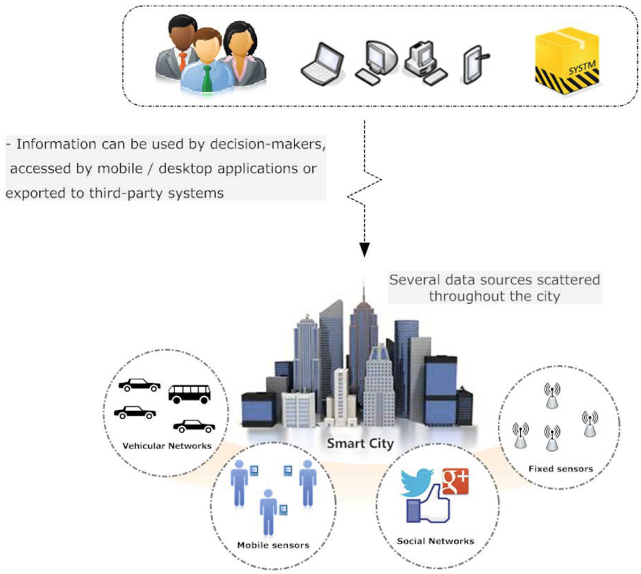

Fig. 1. Problem scenario

4 Proposed Architecture

In this section there will be an examination of an architecture called UrboSenti. UrboSenti is a term that originates from the combination of two Esperantos words: Urbo = urban, city and Senti = feel, sense. We settled on this name, because we want-ed to represent the idea of a computational solution that is able to "feel the pulse" of the city.

Figure 2 provides a high-level view of UrboSenti which involves collecting data from the city, reasoning about them and providing feedback to citizens and other systems. We are adopting a Service Oriented Architecture (SOA) approach to guide our design. In this way, we are able to avoid using well-defined tiers (or layers), since this kind of traditional approach would constrain the value and flexibility of the functionalities of the modules, and thus result in dependencies across the unrelated components. Instead, we designed our architecture in services. This is the SOA mode of revealing the functionalities of the components used by other components or modules, and ensures flexibility and reusability.

Our architecture is split into two key modules: the *Sensing module* and *Backend module*.

The heart and brain of UrboSenti is the *Backend module*. It runs in a data center infrastructure and, in short, is responsible for receiving sensed data, processing it and giving feedback to the citizens and other systems.

Its internal components and services are outlined in Figure 3 and its behavior is explained below.

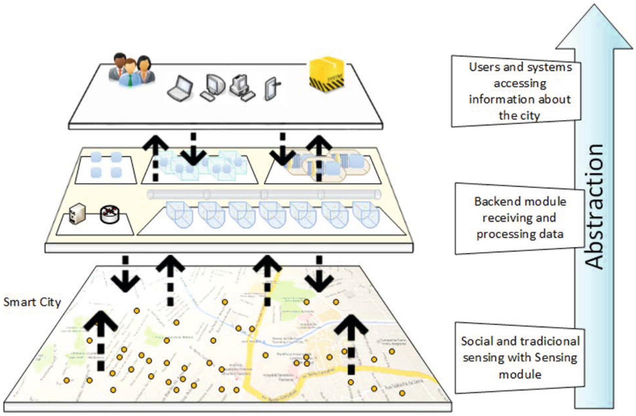

Fig. 2. High-level view of UrboSenti

– **Services Repository:** aggregates all the services available. The services are grouped into categories in accordance with their objectives and those services available are: (i) Data services: used to handle all the data employed by the architecture. It also provides services to retrieve and store data and functionalities as well as to "clean" the collected data from inconsistencies and noise; (ii) Social services: services related to the handling of the relevant data from social networks; (iii) Sensing services: services to interface with

