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Abstract: This document classifies cooperating object applications from socio-economics and application-type perspectives. It gives an overview of applications and application scenarios that can be readily understood today. The overview provides an insight into potential social, legal and economical aspects of the cooperating object applications and their requirements; which in turn an input to the research roadmap preparation study. The document contains six typical scenarios along with their requirements and characteristics.

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1 Executive Summary

This document provides a summary of the relevant state of the art, projects and activities in the cooperating object domain. It is the first step of four studies which are intended to give an in-depth analysis of current state-of-the-art research in the domain. Results of the studies will be used as an input to the road mapping task identifying essential open issues critical for the development of future cooperating objects. The first step in the studies, is the identification of relevant state of the art activities in the cooperating object domain and it is given in this document. The objective of the second study (WP31.2) is to provide an in-depth study of the state of the art in paradigms and algorithms used for the realization of system characteristics and requirements of different application domains. The objective of the third study (WP3.1.3) is to identify the role and effects of the vertical system functions identified as part of the enabling technologies study that encompass context and location management, security, privacy and trust aspects, and autonomic systems management. The objective of the last study (WP 3.1.4) is to describe and classify the set of programming models, paradigms and system architectures that allow us to integrate the enabling technologies identified in study 2 with the application requirements of study 1. The studies are organized to complement each other to fulfill the gaps of technical details.

2 Introduction

The newly emerging micro-sensors and actuators open revolutionary ways for new applications in wireless communications area. By using low-power, low-bandwidth, low-cost tiny sensor nodes and pervasive computing phenomenon, it will be possible to change the way people live and their habits. Recent developments in wireless sensor technology have provided people with being aware of environmental changes. AmI (Ambient Intelligence) paradigm explains the case where the user is surrounded by intelligent and intuitive interfaces able to recognize and respond to his/her needs. It is possible to integrate AmI and wireless sensor network technology in order to monitor different environments and act according to sudden changes.

In the scope of the studies, cooperating object (CO) is defined as a collection of sensors, actuators, controllers or other COs that communicate with each other and are able to achieve, more or less autonomously, a common goal. The inclusion of other cooperating objects as part of CO itself indicates that these objects can combine their sensors, controllers and actuators in a hierarchical way and are, therefore, able to create arbitrarily complex structures.

WP 3.1.1 provides an overview of CO applications and application scenarios that can be readily understood today. The main objective of the study is to identify relevant state-of-the-art projects and activities in the CO domain. For this purpose, both European and other projects outside Europe are considered. Some application scenarios that enable us to better understand the area of CO from the socio-economic and application-type points of view have been identified and analyzed.

The applications and scenarios take into account the state of the art of current service-centric (control applications, pervasive or ubiquitous computing) as well as data-centric approaches (wireless sensor networks). In data-centric approaches, efficient management of data is the major concern whereas service-centric approaches are mostly concerned with the definition of the interface or API in order to provide functionality

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for the user. Hybrid scenarios where service-centric and data-centric technologies must be combined are also considered. Hybrid scenarios and applications have the potential to provide valuable clues for the identification of distinguishing and overlapping features of service-and data-centric approaches. The wide spectrum of potential applications indicate that the constraints for a CO application domain may be much different from another CO application domain. CO applications can be classified in many different ways as each application has common features with others. In the studies, sectors that can benefit from CO paradigm and have social and economic impact in the society are used as the basis of classification. Sectoral classification helped us to analyze the common characteristics and requirements of a specific field of action. Considering the current trends, sectoral areas which can benefit from cooperating objects are defined as follows: control and automation, healthcare, environmental monitoring, security&surveillance, logistics, home&ofice, transportation, tourism and education&training.

The rest of the document is organized as follows: Section 3 contains general characteristics and requirements of data-centric, service-centric and hybrid CO applications. In Section 4 a survey of state-of-the-art CO projects are given in the order of evolvement. Section 5 contains classification of CO applications and projects into sectoral areas. Section 6 illustrates the object symbol set used for the functional description of CO scenarios. Section 7 contains scenarios from control, surveillance, monitoring and transportation domains along with their typical parameters, requirements, roles, traffic, threads, legal/economic issues that best characterize the research performed in the field. Finally, Section 8 summarizes the outcome of the study to be used as a measurement for application domain's importance and acting as a means of weighting conflicting requirements.

3 Characteristics and Requirements of Applications

The characteristics of CO applications are quite different from traditional wireless and wired networks. There are critical factors influencing the architectural and protocol design of these applications, and these factors introduce some stringent constraints. Moreover, the constraints for a CO application domain may be much different from another CO application domain. For example, security requirements in health and security applications can be more critical than in a home application. Therefore, "one size fits all" approach does not work for cooperating objects. In this section we enumerate and briefly explain the typical architectural trends that best characterize the CO applications and system requirements that influence the protocol and algorithm design in the wide sense of the term. These characteristics are used as the basis of analysis of open research issues in different application domains. State-of-the-art research on common characteristics are given in studies WP 3.1.2 and WP 3.1.3. Also, in [32], a good categorization of the requirements and characteristics of wireless sensor networks is presented.The following two properties of CO applications are general *characteristics* that they can have.

Data Traffic Flow: The amount of data travelling inside the network determines the traffic characteristics of an application. In one application the data transferred among nodes can be limited to a few bytes for simple measurements whereas heavy video-audio traffic can be conveyed in another application. Potentially, wireless sensor network traffic does not follow any known traffic patterns. It is non-stationary and highly correlated because of the event-driven characteristic of the WSN. When an event is detected, there are sporadic outbursts of high traffic; otherwise, most sensor nodes will remain asleep for long durations. The traffic characterization of the WSNs is very complex and difficult. All layers of the protocol stack affect the traffic pattern of the network.

Multipath phenomenon, human activities, background noise, node orientation, and interference from other nodes cause to severe changes in traffic pattern of a WSN. The protocols running on the network layer have significant effects on the traffic pattern of the sensor network as well. For example, the traffic characteristics change if two packets with the same destination are combined into one packet. This is a kind of data aggregation.

Network Topology: In a CO application, sensor nodes may directly communicate with an actuator, or a sensor node sends its data to the actuator through several sensors. The first case implies a *single hop* topology whereas the second requires a *multi-hop* sensor network. With current technology, single-hop communication model is more trivial to establish than multi-hop communication networks. Multi-hop topologies have significant challenges such as routing, support for mobility and scalability, etc. Substantial research is still needed on the requirements of multi-hop setups in real life applications.

