Scenarios, Research Issues, and Architecture for Ubiquitous Sensing

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Abstract. This paper describes research issues and work-in-progress concerning ubiquitous sensing. We present scenarios where the current approaches are deficient in addressing the needs for ubiquitous sensing in services and applications on the Future Internet, involving the massive sharing of information from sensors via heterogeneous networks. We propose an information-centric architecture for real-time ubiquitous sensing which capitalizes on the proposed locator/identifier split, thus extending the Network of Information (NetInf) approach. From this we identify the challenges for which we present work-in-progress within the framework of the EU-funded MediaSense project. Firstly, we integrate sensors as addressable objects, exposed by means of sensor gateways and relocatable abstract interfaces. Sensor information is thus made available to applications solely based on identity. Secondly, sensor information is made available in a distributed data model towards searching and browsing. Finally, we evaluate the effectiveness of the architecture in proof-of-concept applications for intelligent commuting, environmental monitoring and seamless media transfer, utilizing two different sensor platforms.

Keywords: Ubiquitous computing, sensors, Future Internet.

1 Introduction

The ability for applications and services to have access to sensor information and be able to act upon it via actuators is becoming increasingly more important; even urgent. This is particularly the case where it concerns our ability to manage energy and to bring about a sustainable environment. As a result of communications becoming more pervasive, in urban areas and rural areas alike, we have become citizens in an electronic world however still needing to stay in touch with artifacts, people and places in the real world. With sensors and actuators massively connected to the Future Internet environment, accounting for the majority of connected nodes, increasing in numbers by orders in magnitude, impacts on the required mechanisms and architecture. Further, it increases the amount of information that should be searchable and accessible to services and applications via the Internet. Thus reachable via heterogeneous networks, involving wireless and mobile communication, networking, and information brokering.

K. Pentikousis et al. (Eds.): MONAMI 2010, LNICST 68, pp. 285–297, 2011.

Several initiatives and projects have addressed this area and recognized the need for an information-centric approach in contrast to earlier network-centric approaches. In particular, the EU-funded 4WARD-project proposed a Network of Information (NetInf) approach in which end-devices are integrated as sources and consumers of network information, thus enabling end-devices as parts of a whole [1]. The NetInf approach, capitalizing on a locator/identifier split, is proposed to enable content-centric networking (CCN) [2], which retrieves content by name instead of network location. The NetInf approach envisages multimedia associated with real-world information from entities (e.g., people, places, artifacts, etc.). Extension though integration of real-world information is a possibility, which is left unexplained.

Scenarios for a sustainable planet involving ubiquitous sensing regarding the environment, transport and social mobile media, which will be further discussed below, constitute requirements on real-world integration. Firstly, sensors and actuators should be integrated as addressable objects. Sensor information is thus associated with entities via interfaces in end-devices and made available to applications in an extended network of information with ubiquitous sensing. Secondly, sensor information must be incorporated and made available in an extendible, searchable and browseable (distributed) datamodel. Thirdly, a pre-condition is that the provision of sensor information is scalable to accommodate the billions of nodes that will populate the Future Internet[1]. Fourthly, sensor information should be available in real-time (i.e., within predictable and reasonable finite amounts of time, relative to the application domain). Finally, as a consequence of extending the NetInf approach, sensors must be reachable by identities and be associated with entities.

Previous efforts have focused on the brokering of sensor information via web service infrastructures and 3G mobile systems, such Mobilife [3], or via clients connected with web services to servers on the Internet [4,5,6,7]. Brokering sensor information centralized via IMS in 3G Mobile Systems is not suitable for our purposes. Web technologies using DNS are not a suitable architecture.

Other related work [8] has focused on network aspects, and the granularity of the actual exchanged context information. While in other cases, on entire systems and exploring what is possible within the constraints of current research[9,10].

The EU-funded project SENSEI [11] proposes a logical architecture which is compatible with the NetInf approach but has as yet not provided answers about how sensors are integrated, how such information be available and searchable in real-time or in a scalable fashion, alluding in its architecture to centralized mechanisms such as LDAP.

In order to address these deficiencies we propose an architecture and middleware for the scalable integration of actuators and sensors in a network of information for ubiquitous sensing.

