Chapter 7.12
Pervasive and Ubiquitous Computing Databases:
Critical Issues and Challenges

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INTRODUCTION

The concept of the so-called Pervasive and Ubiquitous Computing was introduced in the early nineties as the third wave of computing to follow the eras of the mainframe and the personal computer. Unlike previous technology generations, Pervasive and Ubiquitous Computing recedes into the background of everyday life: "it activates the world, makes computers so imbedded, so fitting, so natural, that we use it without even thinking about it, and is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere" (Weiser 1991). Pervasive and Ubiquitous Computing is often referred to using different terms in different contexts. Pervasive, 4G mobile and sentient computing or ambient intelligence also refer to the same computing paradigm. Several technical developments come together to create this novel type of computing, the main ones are summarized in Table 1 (Davies and Gellersen 2002; Satyanarayanan 2001).

BACKGROUND

One of the major challenges in turning the Pervasive and Ubiquitous Computing vision into reality is the development of distributed system architectures that will support effectively and efficiently the ability to instrument the physical world (Estrin *et al* 2002, National Research Council 2001). Such architectures are being developed around two core concepts: self-organizing networks of embedded devices with wireless communication capabilities and data-centricity. To augment physical artifacts with computational and communications capabilities it is necessary to enable miniaturized hardware components capable of wireless com-

Table 1. Elements of pervasive and ubiquitous computing

1. Physical and Virtual Integration **Sensing** Information gathering in the physical world and its representation in the virtual world **Actuation** Decisions in the virtual world and their tangible results in the physical world **Awareness and Perception** Using sensed data to maintain a higher-level model of the physical world and argue about **Ambient Displays** Display information from the virtual world on physical artifacts **World Modeling** Representations of physical spaces **2. System Components** **Platforms** Mobile, wearable or implantable hardware devices with small form factor **Sensors and Actuators** Hardware and software platforms for sensing and actuation	**Software Architectures** Adaptable, large scale, complex software infrastructures and development **Connectivity** High-speed, low power wired and wireless communications systems **3. Deployment** **Scalability** System adaptation to cater for massive scale in terms of space, devices and users **Reliability** Security and redundancy technologies for continuous operation **Maintenance** Structured maintenance processes for reliability and updates **Evaluation** Methods to evaluate the effectiveness of information systems outside the laboratory

munication. However, these same characteristics that allow for instrumentation of physical objects also impose significant constraints. Systems architectures require significant changes due to the severely limited resources available on these devices. One possible solution is offered by the emergence of data-centric systems. In this context, data-centric refers to in-network processing and storage, carried out in a decentralized manner (Estrin *et al* 2000).

One objective of data-centricity is to let systems exploit the anticipated high node densities to achieve longer unsupervised operating lifetimes. Indeed, smaller form factor wireless sensor nodes have limited resources and often cannot afford to transfer all the collected data to the network edge and forward to centralized information processing systems. A practical example of the data-centric approach for network routing is directed diffusion (Intanagonwiwat *et al* 2000). This mechanism employs in-network processing by routing data along aggregation paths and thus removing the need for an address-centric architecture. It exploits data naming as the lowest level of system organization and supports flexible and efficient in-network processing.

In summary, databases have a dual role to play in Pervasive and Ubiquitous Computing: in the short-term they need to provide the mapping between physical and virtual entities and space in a highly distributed and heterogeneous environment. In the longer term, database management systems need to provide the infrastructure for the development of data-centric systems. Each of the two phases is discussed in turn in the following sections.

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