e-SENSE – Capturing Ambient Intelligence for Mobile Communications through Wireless Sensor Networks

Mirko Presser, Alexander Gluhak, Derek Babb, Laurent Herault and Rahim Tafazolli

Abstract—**This paper provides an overview of the e-SENSE Integrated Project, highlighting its strategic importance with respect to other projects in Mobile and Wireless Systems and Platforms Beyond 3G (B3G). The main focus of the project is to capture context through the use of wireless sensor networks and further integrate the context information through an open gateway architecture into B3G. The motivation behind this is to provide real context information for the concept of Ambient Intelligence that is a focal element in many current next generation communication systems, applications and services. e-SENSE approaches this by researching efficient and light weight wireless sensor communication systems including the physical layer up to the transport layer and a distributed processing middleware including distributed services and distributed data processing in a toolbox approach. Further, components of the toolbox are optimised according to sensor network architectures, addressing several or very specific context capturing mechanisms and sensor network applications.**

Index Terms — **Wireless Sensor Networks, Body Sensor Networks, Context Awareness, Ambient Intelligence**

I. INTRODUCTION

Creating the Ambient Intelligent World is the principal focus for FP6 Information Society Technologies research in Europe. Key to Ambient Intelligent systems is to "know" itself, its environment and the context surrounding its use and act accordingly [1].

The aim of e-SENSE is to enable Ambient Intelligence in Beyond 3G Systems, i.e., using wireless multi-sensor networks for making context-rich information (e.g. about the user, his/her social setting, or the environment) available to applications and services. While today's information systems require cumbersome human input or computer-generated data, future systems will be built on continuous streams of real-world physical data provided by numerous sensors linked together. They will perform their tasks in an unobtrusive and intelligent way enhancing the user experience, gathering refined and accurate data, simplifying tasks, increasing communication efficiency and enabling a plethora of novel applications and services and thus increasing the usability, efficiency and value of day to day life as well as business and scientific achievements. The envisaged e-SENSE architecture has the capability to observe and interact with physical phenomena in real time, and with a fidelity that was previously unobtainable.

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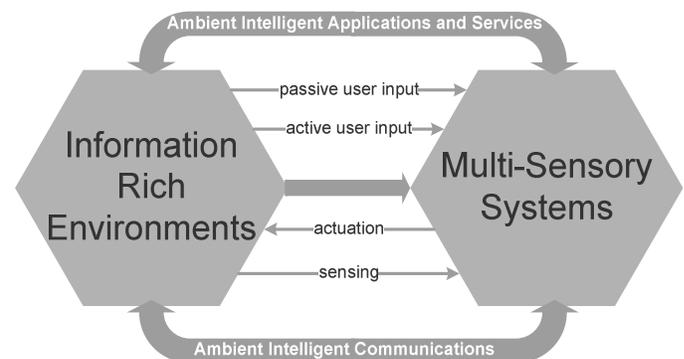
Fig. 1. Basic e-SENSE concept

The following sections provide an overview of the project's objective and motivation as well as give an insight into the technical approach of the project.

II. E-SENSE OBJECTIVES

The main objective of the project is to contribute to the evolution and definition of the future Ambient Intelligent Mobile Systems and Platforms Beyond 3G by integrating ubiquitous Wireless Sensor Networks (WSNs) in B3G mobile systems.

The richness of information that is required to fully capture Ambient Intelligence demands a multitude of multi-sensory information. To obtain this information potentially a large variety as well as a large number of sensors is required. The sensors may communicate among themselves or via gateways with other systems and networks (e.g. other sensor networks, Cellular, WLAN, PAN, or the core network). Even though the majority of the sensors in these areas will be wireless (mainly for ease of deployment and convenience), device integrated sensors and hardwired sensors are of importance to also be considered. Wireless sensors are expected to operate in harsh environments such as close body proximity communications, operate over a long period of time and coexist with other wireless networks. High power, bandwidth efficiency and robustness to interference as well as achieving small physical size are major focus of e-SENSE.

Due to the ubiquitous nature as well as the quantity and spread of sensors within such a system, key requirements for e-SENSE are ultra low power operation (in particular for communications but also for local processing of sensor information) and multidimensional scalability with respect to mobility, number of sensors, diversity of sensor classes, sensor network types and sensor payload types. Also presenting captured information to Ambient Intelligent Systems, achieving transparency with respect to underlying sensor systems is of importance. Key to these are:

- energy efficiency with respect to wireless sensor node architectures
- ultra low power and bandwidth efficient air-interfaces and data transport and networking protocols for wireless sensors, clusters and gateways through cross-layer optimisation
- distributed resource management for wireless sensors
- co-existence with other radio interference / signals
- distributed data processing and collaborative aggregation
- intelligent data centric interface
- self growing, robust, and scalable wireless sensor networks
- self organising sensor networks in mobile and dynamic heterogeneous wireless sensor systems
- self learning and intelligent interfaces for transparent integration of new information sources
- security framework
- privacy for personal or sensitive information

III. MOTIVATION

Addressing these issues, e-SENSE will be able to capture information from phenomena and signals from the real physical environments, transport and pre-process the information. And thus provide the information to other mobile/wireless devices or to sensor applications and services in other networks and most importantly provide information to service platforms and subsequently service providers, effectively enabling Ambient Intelligence, as shown in Fig. 2.