The remainder of this paper is organized as follows: Section 2 discusses the urgent need for ubiquitous sensing in three key areas from which we derive our

[1] http://gigaom.com/2010/04/14/ericsson-sees-the-internet-of-things-by-2020/

requirements for an extension of a network of information. Section 3 discusses the principle operation of the architecture and its components for the scalable integration of sensors and actuators in a browseable network of real-time sensing information available to applications and services via heterogeneous networks. Section 4 examines the effectiveness of the proposed architecture and middleware components applied to the key scenarios in relation to the identified goals. Finally, in section 5 we summarize our findings and section 6 concerning further work beyond the work-in-progress discussed in this paper.

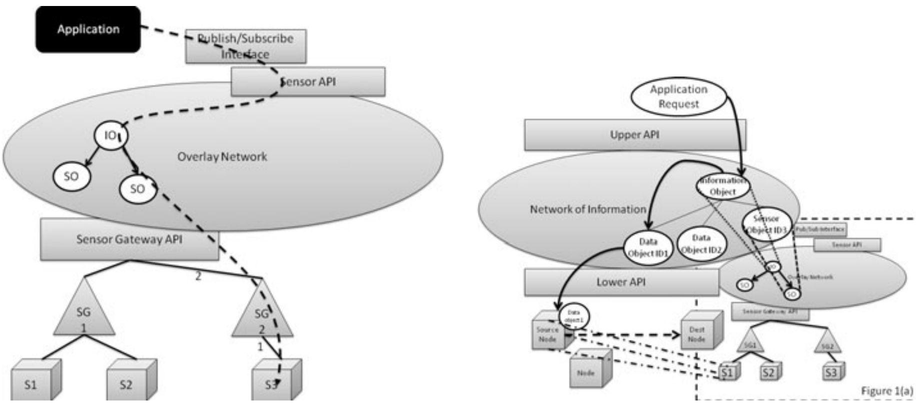
2 Scenarios

In this section, we discuss the urgent need for ubiquitous sensing along with its consequences. The requirements summarized at the end of the introduction above are pivotal to ubiquitous sensing. These general requirements are further elaborated below through an examination of certain key scenarios.

There are huge challenges ahead in the management our environment on a global level. Our knowledge that our way of living is not sustainable has improved due to the proliferation of satellite and other climate monitoring systems. Equally has our understanding that course-grained measures as restrictions for industry or private consumption are very blunt tools. The situation requires more fine-grained tools in interacting with the real world in terms of applications and services that have access to sensor information and actuators on a massive scale. Such tools would enable authorities, industry and consumers to help minimize waste and the misuse of our planet's resources such as energy. This however requires real-world information to be available as distributed data that is searchable and browseable.

Transport infrastructure has to be more responsive to our needs. Thus, the status and actions of the parts and components in a transport system must be monitored and controlled on a much more fine-grained level, with the information being accessible to applications and services that are available to users. The need and even necessity for applications and services to interact with transport infrastructures via communicating sensors and actuators applies to both public transportation (e.g., bus, train, air, etc.) and private transportation (e.g., cars, roads, etc.). When entities participate in such a system, applications would benefit greatly from having timely access to real-world information provided by other entities.

Further, on a global level, individuals have become citizens in an on-line world with an ever-increasing range applications and services. Our communications infrastructure is increasingly populated with novel devices and connecting to appliances in our personal environment for entertainment, utility services, etc. The number of connected devices that we as individuals or as members of families or communities alone wish to interact with, even using a cautious prediction will exceed 50 billion. Entities, sensors and actuators should be able to join spontaneously and be able move in the infrastructure. Thus, individuals will be



(a) The Mediasense Architecture

(b) NetInf framework with the Mediasense architecture

Fig. 1. Extending the NetInf architecture with the Mediasense architecture to support ubiquitous sensing

enabled to stay in touch and perform tasks using content, devices and real-world information that is accessible via heterogeneous networks and reachable based on identity.

We summarize the discussion of the consequences of ubiquitous sensing in relation to a network of information in an elaborated list of requirements:

a) applications can reach sensors using an identity independent of location *b*) sensors are attached to the network of information interfaces which abstract from the implementation of communicating with the sensors *c*) abstract sensor interfaces allow physical sensor hand-off and roaming *d*) sensor information is organized in an extendible datamodel, which allows spontaneous additions *e*) sensor information dissemination support is scalable to accommodate a massive number of nodes exceeding current predictions of 50 billion *f*) a sensor information database must be distributed *g*) a sensor information database must be searchable and browseable *h*) the architecture must support sensor information discovery *i*) a sensor information database must be updated in real-time