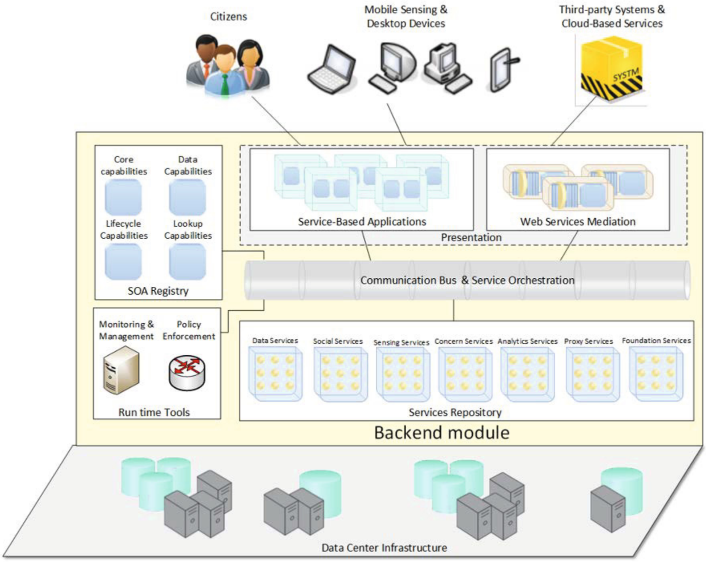

Fig. 3. Backend module

different sensors and aggregate collected data. Its use supports open standards to facilitate data exchange; (iv) Concern services: used to deal with issues of security, encryption and the privacy of data and users; (v) Analytics services: services for mining, classification and reports. In addition to obtaining information, these services are able to correlate data from different sources and predict events in the city; (vi) Proxy services: services to interact with external systems like vehicular or sensor networks and to exchange data with third-party systems; (vii) Foundation services: these comprise all the basic services.
- **Communication Bus and Services Orchestration:** this is the bus used for inter-components communication. It also carries out, the coordination and arrangement of calls and invocations for multiple services so that they can be viewed as a single aggregated service.
- **Web Services Mediation:** this is an intermediary system between external entities, like sensing devices and third-party systems, and Services Repository (invoked by Communication Bus & Service Orchestration components).
- **Service-Based Applications:** all the applications that are built by aggregating the available services from the architecture. Together with *Web Services Mediation*, this composes the most external component of the architecture, called Presentation, which interacts with the users and other systems.
- **SOA Registry:** this it is an identity-management system for available services. Its internal services keep track of the metadata on the services, which give each service a single identity. The information stored for each service establishes ownership for the service and specifies how the service behaves at run time (the lifecycle of the service). It also provides artifacts to handle the UDDI data store and services registry/lookup.
- **Run Time Tools:** these comprise the tools required for the monitoring and management of the services. They contain artifacts generated at run time, such as logged messages, archived performance data, archived health, and the heartbeat of the main components, as well as providing Key Performance Indicators (KPIs) for dashboards and reports of service performance. The Policy Enforcement ensures that the messages are properly formed and that the services are executed properly and are in compliance with service-level agreements.

The other main module of UrboSenti is called *Sensing module*. This module is re-sponsible for social and traditional sensing and encompasses activities of intentional and non-intentional sensing. It runs in mobile devices (e.g. mobile phones, embedded in vehicles, etc) and in fixed sensors scattered around the city. The internal compo-nents are depicted in Figure 4 and its behavior is explained below. It should be stressed that these components are composed of other subcomponents to provide internal services, but these have been omitted for reasons of clarity and limited space.