The e-SENSE project is investigating a new paradigm for bringing the flexibility of information technology to bear in every aspect of daily life. It foresees that people will be surrounded by sensorised environments that provide easily accessible yet unobtrusive support for an open-ended range of novel applications and services, to enrich daily life and to increase productivity at work. This presents a paradigm shift from personal computing to ubiquitous computing, challenging the research community to investigate new building blocks and integrated infrastructures, as well as emerging applications and interaction styles. Relevant knowledge areas include mobile and wireless communications, distributed data processing, data and knowledge modelling, application platforms, human-computer interaction, security, trust and privacy, as well as application research in different settings and sectors. Such a wide variety of topics can only be covered through an Integrated Project which consists of complementary expertise from industry and research institutes from different disciplines which have been brought together to address these issue.
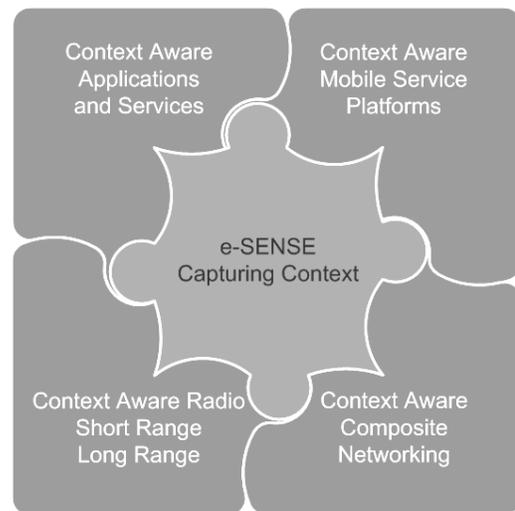

Fig. 2. Positioning of e-SENSE in Beyond 3G

The main reasons for undertaking the proposed research are:
- The research has a **real potential for significant socio-economic impact**: The shift from personal computing to ubiquitous, ambient intelligent systems is a motor for innovation expected to transform IST business over the next 10 years. Infrastructure research will give rise to new products, services and applications, creating economic opportunities as well

as addressing societal concerns such as accessibility, e-inclusion, health, safety, learning and quality of life.

- The research is **very timely**: recent advances have provided crucial enabling technologies (embedded components, sensors, ad hoc networks, location technologies, etc) but there is still a significant gap between these basic building blocks and the potential applications of sensorised environments.

- The research is **highly innovative**: it develops new technology concepts ranging from cross-layer energy-efficient design to distributed services and data processing, explores novel applications ranging from smart maintenance to health, fitness and well-being, and investigates the fundamental architectures required as foundation for fully integrated sensorised environments to capture context in an end-to-end system approach.

IV. E-SENSE APPROACH

The e-SENSE approach organises itself into five work areas that address:

- o Scenarios, Requirements and Socio-Economic Impact
- o System Architecture and Concept
- o Efficient and Light Weight Wireless Sensor Communications
- o Distributed Processing Middleware
- o Test Bed Implementation and Validation through Show Cases

The main technical approaches are detailed in the following four subsections (omitting the area of scenarios, requirements and socio-economic impact) and the overall scope of e-SENSE is also illustratively presented in fig 3.
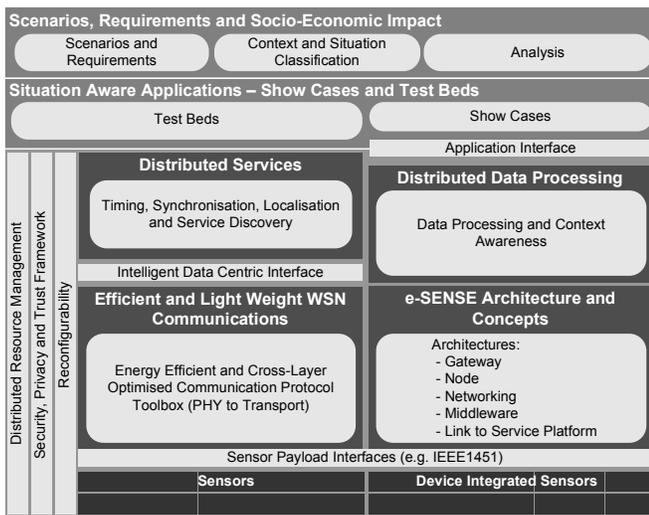

Fig. 3. Scope of e-SENSE

A. System Architecture

The system architecture supports heterogeneous networking, provides connectivity for a wide range of sensor nodes, while managing mobility and limited bandwidth and power resources. It also includes issues related to the node architecture, network topology, interconnection of heterogeneous networks and node discovery. In addition, security components have to be incorporated into the system concept.