3 Concepts and Architecture

The NetInf architecture has identified several base concepts which are influencing the overall architecture, most prominent is the Identifier/Locator split which is a necessary part to enable the addressing of individual ubiquitous sensors (requirement a). On the future Internet when sensors are attached to not only stationary devices, such as weather stations, but also on people via their mobile phones, as well as vehicles and animals, sensors must be able to move and attach to the Internet from the different locations (req. c). Due to an increasing number of sensors, we cannot assign an individual IPv4 address to each sensor. To cope with the increasing amount of sensors and to keep the cost of such sensors to the minimum, we introduce the concept of a Sensor Gateway represented as a triangle in figure 1(a).

Sensor gateways constitute a point of network attachment for sensors in our architecture. Thus sensor gateways communicate with sensors (see boxes in fig. 1(a)) and enable sensor access through a Sensor Gateway API to and from even the simplest sensors (req. b). All sensors and sensor gateways are given a globally unique identity which is stored in a distributed overlay (req. f) and are divided into two types of objects akin to objects in NetInf. The first, a sensor object (SO in fig. 1(a)), contains the identity of the sensor and the location of the sensor gateway that is currently hosting the sensor. The second object is an information object (IOin fig. 1(a)) which similarly to NetInf contains semantically meaningful information. The distributed overlay provides an upper API (see fig. 1(a)) which mediates access to sensors without needing to know the location of an object. The distributed overlay is capable of exchanging context information in real-time by utilizing a distributed hash table (DHT) based on Chord [12] (req. i).

A publish/subscribe API and a socket-like interface are located on top of the overlay API. The application may use this to combine sensor information into new information that is logically stored as a new sensor inside the overlay. For instance, an application could connect to, retrieve all temperature sensors from a municipality, and then provide a new sensor that represents the average temperature of the whole municipality. This publish/subscribe API allows applications to access the raw sensor information, which is illustrated using a dashed line in figure 1(a). In addition to this, the socket interface can ubiquitously find the information, regardless of location, which enables mobile context-aware applications to utilize the architecture. In contrast to previous publish/subscribe solutions, our architecture and API's will be extended to support searching and dissemination in real-time.

3.1 Extending NetInf for Ubiquitous Sensing

By extending the NetInf architecture with the Mediasense architecture we introduce a new kind of data object, a sensor object. For example, an information object that represents a certain song (e.g., Mozart's Eine Kleine Nachtmusik) is associated with a data object. The data object contains a payload (e.g., an mp3 file with a certain encoding). In this example, a sensor object's payload contains the current state or value that is retrieved in realtime (e.g., of the user's proximity, temperature, light, mood, etc.). The information object that represents the sensor contains the sensor's semantical information since sensor values need context to be usable for applications (e.g. it's geographical location, technical specification or other important information), see further [13]. Both sensor objects and their corresponding information objects are duplicated by their realtime updating counterparts in the mediasense architecture as the dashed lines in figure 1(b). The lower API in the NetInf architecture may thus access sensor information through the mediasense upper API in the same way as it accesses a source node. Hence, the upper API of NetInf accesses information regarding

(a) Wireless Sensor Platform

(b) Ethernet Enabled Sensor Platform

Fig. 2. Wireless Sensor Network Gateway

sensors in the same way as other objects. Figure 1(b) shows how the mediasense framework from figure 1(a) is integrated into NetInf.

Mobility in the architecture can happen, as sensor and data object move around in the world. The system is however agnostic of communication medium, and therefore most communication which can move, will utilize ubiquitous mobile Internet-access such as the 3G or 4G networks. However if a sensor or data object has moved between connectivity mediums or devices, and therefore also changed the network connection, an update is required in the architecture. Therefore, when a sensor object appear with a new connection, it will update it's corresponding information object, with current information on the physical location of the sensor object. Which will result in a successful movement of all related information between two physical locations.

3.2 Sensor Network Platform

A Wireless Sensor Networks (WSN) consist of cheap, small and energy constrained sensors interconnecting to create a network, enabling reliable and automated sensor data acquisition with minimal human intervention. These WSNs are an important source of context information and by utilizing the support proposed in section 3 the sensor information can be efficiently delivered to other entities. By extending and improving the wearable bridge described in [14] we have built a prototype sensor-actuator combination, figure 2(a). The prototype consists of two individual devices.