Indoor or Outdoor: Generally speaking, operating environments for CO applications are categorized as *indoor* and *outdoor*. Indoor applications are mostly implemented in home and office environments whereas roadways, railways, and forests may be some examples of outdoor environments for CO applications. Most of the factors listed in this section, such as localization, security and mobility introduce more challenging requirements for outdoor applications.

The other properties, we state below, are the general system *requirements* of CO applications. CO applications require some of these requirements, depending on the task they are focused to. Different applications require different levels of importance of the below properties.

Automation: Nodes can be remotely controlled or fully unattended and autonomous. In the applications of latter class, nodes make autonomous decisions according to the collected information. Particularly, the applications operating without human intervention and including robots and automated machinery require high degree of autonomy.

Context Awareness: In CO applications, some devices or objects may need to have information about the circumstances under which they operate and can react accordingly. These context aware objects may also try to make assumptions about themselves or the objects' (which they monitor or control) current situations.

Fault Tolerance: It is highly possible to lose some sensor nodes during the operation of the network due to their limited power capacity and challenging operation environment conditions. In many outdoor applications, it is impossible to change batteries of sensor nodes. As a result, a CO network must be able to sustain its operations although it faces node failures.

Localization: There are several CO applications for target tracking and event detection, e.g., intrusion, forest fire, etc., that necessitates node and/or target localization. For this purpose satellite based positioning systems are used. The most popular positioning system is GPS (Global Positioning Systems) and it can be used in applications where scalability and cost per node requirements can

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be satisfied. However, the cost of equipping every node with a GPS unit cannot be tolerated in many applications. Also, mounting GPS receiver to sensor nodes increases their size and their power consumption which is not wanted. Furthermore, in some environments such as indoor and undersea, GPS does not work. There are also some proposed GPS-free localization schemes for wireless sensor networks, however it is a significant challenging issue yet.

Mobility: In some applications, all physical components of the system may be static whereas in others, the architecture may contain mobile nodes. Especially applications which can benefit from autonomous robots in the field of action may require special support for mobility. Mobility support for multi hop routing in infrastructureless networks is still a challenging issue. High mobility requirement of the application also affects the design for other characteristics such as localization, synchronization.

Networking Infrastructure: CO networks can be *infrastructured* or *infrastructureless (ad hoc)*. Even in some applications the data can be collected by some mobile nodes when passing by the source nodes. Having an infrastructure or not mostly depends on the operational area of the CO application. For example, some environmental monitoring and surveillance applications established in remote regions require infrastructureless operation, whereas others may benefit from other wireless and/or wired systems in the environment.

Node Heterogeneity: Most of CO applications include different types of nodes that have distinct hardware and software characteristics. For instance, in a precision agriculture application, there may exist various sensor types like biological, chemical, temperature and humidity sensors.

Packaging for Robustness: In many CO applications, the low-power, low-bandwidth, tiny sensors will be used in challenging operational environments. For instance, in a desert, sensor nodes must be covered with some housing structure in order to prevent them from high temperature or other harsh desert conditions.

Power Awareness: It is obvious that power consumption is one of the most crucial performance metrics and limiting factors almost in every CO application. In order to make a system practical for real world scenarios which require long life-time, efficient power consumption strategies must be developed. Long-lifetime is expected especially from an application established for environmental monitoring. For instance, a CO application set up in a remote site such as a desert, must have a long lifetime, since it is not easy to access that environment and to replace the network with a new one. There are lots of researches in the literature focused on developing more power efficient strategies.

Production and Maintenance Cost: Depending on the application type, CO applications containing a large number of nodes and aiming at operating for a long time require low production or low maintenance cost. This need can be determined by some characteristics of the applications. For example, for the networks which are expected to stay alive and operate for a long time, low maintenance cost becomes more important, which can be achieved through higher production costs. Also, these cost constraints have a great influence on the capabilities of the nodes. Cheaper nodes have higher capacity limitations and lower fault tolerance.

Scalability: The number of entities in the application may vary depending on the environment where it is implemented and on its task. Consider an application used for early detection of forest fire which

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is implemented in a huge forest such as Amazons. Due to the fact that sensors should have a small transmission range on the order of a few meters, the network must have on the order of thousands nodes in order to cover the whole area. In such a case, the algorithms running inside the network should scale well in parallel to the increasing number of nodes in a region maintaining the given task of operation properly. In other words, the network should adapt itself to changing node density without affecting the application performance. Scalability is a significant issue especially in outdoor applications.

Security: Ad hoc networking and wireless medium introduce many security flaws which make CO networks open for various types of malicious attacks. The system may be threatened by unauthorized users trying to access the network. Also, there are security risks on the physical layer of the network. For example, jamming signal may corrupt the radio communication between the entities in the mission-critical networks.

Real-time/low end-to-end delay: End-to-end delay requirements are very stringent in real-time applications. For instance, in a manufacturing automation application actuation signal is required in real-time. Additionally, low end-to-end delay may be an essential requirement in some delay-sensitive applications such as target tracking.

Reliability: End-to-end reliability guarantees that the transmitted data is properly received by the receiving-end. In some applications end-to-end reliability may be a dominating performance metric whereas it may not be important for the others. Especially, in security and surveillance applications, end-to-end delivery has high importance.

Time Synchronization: Associating the data coming from multiple objects to the same event, data aggregation, data fusion, target or event tracking tasks and cooperation make time synchronization among communicating entities a key issue in many applications.

4 State-of-the-Art Projects

Several projects are underway in the CO domain. In this section, a survey of activities in the order of starting period is given. It is worth to note that only few readily available application scenarios featuring wireless sensor networks exist today. Current projects are mostly at the stage of understanding and analyzing some application-specific requirements. This is a natural outcome of the fact that WSN technology currently provides solutions for very basic requirements. Therefore, in the survey, projects in design phases are also given in order to illustrate the wide spectrum of the potential.
The criteria used in selecting the projects are twofold: studying various deployment environments such as home, office, factory, desert, forest to identify the requirements of different physical setups and application's social and economic impact in improving people's life.

CyberGuide (1995): The project, developed by Georgia Tech, aims at providing people with navigating physical and cyber spaces by using portable computers. The visitors carry CyberGuide intelligent tour guide and obtain information about the surrounding environment, such as the positions and features of the objects in the area, their locations, etc. Also it is possible for them to communicate with each other and with central computers. Furthermore, e-mail and web connectivity are provided.