- **Micro-kernel:** The core of this module. Its main function is to provide basic services for more external components. Internally, the Micro-kernel is

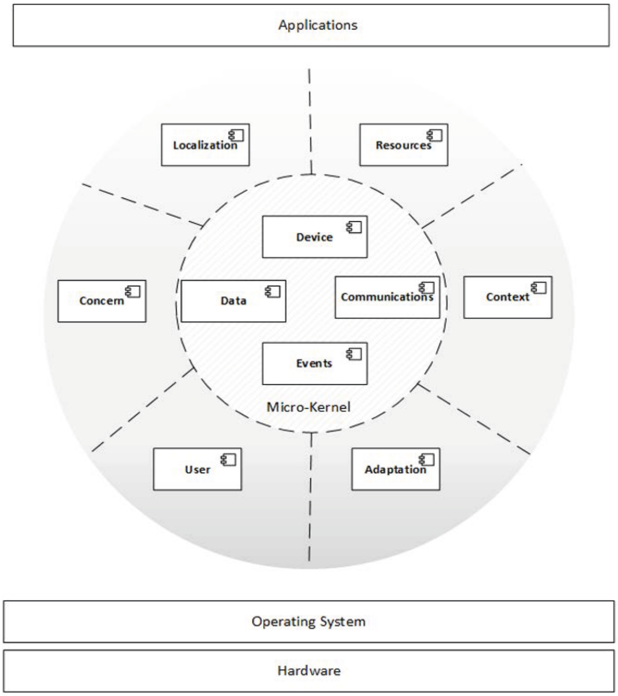

Fig. 4. Sensing module

structured in the following: (i) The Device: this provides basic information about the running device (name, network address, interfaces, GPS, internal sensors, etc); (ii) Communications: this provides methods to send and receive messages by means of the available network infrastructure, such as IEEE 802.11b/g/n (structured and ad-hoc), GPRS/EDGE/3G and Ethernet as the underlying system for TCP/UDP communications. When the network infrastructure is not available, this module provides support for a Delay Tolerant Network approach via Bluetooth interface; (iii) Data: handling operations for storing and retrieving data; (iv) Events: capturing external events of interest (a positional change due to a users movement, alteration of interface status, etc). The detected events are available for use by other components.

- **Localization:** handling localization issues such as geopositioning information, Points Of Interest (POI) and Location Based Services (LBS).
- **Resources:** set of components and services for monitoring local resources and discovering resources from other devices
- **Concern:** handling security, privacy and encryption issues.
- **Context:** group components and methods for context-awareness (i.e. context reasoning, context knowledge, context discovery, context prediction)
- **User:** handling the users preferences, social networks profiles and basic knowledge of the user.

– **Adaptation:** components and services to make adaptations to the behavior of the device. This employs a set of policies and knowledge to describe how to adapt the application and monitor basic quality of service data to infer when the adaptation is needed.

At the top is the Application layer which represents the sensing applications. At lower layers, are Operating System and the Hardware of the device.

The development of UrboSenti has been started. Currently we are mainly working on the Sensing module, or more specifically on the Micro-kernel. The basic functionalities of all the internal modules, except the Communications module, have been carried out. We are coding this module so that several network interfaces can be used to send and receive data in accordance with the existing infrastructure. We already have support for TCP/UDP communications with the aid of the wireless and wired infrastructure. However, we are stuck with Bluetooth communication used in Delay Tolerant Networks paradigm. At this stage, we are facing difficulties about paring new devices in suitable time and exchanging information with existing devices without timing out. However, we hope to solve this issue soon so that we can be in a position to start coding the external components of the Sensing module. After this, our focus will be on the Backend module. This module has a good deal of coding material and requires a long time to be carried out. In other words, we have a hard task to ensure that the two main modules will be able to exchange data and that the pro-posed platform can be used in a real scenario.

5 Conclusions and Future Work

In this paper, we have described the early stages of our attempts to build a new ubiquitous service oriented architecture for urban sensing called UrboSenti. We have also outlined our initial design for the software modules, their internal components and the provided services. The proposal has one significant difference from that of other researchers, which is that our approach is able to fill the gap that has been left by related studies and addresses the computational challenges raised by our initial problem-scenario. Moreover, this should encourage us to conduct further research into the multidisciplinary area of Smart Cities with the aim of improving services and applications for urban sensing.

As way of making a step forward in this research, it is worth highlighting the need for the proposed modules to be encoded and to find a way to simulate the implementation before it is put in a real test-bed.

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