The first device is the large box, which is capable of measuring temperature and humidity; by connecting the box as a power strip, we can also measure the power consumption of up to two household appliances simultaneously. Apart from measuring the power consumption, the prototype provides actuators that can control the power sockets individually. This sensor is aimed towards home usage, and utilizes the Zigbee radio protocol instead of bluetooth to communicate with the second part. The line in figure 1(a) denoted with number 1 indicates communication using wired or wireless sensor-specific hardware and protocols.

The second device is shown in the embedded picture in figure 2(a) and is the hardware part of a sensor gateway. Several sensors can communicate with this gateway and several gateways can communicate with an entry point into the mediasense overlay in figure 1(a) denoted by the number 2. This protocol is based on HTTP and uses GET and POST messages for communication with a subset of response messages.

Important to note is that when a new sensor registers with a sensor gateway and the sensor's type is not recognized, then the sensor gateway will retrieve a module from the overlay, which enables communication with the new sensor without user intervention. This enables sensors to be truly mobile by only requiring a nearby sensor gateway, which possesses the required hardware protocol and a basic sensor identification protocol. The sensor gateway detects a node that has the sensor gateway API during the initialization phase using IP broadcasts. This API may be located on the local host or the local network.

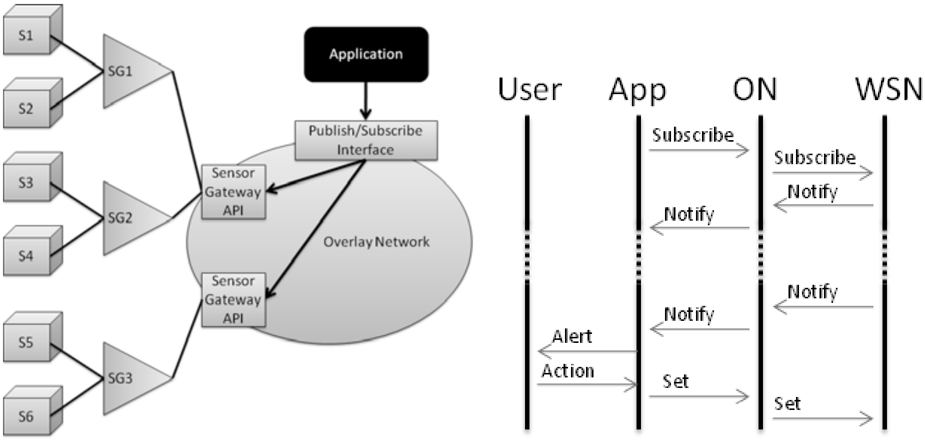
An extension to this sensor network platform has been developed for use in areas where the use of a computer as a gateway between the Zigbee network and IP network is not possible. This sensor platform employs simpler radio protocol but has an Ethernet interface, see figure 2(b), and offers both sensor information as IP-addressable web pages and sensor information in the mediasense overlay. Currently, only environmental monitoring(temperature, humidity) is enabled with this platform but more sensors and eventually actuators will further complement the platform later.

4 Functional Verification

This section evaluates the effectiveness of the architecture as it is applied to three different scenarios that are presented as three proof-of-concept prototypes. In different places we reference back to the requirements list presented in section 2.

4.1 Environmental Awareness

Due to advancements in technology, sensor solutions are becoming inexpensive; this enables more pervasive use of sensors in environmental awareness applications. One scenario under current investigation is the use of sensors to monitor the environment in cross-connection rooms and other broadband installations of ISPs. There exists an urgent need to monitor the local environment of such infrastructure with regard to temperature, humidity and power consumption, etc. ISPs need to react pro-actively to changes in the environment that currently remain undetected. By having sensors able to detect events, from temperature and humidity to events such as flooding or fire, a more rapid and correct response can be engaged.



(a) Architecture Overview (b) Signalling Overview

Fig. 3. Environmental Sensing Architecture

Thus, sensors must be able to provide environmental information in real-time (req. i) and be accessible to an ISP's monitoring center (req. g). The information must also be available to maintenance staff who are mobile (req. a). The architecture should scale and use a low amount of bandwidth to allow for extending the ISP's infrastructure globally (req. e).