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Some potential applications of the guide are translating Japanese signs and menus for a visitor to Japan, providing the map of a space, tour guide for art museum, recognizing faces and people at cocktail parties, etc. In the late nineties, a series of Cyberguide indoor and outdoor prototypes were produced by students at Georgia Tech. It uses GPS navigation system for positioning. The project must support both indoor and outdoor communication. The mobility must be provided as well. Furthermore, it must be cost-effective in order to attract visitors' interest. It must also provide accurate location information of the visitor and/or surrounding places, streets, etc. For further information, refer to [43]

ActiveBat (1998): This system, developed by Sentient Project Group in ATT Labs, Cambridge, provides the location information of the objects in indoor environments. It is an ultrasonic location finding system using trilateration principle where position finding is done by measuring the distances between the reference points and objects with unknown locations. In the ActiveBat network, transceivers mounted on walls and ceilings are the reference points and they communicate with transmitters (Bats) carried by users in the environment. Also, there are RF controllers using radio signals for control and time synchronization purposes. First of all, the Bats send ultrasound signals, and transceivers mounted at known points on the ceilings receive those signals. In the second step, they estimate the time-of-arrival of ultrasonic signals, and by using speed-of-sound, the distance from the reference points to the object is calculated and the position of the object is estimated through trilateration [22]. ActiveBat products have been deployed in some pilot sites since 1998. The location estimation accuracy of ActiveBat is about 9cm (95 percent). The tags and transceivers are cheap, however, the system administration is expensive. The main limitation of ActiveBat is the requirement of ceiling sensor grid [33]. Computer Laboratory, Digital Technology Group, another research group in Cambridge University, also works on indoor tracking systems, reliable location systems, and location privacy issues.

Smart Dust Inventory Control (1998): The Smart Dust project, developed by Robotics and Intelligent Machines Laboratory, Department of Electrical Engineering and Computer Sciences University of California at Berkeley, aims at building a self-contained, millimeter-scale sensing and communication platform for a massively distributed sensor network. It is planned to implement those sensor network in a wide range of applications. The projection is that this device will be about the size of a grain of sand and will contain sensors, computational ability, bi-directional wireless communications, and a power supply, whereas the cost of deploying hundreds of those devices stays feasible. Inventory control is an application area targeted by Smart Dust. A product is monitored from manufacturing step until it is delivered to the end-user. The operation is as follows: the carton talks to the box, the box talks to the palette, the palette talks to the truck, and the truck talks to the warehouse, and the truck and the warehouse talk to the internet. It will be possible to know where your products are and what shape they are in any time, anywhere. FedEx tracking on steroids for all products in the whole production stream from raw materials to delivered goods is planned to be an implementation area of this project [31]. The nodes in the network build a single-hop network that monitors a product from manufacturing step until arriving to the end-user. Maintenance cost and power consumption must be taken into consideration because it is a long-lasting application and it is impossible to change the battery of a node mounted on the product.

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Smart Dust Product Quality Monitoring (1998): Another application area of the Smart Dust project is product quality monitoring. In a factory environment, the products can be monitored for their quality assessment. For instance, the temperature and humidity monitoring of meat and dairy products give information about their freshness [31].

Smart Sight (1999): It is a tourist assistant system equipped with a unique combination of sensors and software and developed by Carnegie Mellon University. The aim is to translate from and to local language, handle queries posed and answer in spoken language, and provide the positions of the users and the surrounding objects. The assistant is a wearable computer (consisting of a Xybernaut MAIV and a Thinkpad 600) including microphone, earphone, video camera, and GPS to determine users location. This combination enables a multimodal interface to take advantage of speech and gesture input to provide assistance for a tourist. The system would have better knowledge of the environment than the tourist with accessing local database and the Internet. On the other hand, the software supports natural language processing, speech recognition, machine translation, handwriting recognition and multimodal fusion. As an example, a tourist in a foreign country may stand in front of an information sign, circle the text and ask "what does it mean?"- for which the language translation module can then offer an informative interpretation. Two applications were in development in 1999, requesting information of close by landmarks and a possibility for tourists to store information about places they find interesting [52]. The Smart Sight users carrying wearable computers directly communicate with the data center, that is, the network is single-hop. Devices in the network are carried by people, therefore, it must support mobility. Furthermore, the product and maintenance cost must be low in order to get people's interest. Power consumption is another issue, because it would not be easy for tourists to replace exhausted battery with a new one.

EasyLiving (1999): Adaptation of cooperating object and wireless sensor networks to indoor environments has attracted many interests in recent years. Researches have focused especially on creating autonomous, intelligent environments. EasyLiving, developed by Vision Group at Microsoft Research, aims to adapt cooperating objects and wireless sensor networks to indoor environments for creating autonomous, intelligent environments which is a space that contains myriad devices that work together to provide users with access to information and services. Both stationary (acoustic speakers, ceiling lights) and mobile (laptops, portable phones) devices may participate into the cooperation. The project will allow the dynamic aggregation of diverse I/O devices into a single coherent user experience [34]. In an intelligent environment, devices such as mice, keyboards, active badge systems, cameras or wall switches, provide the input to the system, and output of the system is given on the devices such as home entertainment systems, wall-mounted displays, speakers or lighting. Apart from I/O devices, there will be devices dedicated to provide computational capacity to the system. The main components of the system are middleware (to facilitate distributed computing), world modelling (to provide location-based context), perception (to collect information about world state), and service description (to support decomposition of device control, internal logic, and user interface). Media Control is one of the EasyLiving demo systems. When a user is authenticated to the system, his preferences are loaded that direct automatic behaviors. Users can have behaviors that direct various media types, such as a CD, MP3, DVD or VCR, that plays based on their location context. It is still an open challenge to define automatic behaviors and preferences for an intelligent environment in a consistent user-friendly manner.

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RoboCup (2000): is an international joint project aiming at promoting Artificial Intelligence (AI), robotics, and related field. It chose to use soccer game as a central topic of research where wide range of technologies can be integrated and examined. The ultimate goal of the project is to develop a team of fully autonomous humanoid robots that can beat the human world soccer champion team. It is apparent that innovations obtained from the RoboCup can be applied for socially significant problems and industries. Design principles of autonomous agents, multi-agent collaboration, strategy acquisition, real-time reasoning, robotics, and sensor-fusion are some of the most significant topics that must be investigated for developing a robot team actually performing a soccer game [50].