The overall architectural design will be based on system components (air-interfaces, protocols) that are already specified in various standardisation organisations/industry alliances (e.g. 802.15.4, ZigBee [3]), are available in the short term (e.g. 802.15.4a) or can be provided by consortium partners. The goal of this task is to select a set of common requirements leading to an efficient architectural design of a wireless sensor system.

Sensor Node Architecture
Based on the functional requirements for wireless sensor systems and the corresponding technical communication requirements, the overall architecture of the sensor nodes including hardware and software aspects will be defined. The hardware architecture of the node, including sensors and actuators and their interfaces, will comprise memory, processor, communications, RF, baseband processing, network protocol stack, antenna, and energy and security management blocks. The software architecture will take into account the numerous software elements embedded within the nodes, such as application or communication software.

Sensor Network Architecture
The objective of this activity is to develop the architecture of the e-SENSE wireless sensor network. The network comprises low-cost sensor nodes, smart control nodes (e.g. cluster heads), as well as access points (e.g. gateways) that provide connectivity with the backbone core networks, the Internet, and other mobile communication systems including cellular, WLANs, and WPANs. It will enable powerful connectivity between personal devices and heterogeneous sensor networks that are owned by the user or are part of the ubiquitous sensor-enabled environment, or connectivity between a potentially large numbers of sensors with a back-bone network based application for processing environmental data or performing asset monitoring functions.

Distributed Processing Middleware and Service Architecture
The distributed processing middleware and service architecture combines the functionalities provided through localisation, timing and synchronisation and service discovery and provides means of intelligent management of resources (e.g. outsourcing of complex functionalities such as service discovery), distributed signal and data processing. The interface to the network architecture will be provided through an intelligent data centric API. Further, the distributed resource management configures the reconfigurable e-SENSE communications framework according to dynamics with respect to tasks and resource availability.

B. Efficient and light weight wireless sensor communication systems

The objective is to design a set of algorithms spanning from the physical to the transport layer in a toolbox format and subsequently aimed at increasing the system efficiency in terms of energy savings and application performance through optimisation. The proposed solution will be based on a cross-layer approach, where the schemes working at different layers of the protocol stack will be sharing common information in order to drive the system towards globally optimal solutions. In particular, this efficiency refers to system-wide aspects and is not just meant to improve the quality of a single radio link.

With these objectives in mind, the first optimisation will be performed on RF hardware. Design methodologies for greatly reducing the energy efficiency of air interfaces will be studied and validated. Novel RF sensing techniques will be studied to, e.g., localise and estimate the distances of devices. These novel physical layer algorithms will enable the devices to access topology related information that, in turn, will be exploited by any other layer of the protocol stack according to a cross-layer philosophy. That is, physical, medium access control, routing and transport solutions, will be considered in a coordinated fashion with the aim of creating a re-configurable solution (depending on application requirements) and aimed at increasing system efficiency through topology awareness, cross-layer design and cooperation among nodes.

C. Distributed Processing Middleware

A defining characteristic of nodes in sensor networks is that computing and communications resources are a scarce and valuable commodity. This is particularly true in scenarios with heterogeneous sensors, as is the case in e-SENSE, where some sensors may have almost no resources, while others are relatively better off. Currently this leads to centralised architectures where sensor data is transported to a single point where a resource-rich platform performs all the data processing. However, the increasing deployment of sensors on the body and in the environment offers an opportunity to distribute much of this data processing to the sensor nodes themselves. This has the advantage of providing more scalable and resilient solutions, while reducing or eliminating the need for centralised nodes. However, for these advantages to be realised, it is necessary to develop a number of middleware support mechanisms to facilitate the development of distributed sensor-based applications.

Many of the applications that are typical for e-SENSE are collaborative in nature: the nodes share data among each other, transform data, thereby essentially performing the task that is required. This approach is essentially different from using a traditional centralised approach, where all transformations on and decisions based on data is performed by a single entity, and based on a complete set of data. The challenge involved in employing a collaborative approach to data transformation and decision making is twofold. One is the co-ordination between the entities involved in performing the task at hand is non-trivial, and will become more complex as increasing pervasiveness of sensors increases the potential number of collaborators. The other is caused by the fact that all the operations on the data will have to be made with the availability of only a subset of the data.