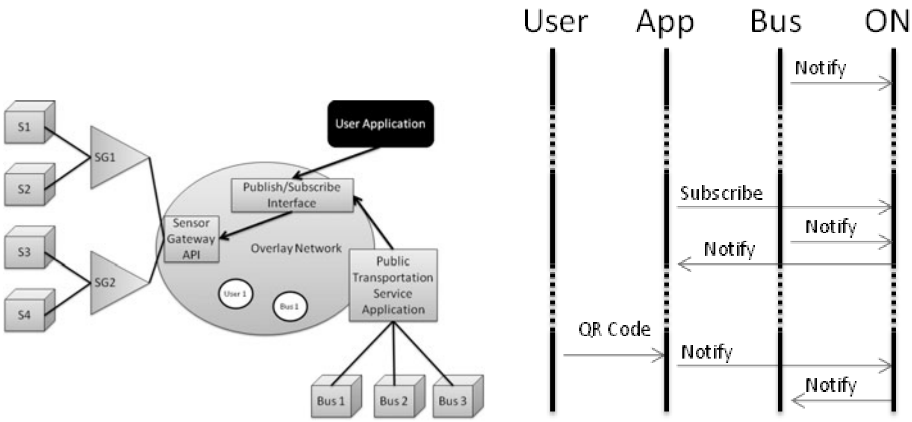
Our architecture supports this scenario by enabling sensors to be accessed globally with the aid of a sensor gateway at each location(req. a). Our architecture allows access to sensors from a remote monitoring application, be it a central facility or a mobile device.

Figure 3(a) presents the proof of concept. On the left side there are multiple sensors that may be located at several installations of the operator. The sensors are attached to local sensor gateways, which communicate with the overlay through a sensor gateway API. Management software, be it a stationary computer or a mobile terminal, is connected to the infrastructure from the other end. Compare with figure 1(a). The system scales by adding more nodes associated with sensor gateways and APIs (req. e).

Figure 3(b) shows the signaling in a scenario when a monitor application subscribes to sensors at each location. The sensor gateways join the overlay, which in turn shares information from associated sensors. Later the user is notified of some event that in response can access actuators via the overlay.

4.2 Context Aware Commuting

With the introduction of smart phones for the mainstream market, there are an increasing number of sensors available to be exploited for the benefit of the user. Mobile applications and services may benefit from knowledge about the user's context through gaining access to sensor information (e.g. temperature, GPS coordinates, nearby WLAN). Sensor information may be further combined



(a) Architecture Overview (b) Signalling Overview

Fig. 4. Commuting Support Architecture

with the user's digital information (e.g., schedule and contacts) in order to determine other relevant information such as the user's current destination. Mobile applications and services may combine such knowledge with public transportation system information in order to provide suggestions concerning travelling preferences, travel time, cost, or information concerning the destination. Such a system require both access and storage of a digital profile of a user containing personal preferences and automatically acquired sensor information as well as access to information from public transportation systems thus creating a NetInf containing real-world continuously updating data.

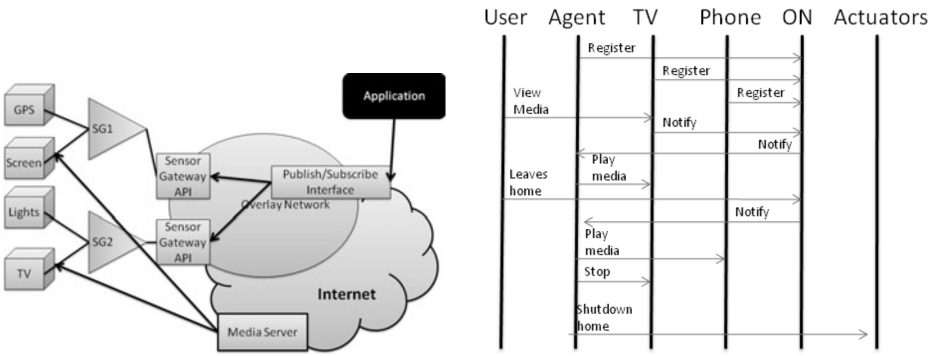
Our architecture supports this by providing both the ability of the public transportation system to input timetables and location of their vehicles as well as the user's ability to connect when desired to synchronize their personal profile with fresh data and acquire travel suggestions from the system.

The initial prototype uses QR codes[2] to detect the proximity of a bus stop, but the context service can also find the bus stop by other means, such as GPS and nearby bluetooth devices. After positioning the user at a bus stop, the service can provide information about the bus route; the information could include a timetable, the time until the next bus arrives and its route displayed on a map. Figure 4(a) shows how several busses are connected into the architecture from one side and the users' connection from the other.