Probeware (2000): This project refers to educational hardware and software used for real-time data acquisition, display, and analysis with a computer or calculator. It is a ubiquitous computing application. It is also known as Microcomputer-Based Labs (MBL). When it is used with a calculator, it is known as Calculator Based Labs (CBL). The Probeware hardware consists of probes that use sensors to convert some physical property into an electrical signal. Temperature, light, and distance probes are most common, over 40 kinds of probes used in education. By connecting probes to a computer running suitable software, students can observe data displayed in a variety of formats as it is being collected. Probeware has been widely used in science, mathematics, and technology education. Software running on probes can usually represent the data from the probe as a number, dial, or graph. By providing students with seeing the display change in real-time, that is, as soon as the physical input changes, learners quickly catch the physical change with the way the representation changes. For example, an increase of temperature at the sensor causes the line go up on a graph on the display. Also, some software may be needed to analyze the data as soon as it has been collected. For example, the user may want to fit data to a function or filter out noise. The main role of the probeware is to decrease the drudgery, allow students to focus more on the experiment, and increase the amount and range of experimentation students can undertake. While it is becoming cheaper, the probeware continues to be refined, and gaining increased flexibility. Current developments in the probeware search for the ways data can get from sensors into computers. Smart probes include a microprocessor that converts the sensor signal directly into a computer-readable format that can be plugged into a computer. They may communicate with computers via standard serial inputs, USB, or computer-specific ports. Also, there are future plans that investigates the possibility of wireless probes that communicate over a infrared or microwaves as well as sensors that connect directly to the Internet and can be read anywhere providing Internet connection [44].

The Traffic Pulse (2000): The Traffic Pulse network is the foundation for all of Mobility Technologies applications [12]. It uses a process of data collection, data processing, and data distribution to generate the necessary information to travellers. The data is collected through a sensor network, processed and stored in the data center, and distributed through a wide range of applications. The sensor network installed along major highways collects information such as travel speeds, lane occupancy, and vehicle counts. The data is then transmitted to the data center for reformatting. The roadway conditions are continuously monitored on a 24/7 basis and updates are provided to the data center in real time by the sensor network. In each city, the data center, called traffic operations center, is established. It collects and reports on real-time event, construction, and incident data. Each center produces the information through a wide range of methods: video, aircraft, mobile units, and monitoring of emergency and maintenance services frequencies. The sensors established along

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the roads communicate with data center via multi-hop network. They are static, therefore mobility is not an issue for this application. Algorithms run on the network must maintain their operations when the number of sensors is increased, that is, scalability is a need. Besides, the maintenance cost must be as low as possible, because the network will be in operation for long time. The state of the monitored roads must be distributed among cars as quick as possible in order to properly arrange traffic that dictates low end-to-end delay. Data center hosts both real-time applications and a database of archived traffic information collected by the sensors and the traffic operations center. A multi-tiered architecture is used to provide highly scalable, flexible and secure platform on which products and services are based. Today, Traffic Pulse Networks is in operations and broadcasts benefits such as highest quality digital and analog local traffic content, web-based product delivery, unique broadcast applications system, 2D mapping solutions, 3D animated fly-over, for radio and TV broadcasters, cable operators, and advertisers who sponsor local programming.

Smart Kindergarten (2000): According to the Smart Kindergarten project, proposed by University of California, Los Angeles, children learn by exploring and interacting with objects such as toys in their environments, and the experience of having the environment respond (casually) to their actions is one key aspect of their development. The project aims at implementing wireless sensor network technology in the early childhood education environment, thus, providing parents and teachers with the comprehensive investigation of students' learning processes [16]. Some questions that can be answered with the help of such a project are "How well is student X reading the story book Y?", "Is student A usually isolated?" , "Does student A tend to confront other students?" etc. A group of wirelessly networked toys being capable of processing, wireless communication, and sensing the environment, would be used as the application platform together with a background computing and data management infrastructure. Aural, visual, motion, tactile and other feedback may be provided by a networked toy, and it may be able to sense speech, physical manipulation, and absolute and relative location. As a result, Smart Kindergarten enhances the education process by providing a childhood learning environment which is individualized to each child, adapts to the context, coordinates activities of multiple children, and allows unobtrusive evaluation of the learning process by the teacher [39].

WaterNet (2000): WaterNet project, funded by EU, uses wireless sensors in order to design a monitoring system for the sources of drinking water which are mainly rivers for Europe. The destination of the WaterNet project is to provide the users, especially water drinking authorities, with a suitable monitoring technology and it has demonstrated the usability and appropriateness of newly deployed methods in real-life applications. Operators and authorities responsible for monitoring large-scale processes such as drinking water production and waste-water treatment plants, have to manage large amounts of data coming from on-line sensors and laboratory analysis. The WaterNet project team has developed and validated, on real applications, a tool capable of providing real time environmental and process monitoring system information processing. It provides a number of useful methods which allow operators to effectively deal with large quantities of real time data by processing high level assessment information in a form that is wished for.

First of all, sensor readings are aggregated. In the second step, the river state and its evolution is

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assessed and interpreted. In the last step, information of different levels of abstraction are presented to specific but widely varying user classes.

The sensors communicate in a multi-hop network fashion. The system must support scalability in order to maintain its operation when the number of nodes is increased. It must also use power efficient algorithms in order to attain longest possible life-time. Furthermore, some level of robustness is required, because it is an outdoor environmental monitoring application that may suffer from harsh operational conditions. Even when robustness is provided, there will be some node failures. In such a case, fault tolerance should be provided for accurate monitoring. The WaterNet requires a system architecture based on distributed, self-contained computational units enabling multiple users with different needs to share and exchange data. The tool developed by the WaterNet team was validated at two application sites (in Paris and Barcelona) over a period of 4 months. A tool designed to operate on a Windows NT platform and SQL Server was developed during the project programme. Specific methods for validation, assessment and classification were implemented, tested and validated at the application sites [49].

Zebra RFID Product Tracking (Early 2000s): This project is based on the RFID technology. It is a method of remotely storing and retrieving data using devices called RFID tags. An RFID tag is a small object, such as an adhesive sticker, that can be attached to or incorporated into a product. RFID tags contain antennas to enable them to receive and respond to radio frequency queries from an RFID transceiver. Today, they are on-the-shelf products making automatically tracking and identifying products, no matter how they are produced and processed possible with RFID technology [51].