Besides challenges, this distributed approach to data transformation and decision making brings opportunities. The most important one is performance. The costs associated with the transport of sensor data are high, in relation to the energy budget of most sensor nodes. Localising the data processing and decision making task produces a rather small set of result data and decisions and reduces the communication needs. Instead of the raw data, partial results will be communicated.
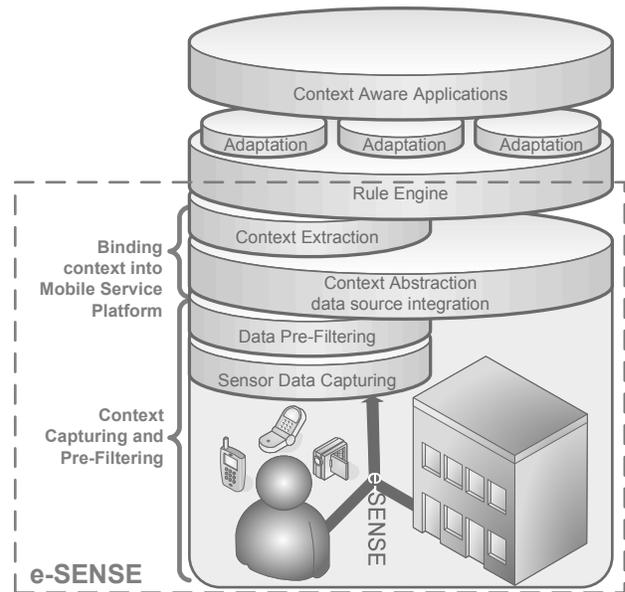

Fig. 4. Information Processing Chain and link to Service Platform

In scenarios with sensors distributed across an extended geographical area, the transport of all this data is generally too expensive, and processing all this data in real time at a central computer might be impossible or infeasible.

e-SENSE has categorised the functions required for a Distributed Processing Middleware for sensor networks into:

- o Distributed services, which addresses common services such as timing and synchronisation, service discovery, etc.
- o Distributed Data Processing, which addresses mechanisms to enable collaborative processing, context awareness support, etc.
- o Data Centric Resource Management, which aims to optimise computing and communications resources in a data-centric network.

D. Testbed Implementation and Validation through Show Cases

e-SENSE aims to implement and validate the concepts and protocols of the sensor networks developed within the project as well as provide a limited set of show cases. For this purpose the deployment of the developed concepts and protocols on two independent testbeds is envisioned.

The first of the testbeds will be based on body sensor network concepts, and mainly concerned with the collection of physiological data, e.g. ECG, breathing rate, body temperature, skin conductance levels, voice. The second, a campus wide environment sensor network tesbed, will mainly focus on sensing physical data of a user space, e.g. office space.

Key features of the sensor networking technologies being developed and that are to be validated in this project include:

- Throughout energy efficient communication and operation
- Distributed data processing, and services
- Context availability (and potentially its uses within a confined system)
- Context capturing mechanisms

To show these key features as well as the added benefit of sensor information regarding context awareness a limited number of concept validations and subsequently show cases will be developed. A particular challenge for the show cases will be the integration of biometric sensor data with environmental sensor data to provide context and assist in determining user mood.

V. PROJECT DETAILS AND CONSORTIUM

Acronym	e-SENSE
Title of the project	Capturing Ambient Intelligence for Mobile Communications through Wireless Sensor Networks
Proposal number	IST-4-027227
Contract number	027227
Starting date End date	01/01/2006 31/12/2007
Duration	24 months
Project Officer(s)	Paulo DE SOUSA
Logo	
Website	www.ist-e-sense.org

For e-SENSE an expert consortium of 23 partners from 11 countries has been assembled: 7 industrial partners (including 1 operator (Telefonica) and 6 major industrial companies (IBM, Fujitsu UK, Mitsubishi France, Thales UK and EADS) with a strong research history in sensor-based networking, processing and computing and 1 management company (ALMA)), 2 SMEs (HFC, Ambient Systems) with expertise in body sensors, human factors, and sensor-data processing, 4 research institutes (CEA, IMEC, CSEM, FhG Fokus) with expertise in low power air-interfaces and sensor-network

architecture and 10 academic institutions (including some of the major European Universities in sensor research: UniS, AAU, Aegean, CFR (consortium of Italian universities), TUD, ETHZ, KCL, UO, UT, and UPMF). For more detail and public project output, see [2].

REFERENCES

[1]   The Vision Book by DG Information Society – European Commission

[2]   e-SENSE website, http://www.ist-e-sense.org/

[3]   ZigBee Alliance website, http://www.zigbee.org/