The architecture enables users to retrieve information from remote buses and maintain an online profile allowing bus drivers to receive notifications when someone is waiting at a bus stop.

The signalling for this scenario is detailed in 4(b), where a bus is continuously submitting context information to the service. Later a user connects and registers in order to obtain information regarding the bus.

[2] http://www.qrcode.com/index-e.html



(a) Architecture Overview (b) Signalling Overview

Fig. 5. Seamless Media Transfer Architecture

4.3 Seamless Media Transfer

By incorporating sensors providing real-time data about users and media into a NetInf, we enable the architecture to decide where it should deliver content based on the recipient's current and future whereabouts. When leaving our residence, an ongoing media session may follow us. Seamless media support transfers the media session from the media center in our residence to a mobile device. In the process the seamless media support shuts off devices that are not required using the actuator power strip presented in section 3.2. Figure 5(b) presents the signalling used when the user starts playback of some media and then leaves the home. In figure 5(a) the first sensor gateway (SG1) is connected via Bluetooth to a mobile phone and the sensor gateway API runs in user's mobile phone. The second sensor gateway (SG2) is located in the residence. Mobile phone, TV, and media server are connected to the MediaSense overlay, which enables the user's agent to respond to sensor information, move the media session to mobile and minimize energy consumption at home.

5 Conclusions

Above we described research issues and work-in-progress concerning ubiquitous sensing. In order to derive requirements and key research issues, we presented three key scenarios where current approaches are deficient in addressing the needs for ubiquitous sensing in services and applications on the Future Internet. In particular, services and applications require the massive sharing of information from sensors via heterogeneous networks. Further, services and applications must be able to connect to sensors using an identity and not a location, adhering to the observations of the NetInf approach. Sensor information must be current (in real-time) and available in a searchable and browseable distributed data model.

In response to these challenges, we propose an information-centric architecture for real-time ubiquitous sensing which capitalizes on the proposed locator/identifier split, thus extending the Network of Information (NetInf) approach. Sensors are exposed as first-class objects in a distributed information base using relocatable abstract interfaces. Sensor information is thus made available to applications solely based on identity through sensor sockets. Further, we presented work-in-progress within the framework of the EU-funded MediaSense project, involving proof-of-concept prototypes including two sensor platforms and gateways for the sharing of sensor information in a peer-to-peer context information network via abstract interfaces. We evaluate the effectiveness of the architecture in prototypes pertaining to the three key scenarios (intelligent commuting, environmental monitoring, and seamless media transfer) in terms of the list of requirements and key research issues. We demonstrate the integration of sensors and actuators as information objects that may be reached via their identities, by means of sensor gateways and relocatable abstract interfaces.

6 Future Work

Further research in the area of ubiquitous sensing on the Future Internet should focus on extending the proposed support. In particular, the massive and seamless sharing of sensor information requires new mechanisms to enable seamless and ubiquitous sensor connectivity. We are working on extensions to the presented support to include the ability to establish and maintain context sockets, which can deliver seamless connections to heterogeneous sources. Further, the dynamic relation between presence entities and sensors mandates the search for effective extensions to presented middleware for the massive sharing of sensor information. The sharing of sensor information in real-time, search and browse, as well the discovery of sensor information require scoping mechanisms to be effective, where current approaches offer insufficient answers. Real-time properties and other properties involved in ubiquitous sensing which were discussed earlier require evaluations of not only of the architecture, as presented above, but other aspects as well. Such an evaluation may require a method to classify the constraints in real-time context aware applications. We envision that the main aspects would be responsiveness of the system, i.e. the delays, together with scalability since the system will contain the billion sensors of tomorrow. The goals for the system is to enable a perceived real-time delivery of it's content which also allows for the inclusion of millions of sensors. The tools used for the evaluation could initially comprise of simulation software, but as methods are developed subsequently entail monitoring of infrastructure, including analysis support. Further research should also entail efforts towards abstracting physical sensors into logical objects creating higher-level interaction for applications and services attempting to navigate the heterogeneous properties inherent in reasoning over ubiquitous sources.

Acknowledgments

The work was conducted under the MediaSense project and partially funded by the EU Regional Fund and the County Administrative Board of Vsternorrland. The authors acknowledge Muhammad Amir Yousaf and Prof. Bengt Oelmann for the development of sensor platforms used throughout the project, as well as Roger Norling for implementing the context-aware bus system in cooperation with Swedish Connection.

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