CarTALK 2000 (2001): It is an EU Project working on driver assistance systems based on the interaction among vehicles. The development of cooperative driver assistance systems and a self-organizing ad hoc network as a communication basis with the aim of preparing a future standard is the main target of the CarTALK 2000 [42]. In terms of assistance system, the main points are the assessment of today's and future applications for cooperative driver assistance systems, development of software structures and algorithms, such as new fusion techniques, and testing and demonstrating assistance functions in probe vehicles in real or reconstructed traffic scenarios. On the other hand, in order to attain a suitable communication system, algorithms providing ad hoc networks with extremely high dynamic network topologies are developed and prototypes tested in the vehicles. Some application branches of the project are information and warning functions (a vehicle breakdown, and traffic density), communication based longitudinal control (preventing accidents that occur because of the inattention of the vehicle in front), and cooperative assistance systems (controlling highway entry and merging).

CORTEX Car Control (2001): Transportation is one of the most suitable areas for CO applications. Future car systems will potentially be able to transport people without human intervention. CORTEX Car Control is an EU project that searches for the possibility of such a system. In this application, each car has several sensors with different tasks and an actuator that makes decisions according to sensor readings. Cars cooperate with each other to arrange traffic and to share information about road conditions [5]. The control car system automatically selects the optimal route according

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to desired time of arrival, distance, current and predicted traffic, weather conditions, etc. The cooperation of cars provides people with moving safely on the road, and reduces traffic conditions. Also, traffic lights are able to communicate with cars, that is, each car senses the traffic lights and moves according to their state. The network inside a car is single-hop, that is, sensors directly communicate with actuator, whereas there is a multi-hop network among cars. Event localization, such as obstacle detection and determination of jammed roads, is a significant characteristic of the project, therefore, it must be provided. Furthermore, the number of cars participating into the communication changes randomly which requires ad hoc (infrastructureless) communication support. Also, when the number of cars increases, scalability is needed in order to provide proper work of algorithms. When a car realizes an obstacle on the road, it must broadcast that news to other cars as quick as possible, that is, minimum end-to-end delay must be provided. Currently, the project is implemented in laboratory environments. There are some developed robot cars equipped with GPS receiver, 802.11b communication module and sensors. However, it seems that the realization of the project in the real world still needs some time, because problems faced in the requirements of the project have not been solved yet [37].

CORTEX Smart Room (2001): Recent advances in mobile and pervasive computing, and in wireless sensor networks have led to the idea of integrating them with our daily lives. The CORTEX project works on the concept of sentient object, an intelligent software component that is also able to sense its environment via sensors and react to sensed information via actuators. There are mainly two application categories, namely personalized intelligent services and multi-person triggered actions. An example scenario of the first category is as follows: While Alice enters the sentient room (assume that it is a semi-public living room), her identity is captured by some device in the room and it starts to behave intelligently in her preferred way. The room realizes that it is too dim for Alice to do a given task under the current light density, therefore, it automatically turns on extra lights. It adjusts the room temperature to the level that Alice feels comfortable. On the other hand, when she sits on her armchair, the room knows that she is relaxing and does the following according to her preferences: switching on the TV and the Hi-Fi system, tuning to her favourite music channel, and starting playing it. By collecting raw sensory data from embedded sensors, the intelligent room can then process and analyze them to deduce high-level context and personal preferences that change with various situations, such as time of the day, location, working or relaxing, etc. On the other hand, consider a scenario where more than two people are involved in the room simultaneously. Assume that a group of people are in the room and talking to each other. In this case, the room might infer that there is a meeting and start to react according to the meeting scenario, for instance, switching on the plasma screen, displaying one of the attendee's slides [5]. The main requirements of the CORTEX Smart Room application are sentience, autonomy, cooperation, and distribution. The sentient room consists of a number of sensors and actuators, which are actually abstract wrapper objects around driver software for particular hardware devices. Sensors collect data about environment, while actuators attempt to change the state of the real world in some pre-defined way. A wrapper object around the air-conditioner is an actuator example, which consumes CORTEX related software events and changes the room temperature through this conventional room device. Furthermore, every sentient object has its own internal control logic and is able to make autonomous decisions by itself, thus, requiring some degree of autonomy. The sentient objects should be capable of cooperating with other sentient objects in order to fulfill their task. Distribution scale is another important issue,

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because the sentient room application should accommodate a reasonable number of sensors and actuators.

Habitat Monitoring on Great Duck Island (2002): The Intel Research Laboratory at Berkeley initiated a collaboration with the College of the Atlantic in Bar Harbor and the University of California at Berkeley to deploy wireless sensor networks on Great Duck Island, Maine, in 2002. The task of the network is to monitor the microclimates in and around nesting burrows used by the Leach's Storm Petrel. The objective of the project is to develop a habitat monitoring kit that enables researchers worldwide to participate in the non-intrusive and non-disruptive monitoring of sensitive wildlife and habitats. For this project, temperature, humidity, barometric pressure, and mid-range infrared sensors are used. Motes periodically sample and relay their sensor readings to computer base stations on the island. These information are fed into a satellite link in order to allow researchers to access real-time environmental data over the Internet. Firstly, 32 motes were deployed on the island, and, at the end of the field season in November 2002, over 1 million readings has been logged from those sensors. In June 2003, a second generation network with 56 nodes were deployed. The network was extended in July 2003 with 49 additional nodes and again in August 2003 with over 60 more burrow nodes and 25 new weather station nodes. These nodes form a multihop network transferring their data back "bucket brigade" style through dense forest. Some nodes are put more than 1000 feet deep in the forest providing data through a low power wireless transceiver [47].

BioWatch (2002): In recent years, bioterrorism has become a significant threat for humanity. The developments in the micro and nano technology have brought about the idea of early detection and response to a bioterrorism event with wireless sensor networks. BioWatch project has been developed by the U.S. Department of Homeland Security for this purpose. It is an early warning system rapidly detecting biological materials in the air. Those materials may stem from an intentional release. The system helps public health experts to determine the presence and the geographical extent of biological substance by collecting air samples by a series of sensors. It allows federal, state and local officials to more quickly determine emergency response, medical care and consequence management needs.

During the operation of the system, aerosol samplers mounted on preexisting EPA (Environmental Protection Agency) air quality monitoring stations collect air, passing it through filters. These filters are manually collected at regular intervals and are analyzed for potential biological weapon pathogens using polymerase chain reaction (PCR) techniques [36]. It is foreseen that this system will provide early warning of a pathogen release, thus alerting authorities before victims begin to show symptoms. Today, BioWatch is a nationwide-operating project focusing on major urban centers. The initiative of the BioWatch has been operating in many of the nation's urban centers since early 2003. It became one of the most important tools used by public health agencies to warn citizens against the presence of biological agents.

