Infrastructure for Smart Cities: The Killer Application for Event-based Computing

Alejandro Buchmann
Databases and Distributed Systems Group
Technische Universität Darmstadt
buchmann@informatik.tu-darmstadt.de

Smart cities are part of the Ambient Intelligence vision that foresees the vanishing of computational devices into the fabric of society and the ubiquitous availability of intelligent services in support of our daily lives. In this vision we should not be burdened by conscious manipulation of devices and ever more powerful but also complex interfaces. Instead, devices should be able to communicate and cooperate and support us in a proactive manner. For this vision to become true, an infrastructure is needed that can provide for the seamless provisioning of intelligent, pervasive, context-aware services throughout all the domains of our daily lives. As we move in our daily activities from the home to means of transportation and public spaces, to spaces for work and leisure, the infrastructure must be capable of supporting us in a variety of places, situations and contexts. Accordingly, the notion of context must be very rich and must encompass a deep understanding of the user and his or her needs and preferences, as well as the availability of resources in a dynamically reconfiguring environment.

The spontaneous interaction of devices and the wealth of sensors providing data and detecting events make the traditional computing paradigms based on simple request/reply or point to point messaging inadequate. Instead, event-driven processing is needed, in which producers and consumers of events are not aware of each other's existence and events are delivered to interested parties by a broker (network) and the corresponding notification mechanisms [1].

Event services are a crucial part of the infrastructure for smart cities. The *event composition and management service* will be responsible for defining, detecting, composing and managing events. Simple events will be collected from sensors, positioning devices, and other event sources. Simple events may either be consumed directly by reactive components or may be filtered and composed. Event algebras are needed for defining valid event compositions. Both graph based and query based composition mechanisms will be used. The event management service is also responsible for storing and managing the event definitions and event state. Stateful event composition is needed, whenever complex event patterns for which events may have to be collected over longer time intervals must be analyzed.

The complexity of the application stems from several factors that compound each other:

- ***The rich set of events.*** Events range from simple sensor readings, different kinds of aggregations, to complex events, such as traffic patterns, temporal events (both physical and logical time), positioning and other types of context-sensitive events.
- ***Extremely large numbers of sensors and mobile devices***. Even for a medium sized city with only 100 000 inhabitants, each with his/her own positioning and authentication device, several personal computing and communication devices ranging from cell-phones to PDAs and laptops, multiple processors in such smart devices as glasses or health monitoring devices, multiple processors in each car interacting with the environment, etc., the total number of devices will be in the millions.
- ***Heterogeneity of devices***. The broad range of capabilities characterizing the devices, ranging from resource rich to resource frugal, from stationary to mobile, from high-bandwidth wired to low-bandwidth wireless communication, from devices with stationary power supply to power constrained battery-driven devices requires a variety

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of protocols and management policies. Furthermore, different lifecycles for the various technologies involved will require spanning multiple generations of technologies.

- ***The need for seamless integration across multiple domains and spaces.*** In spite of the advances that have been made in the areas of ubiquitous and pervasive computing, most of these efforts have concentrated on insular solutions that are limited in scope, for example, the home or car, or have been oriented at solving individual aspects of interaction. Providing seamless integration and event-driven computing across these insular solutions is an unsolved problem.
- ***Unstable communication and interference.*** Stable and lossless event processing under unstable communication and mobility is a major challenge. The problem gets compounded whenever the density of devices increases and the risk of interference and inadvertent miscommunication increases.
- ***Quality of service requirements.*** Event processing must occur with well defined quality of service guarantees. These may range from availability and dependability to the observance of timing constraints and the support for privacy and security.
- ***Proactive computing, in which devices cooperate and provide the user with choices.*** To support proactive computing it is necessary to anticipate a user's needs, deriving knowledge from his or her profile and from previous experience and correlating this knowledge with the current context. Huge amounts of context data and events must be tracked, processed and correlated.
- ***Device orchestration and self-X properties.*** In highly dynamic environments devices must be discovered, their resources must be detected and the interaction of devices must be orchestrated. In the extreme, these large distributed systems must be self-configuring, self-protecting, and self-healing since no central administration will be possible. The basis for Self-X behaviour is (recursively) the detection of events, the comparison of situations to standard situations and the triggering of the corresponding actions.

The vision of Ambient Intelligence and the scenario of providing context-aware services in the cities of the future prompted the European Commission to include in its call for the 7th Framework Programme "the next generation of ubiquitous … service infrastructures for communication, computing and media" [2]. Event-based computing plays a central role in the realisation of this vision. The richness of events, the sheer size of the application, the heterogeneity of devices and technologies, the need for seamless integration and fulfilment of quality of service guarantees, device orchestration, and self-management of the infrastructure will make this the killer application for event-driven computing.

References:

[1] Buchmann, A., Bornhövd, C., Cilia, M., Fiege, L., Gärtner, F., Liebig, C., Meixner, M., Mühl, G.; DREAM: Distributed Reliable Event-based Application Management, in Web Dynamics, Springer, May 2004.

[2] ICT FP7 Work Programme http://cordis.europa.eu/fp7/ict/programme/home_en.html, 2007

Further material can be found under http://www.dvs1.informatik.tu-darmstadt.de/publications/