Pervasive Wireless Sensor Networks

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INTRODUCTION

Throughout the history of computing, there has been a trend for the ratio of processing elements to people to increase, resulting in the creation and popularization of new usage paradigms. At the start of the modern computer age, many individual users shared a single mainframe in one central location. In the early 1980s, however, significant developments in microprocessor technologies ushered in the desktop era, resulting in a one-to-one correspondence between individual users and their computers. Computer resources were now intrinsically distributed. The growth of the internet allowed these resources to connect to each other. The *pervasive computing* paradigm is the next logical stage in this trend, resulting in the original computer-human ratio reversing, so that multiple computational devices are available to each individual user. In reality, this point was passed a number of years ago. Mobile phones, personal digital assistants (PDAs), portable music players, as well as numerous embedded devices that people now take for granted, has resulted in computing technologies being embedded into the fabric of everyday life. Thus, for the first time, the desire of computing resources being available on an anywhere, anytime basis is a realistic objective.

In addition to computing being available everywhere, *pervasive computing* has a second key element. This tenet states that user interaction with these universal computing elements should occur in as natural and intuitive a manner as possible. Thus, *pervasive computing* technology should be assimilated transparently into the user's natural environment.

Rather than deal with the entirety of this broad topic, the focus of this article is to provide an overview of the key developments on one particular technology which is essential to the realization of the *pervasive computing* vision: the *wireless sensor network*.

BACKGROUND

The original vision for *pervasive computing*, originally termed ubiquitous computing and frequently referred to as such, was articulated in 1988 by *Mark Weiser* (1952-1999), then of Xerox's *Palo Alto Research Center* (PARC) in California. The fundamental concept underlying his proposal was that a person's interactions with computers should be as natural and intuitive as possible. One important consequence of this is that interactions should not be localized to a desktop-style interface, but rather, should be embedded within everyday objects, thus facilitating access to computational resources when and where necessary. In essence, it is a fusion of the anytime, anywhere computing concept augmented with an inherent need for embedded and intelligent user interfaces. Weiser observed that the technologies which have the greatest impact are those that people do not regard as technology *per se,* but, rather, as an integral component of their environment. He used writing, perhaps the original precursor to the information technology revolution, to illustrate his concept (Weiser, 1991, p. 94).

Pervasive computing technologies should be seen as an extension of an individual's own capabilities, rather than an interface to a restricted set of predefined abilities. Instead of limiting people to a standard interface, *pervasive computing* envisages many different kinds of devices and interfaces for a myriad of tasks (Abowd, Mynatt, & Rodden, 2002). As an demonstration, *Weiser's* team at *PARC* developed three kinds of devices corresponding to the inch, the foot, and the yard scale, which they entitled tabs, pads, and boards, respectively. These devices were designed to emulate commonly used office objects like post-it notes, paper note books, and bulletin boards, while providing enhanced computational capacities tailored to the scale of the device in question, and portability where appropriate (Weiser, 1991, p. 103).

With the benefit of hindsight, it can be seen that *Weiser's* vision was ahead of its time. Early attempts to construct prototype systems ran into constant technological hurdles, both in the hardware and software realms. Among the problems encountered were the non-existence of high-capacity wireless networks, display units which struggled to produce output of acceptable quality, a lack of software support for roaming *user contexts* (which had to be developed from scratch), and the absence of practical, easily deployable *sensor networks* to collect the prerequisite information necessary to determine the prevailing context for pervasive systems to adapt their services accordingly. Because of this, the initial focus of pervasive computing researchers was primarily addressed towards remedying the perceived technological deficiencies, rather than on design and usability issues. However, a cross-disciplinary approach is necessary to realize the full *pervasive computing* vision. Thus, research must continue in diverse areas such as Human Computer Interaction (HCI) and software development methodologies.

In the time since Weiser's paper, the parameters and goals of *pervasive computing* have become more clearly defined, so much so that it is already being incorporated into related research areas, such as ambient intelligence (AmI) (Raisinghani, Benoit, Ding, Gomez, Gupta, Gusila, Power, & Schmedding, 2004). With regard to the engineering and software design issues, *pervasive computing* can be seen as an extension of distributed systems and mobile computing (Satyanarayanan, 2001, p. 11). The *wireless sensor network* is a clear product of these areas, as well as energy-efficiency research, *sensor* miniaturization, and a widespread desire for better information gathering technologies. This article is concerned with the technical engineering and software design issues of WSNs, rather than any anthropocentric matters.

WIRELESS SENSOR NETWORKS

The study of *wireless sensor networks* (WSNs) started in earnest in the late 1990s (Pottie, 1998). It was only then that a practical combination of processing, communications, and sensing capabilities could be integrated into a single battery-powered miniature device (see Figure 1). Early research focused on creating networks of these devices, usually through automated, cooperative means initiated by the *sensor nodes* themselves (Intanagonwiwat, Govindan, & Estrin, 2000). Later, research expanded into network security, power management, ensuring adequate sensing coverage, distributed signal processing, and *sensor* fusion, querying and reprogramming nodes, and *sensor* localisztion. Although ongoing development unveils large-scale *sensor*

Figure 1. Examples of sensor nodes: 25mm and 10mm wireless sensor modules - courtesy of Tyndall National Institute, Cork, Ireland. Copyright 2006 Tyndall.