COMETS (2002): COMETS Real Time Coordination and Control of Multiple Heterogeneous Unmanned Aerial vehicles (EU Project, IST-2001-34304), is a system that integrates multiple heterogeneous Unmanned Aerial Vehicles (UAVs) for missions such as surveillance, monitoring, mapping and search [13, 30]. Currently both helicopters and airships have been integrated in COMETS. The COMETS

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consortium includes seven partners from five countries and the scientific and technical coordinator is AICIA.

The COMETS system is based on the cooperation of heterogeneous objects with different properties and characteristics. Currently both helicopters and airships have been integrated. Thus, it exploits the complementarities of different UAVs in missions where the cooperation of several autonomous vehicles is very valuable due to the requirements on the required coverage, redundancies and flexibility when comparing with the use of a single UAV with long endurance flight and important on-board capabilities.

The COMETS architecture comprises a Ground Segment and the UAVs. The Ground Control Center has a Mission Planning System, a Monitoring and Control System, and the ground part of the Perception System. Also, a teleoperation station for the guidance of remotely piloted vehicles is present. The cooperative perception system has a set of basic functions for aerial image processing, and integrates detection, monitoring and terrain mapping functions.

Each UAV in the Flying segment is endowed with: a) Its Onboard Proprietary Components, that gathers the various functions specific to the UAV (flight control, data acquisition, possible data process), b) a Generic Supervisor, that interfaces the UAV with the other COMETS sub-systems (ground segment and other UAVs) and controls its activities, and c) a deliberative layer which provides autonomous decisional capabilities to the UAV. The communications system used in COMETS is realized via a distributed shared memory, the blackboard.

The first Mission Application of COMETS is fire alarm detection, confirmation, localization, and monitoring. Forest fire experiments have been conducted in Portugal, in May 2003 and May 2004. The final demonstration was also in Portugal in May 2005.

Scalable Coordination of Wireless Robots (SCOWR) (Early 2000s): It is a wireless sensor network application developed by University of Southern California [17]. The aim of the project is to merge artificial intelligence in robotic applications. It is a dynamic adaptive wireless network with autonomous robot nodes. The main target is to develop, test and characterize algorithms for scalable, application-driven, wireless network services using a heterogeneous collection of communicating mobile nodes. Some of nodes will be autonomous (robots) in that their movements will not be human controlled. The others will be portable thus making them dependent on humans for transportation. There will be not only mobile nodes but also static computers on the network, that is, the system must support heterogeneity. Due to the fact that the system will have numerous wireless mobile robots, it must support mobility and ad hoc communication. Also, the system will mainly consists of robots and they will make autonomous decisions, therefore, it requires a high degree of autonomy. The mobility leads to the frequent changes in the number of nodes and the topology of the network. In terms of power efficiency, it would not be a good strategy to run centralized algorithms for this case. Also, the nature of wireless sensor networks requires decentralized (distributed) algorithms. Therefore, the degree of distribution has importance for SCOWR. One application area of the project may be forest-fire detection. In such a case, the location information of the event or node may be significant. Also, the end-to-end delay may be required to be as low as possible for such event-detection applications. To sum up, the SCOWR team has already designed prototypes of autonomous robots and aerial vehicles. In the near future, it may be possible to use them in various wireless sensor network applications.

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Oxygen (Early 2000s): The aim of the project, developed by MIT Computer Science and Artificial Intelligence Laboratory, is to provide people with direct interaction with devices either handheld or embedded in the environment. As a result of this interaction, they will learn and adopt our needs and wishes. Instead of traditional interaction means such as typing and clicking, users will use speech and gestures that describe their commands. For example, when somebody enters the room, the conditions in the room will be adjusted with respect to his/her intent and mood. With the help of speech and vision technologies, people will be able to communicate with Oxygen devices as if they interact with other people.

The operational environment of the Oxygen will be highly dynamic and include various human activities, therefore, it must have some properties such as pervasiveness, being embedded, nomadic, easily adaptable, etc. Microphone and antenna arrays, different handheld devices will be used. The main difference of those components from other such devices is the fact that they must be power efficient. For further information, refer to [18].

Smart Mesh Weather Forecasting (Early 2000s): This project was deployed for meteorology and hydrology monitoring of Yosemite National Park. It is developed by Scripps Institution of Oceanography and United States Geological Survey. Over half of California's water supply comes from high elevations in the snowmelt-dominated Sierra Nevada. Natural climate fluctuations, global warming, and the growing needs of water consumers demand intelligent management of this water resource. This requires a comprehensive monitoring system across and within the Sierra Nevada. A prototype network of meteorological and hydrological sensors has been deployed in Yosemite National Park, traversing elevation zones from 1,200 to 3,700 m. Communication techniques are tailored to suit each location, resulting in a hybrid network of radio, cell-phone, land-line, and satellite transmissions. Results are showing how, in some years, snowmelt may occur quite uniformly over the Sierra, while in others it varies with elevation [15].

FloodNet (Early 2000s): FloodNet, developed by Envisense consortium, aims at monitoring rivers that have flood threat by deploying wireless sensor network across the river or floodplain. By processing and synthesizing collected information over a river and functional floodplain, FloodNet obtains an environmental self-awareness and resilience to ensure robust transmission of data in adverse conditions and environments. The coordinated efforts between sensor nodes which are fixed at specific points within a river or floodplain provide the spatio-temporal monitoring of an environment. The sensor readings are collected at data center where FloodNet management provides a platform by which expert decisions can be made regarding flood warning and mitigating activities. In an emergency case, operational instructions indicating that operation rooms should become active and take necessary measurements can be issued through various media such as pagers, telephones, computer screens. Also, the design of the data management should provide responsible authorities with direct activation of flood warning road signs, flood warden notification, emergency services data provision, etc [46]. The FloodNet requires efficient power management strategy and long lifetime. Besides, sensor nodes must be robust to harsh river and floodplain conditions. The number of nodes in the network may be on the order of thousands, therefore, scalability is another issue that needs to be solved. Also, the mission of the network requires lowest possible end-to-end delay. Today, there is a FloodNet application deployed at the River Crouch, Essex. It was deployed and activated

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on 30th April, 2004 and presently consists of six nodes each equipped with a pressure sensor. The sensor is mounted underwater close to the riverbed and has a thin breath pipe that connects it to the surface in order to allow it to compare pressure at its location to that in the atmosphere. The difference in pressure can then be used to estimate water depth. The topology was determined with respect to the topology of a hydraulic model of the study site and was not limited by technology considerations such as radio range [46].

GlacsWeb (Early 2000s): It is an Envisense's monitoring system project for a glacial environment that will be transferable to other remote locales both on Earth and in space. The aim is to obtain information from glaciers about global warming and climate change. The network consists of probes embedded in the ice, a base station on the ice surface, a reference station relatively far from the glacier (on the order of kilometers), and the sensor network server. Subglacial probes containing various sensors, beneath the glacier are used. Sensor readings are collected by a base station on the surface close to the glaciers. The information is then sent to the data center via reference station. In order to accurately research this environment, the system must autonomously record glaciers over a reasonable geographic area and a relatively long time that requires long lifetime. Due to the harsh environmental conditions of glaciers, robustness, fault tolerance, and network reliability are the other main needs of the project. It is infrastructure based, that is, all nodes are only one hop away from the base station. Scalability is also a significant issue together with power consumption and production cost. It also must be as noninvasive as possible to let the sensor nodes, or probes, mimic the movement of stones and sediment under the ice [46]. The GlacsWeb was installed in Summer 2004 at Briksdalsbreen, Norway. The Sensor Network Server (SNS) is based in Southampton. The low-powered probes are placed near the bottom of the glaciers and move with the ice, recording temperature, pressure, speed and the makeup of the glacier's sediment. They send back their data to the surface by radio, and these are picked up on a surface base station, which also records temperature and velocity. It has a webcam and snow meter, and it is able to track the position of these probes put in glacier. The base station then sends the information by radio to the monitoring team's campsite (reference station). That data is then fed into a computer and put online to make it available instantly to glaciologists around the world.

PinPtr (Early 2000s): It is developed in Electrical Engineering and Computer Science department at Vanderbilt University. Currently, most of the communications systems based on acoustic signals face sever performance degradations when used in urban terrain because multipath effects typically corrupt the available sensor readings. However, PinPtr claims that they develop an acoustic system that works well even in complex urban environments. It provides an accuracy of 1m and latency smaller than 2 seconds. The PinPtr system uses a wireless network of many low-cost sensors to determine both a shooter's location and the bullet's trajectory by measuring both the muzzle blast and the shock wave. It estimates the source location based on the Time-of-Arrival (TOA) of acoustic events, reference sensor nodes with known locations, and the speed of sound. The PinPtr sensor-fusion algorithm running on a base station performs a search on a hyper-surface defined by a consistency function that provides the number of sensor measurements. Those measurements are consistent with hypothetical shooter positions and shot times. The algorithm automatically categorizes measurements and eliminates those resulting from multipath effects. A fast search algorithm finds the global maximum of the surface that gives the shooter position. The number of sensors in the network may be on the order of hundreds. They can be deployed manually and placed in predetermined locations, or disseminated randomly by some other means. After the deployment phase, the sensors automatically set up an ad hoc communication network, define their locations, and establish a time base. When an event is detected, the TOA is measured and by means of a specially tailored data aggregation and routing service the measurement is sent to the base station via the network [27]. The sensors communicate with base station via multi-hop network. It seems that the most challenging issues of the PinPtr are time synchronization and random nature of the radio channel. The accuracy of the measurement strongly depends on those points.

Vehicle Tracking and Autonomous Interception (Early 2000s): This project proposes a networked system of distributed sensor nodes, called PEG, that detects an uncooperative agent called the *evader* and helps an autonomous robot called *pursuer* in capturing the evader [35]. Unlike environmental monitoring, it not only obtains measurements of the physical disturbance caused by evader, but also takes action in as short as possible duration. The *pursuer*, a cooperative mobile agent, tries to intercept the evader using information collected by the sensor network and its own autonomous control capabilities. There is a clustering structure in the network and each cluster of nodes sensing sufficiently strong events can compute an estimate of the location of disruptive vehicle. Evader localization and mobility are the main characteristics of this multi-hop network. Furthermore, the number of nodes employed in the network may vary according to the application area. In such a case, algorithms must allow the network to maintain its operation. Also, the pursuer will make autonomous decisions about the evader, that is, autonomy must be supported. This network may be established in many outdoor environments where conditions may be harsh which requires robustness and fault tolerance. A network of 100 motes was built in a 400 square-meter field in 2003. The evader was a four-wheeled robot remotely controlled by a person. On the other hand, the pursuer was an identical robot with laptop-class computing resources. As a result, it was demonstrated that PEG successfully intercepted the evader in all runs.

Ubiquitous Computing Support for Medical Work in Hospitals (Early 2000s): It is developed by Centre for Pervasive Healthcare Department of Computer Science, University of Aarhus, Denmark. This project aims at creating new computer systems using ubiquitous computing instead of traditional computer technology designed for office use. The vision of the project for the hospital of the future is a highly *interactive hospital*, where clinicians can access relevant information and can collaborate with colleagues and patients independent of factors like time or place. Suppose that a patient is lying on an interactive bed. On the other side there is a public wall-display in another room, clinic or hospital and a nurse is having a real-time conference with a radiologist. This project must support localization of patients. Besides, scalability is a must due to the fact that it may comprise many hospitals and clinics distributed in a large geographical area. Mobility is another significant characteristic of this medical work. The work so far has been concentrating on creating a basic infrastructure to be used in hospitals, and on creating some example of clinical applications running on top of this framework. The most significant challenging areas for such an infrastructure are *collection of services, security (in terms of authentication and authorization), context-awareness, and collaboration*. In the framework of creating *interactive hospitals*, *interactive hospital beds* will play an important role. The bed has an integrated computer and a touch sensitive display. What is more, various sensors are mounted on the bed, and they can identify the patient lying on it, clinician

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standing beside it, and various medical stuff embedding RFID tags. As an example, when the nurse arrives with the patient's medicine, the bed logs the nurse, check if the nurse is carrying the right medicine for the right patient, and it can display the relevant information on the screen [2].

Monitoring Volcanic Eruptions with WSN (Early 2000s): This project aims to implement a wireless sensor network composed of low-frequency acoustic sensors to monitor volcanic eruptions. The network, based on Mica2 sensor mote platform and consisting of three infrasonic (low-frequency acoustic) microphone nodes was deployed on Volcanò Tungurahua, an active volcano in central Ecuador, in July 2004. Those microphone nodes transmit data to an aggregation node, which relays the data over a 9 km wireless link to a laptop at the volcano observatory. In order to provide infrasonic sensors with synchronization, a separate GPS receiver was used. This deployment in the small scale proved a proof-of-concept as well as a wealth of real acoustic signals. For providing scalability, a distributed signal correlation scheme, in which individual infrasonic motes capture signals locally and communicate only to determine whether an "interesting" event has occurred was developed. One significant benefit of this scheme is that by only transmitting well-correlated signals to the base station, effective radio-bandwidth usage is provided [41]. Apart from scalability and synchronization, localization and robustness are the other main characteristics of the project. The location information of the volcanic explosions is necessary for the determination of the places that can be affected by volcano. On the other hand, it is apparent that operational conditions are not good for sensor network. They must be robust against harsh environmental conditions.

Wireless Sensors for Wildfire Monitoring (Early 2000s): National parks, wilderness areas, environmentally and economically sensitive urban-wildland interfaces are prone to wildfires that may lead to significant disasters in terms of both property damage and life safety. On the other hand, environmental monitoring applications with wireless sensors have attracted significant interests in recent years. Wireless, low-power, low-bandwidth, low-cost sensors can be used to collect environmental data such as temperature, humidity and pressure in order to monitor the wildfire-prone regions. Those sensors can be equipped with GPS receivers which provide location information for collected data. The aim of the project is to develop some part of a set of real-time database management and wireless data acqusition tools for rapid and adaptive assessment of the impact of catastrophic events such as earthquakes, fires, hurricanes, or floods [7]. For this purpose, the project mainly focuses on developing and field testing an asset tracking system for location and environmental monitoring of firefighting personnel; and, investigating possible "spin-off" applications in other domains, such as monitoring of structural health, geologic hazards and or environment [7]. Currently, the results from a testbed implemented near San Fransisco, California are available. The system includes environmental sensors measuring temperature, humidity and barometric pressure with an on-board GPS unit attached to a wireless, networked mote, a base station and a database server. The sensor readings are stored into a MySQL database, which is queried by a browser-based client interacting with a web server database bridge. The system can be operated using any web browser. The sensors are aggregated on a printed circuit board plugged into the Crossbow's Mica2 mote running the TinyOS. Performance of the monitoring system during two prescribed burns at Pinole Point Regional Park (Contra Costa County, California, near San Fransisco) is promising [7]. The wildfire monitoring system with wireless sensors provides a proof-of-concept implementation for wireless instrumentation in destructive, environmentally hostile wildfires. Results from testbed implementation unveil that the

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commercial development of the system is not far. Furthermore, the protection of the motes should be better in heavier fuels.

Ubisense (Early 2000s): It is a location-finding system developed by Ubisense company. The main difference between Ubisense and other location-finding systems such as ActiveBat is that its sensor products uses ultrawideband (UWB) technology to communicate with and locate the objects in real-time up to an accuracy of 15cm in 3D. The main advantage of UWB technology is the fact that it provides a high level of accuracy with low infrastructure requirements. It is claimed that the Ubisense is the first commercially available platform that provides both high accuracy and high scalability requirements together with cost effectiveness [21].

Networked Ubisensors are installed and connected to the existing infrastructure of the building. They use UWB communication in order to detect the position of Ubitags carried by the objects in the environment. The positioning is done by using speed-of-light and trilateration. In the second phase, the Ubisensors send the Ubitag location information to the Ubisense software platform that creates a real-time view of the environment which can be used by any number of simultaneous programs used for different purposes, such as responding immediately to the changes in the environment.

Sustainable Bridges (2003): This project, funded by EU, examines the high-speed train railway bridges which are expected to meet the needs of the next decades. These needs are basically expected to be an increase on the capacities, heavier loads to be carried or increments in the speeds of the trains concerning the increased traffic on the railways. All types of bridges are to be considered in this scenario. The network of the railways in Europe will be inspected primarily. To meet the increasing capacities and loads can basically be realized by assessing of the bridge structure, determining the true behaviour of the structure, strengthening of certain portions of the bridge or by monitoring of critical properties. Any irregularities during the design and construction of bridges and railways or while they are in service can be detected with existing structures, however, it is very obscure if they could carry much greater loads or handle much faster trains. That is why a new monitoring and alerting mechanism should be used. The overall goal is to enable the delivery of improved capacity without compromising the safety end economy of the working railway. The most recent technique to determine the irregularities in the bridges is the installation of wired monitoring systems to analyze the structural behaviour. However, such monitoring systems use standard sensors and several other devices which are time consuming to install and very expensive to spread around. Also kilometers of wires are needed for their communications, which means a waste of money and a high risk of communication failure in case of an irregularity in the medium. An alternative way to monitor such railways and bridges is equipping them with a wireless monitoring system, using micro-electromechanical systems. Hence, the set up cost of a communication system will disappear (getting rid of wires), and using of small and intelligent sensor carrying devices will dramatically reduce the production and maintenance costs [28], [9].

AUBADE - A wearable EMG Augmentation system for robust emotional unDErstanding (2003): This project, funded by EU, aims to improve the monitoring and assessment of the psychological state of patients, people feeling high stress or people under extraordinary conditions. In other words, it will create a wearable platform, also called wearable mask, to ubiquitously monitor and recognize

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the emotional state of those kind of people in real time. Several kinds of biosensors construct the wearable mask. They will be on the user's face and collect physiological data such as skin conductivity, heart rate variability, respiration rate, etc. These raw data will be sent to the centralised system for decision-making via the data acquisition module where pre-processing of the data is done. Also the intelligent emotion recognition module will be used to extract the psychological state of the user from sensor readings.

The main topics of the project work will be biosensors, wearable systems, signal processing, decision support systems, communications standards, security mechanisms, and facial muscle movement representation. Currently, laboratory work has been continuing and some prototypes have been developed [20].

Sun RFID Industry Solution Architecture (2003): This project was developed by Sun Microsystems and uses RFID technology for the pharmaceutical supply chain management. The main aim is to develop a global RFID architecture to provide pharmaceutical industry with preventing drug counterfeiting, thus, improving the health and safety of the people. The scenario is as follows: At the bottom of the supply chain, RFID tags are mounted on vials or bottles, boxes, cases. They are red by RFID readers which can be handheld devices or located at fixed positions. As a result, drugs are traced along the supply chain.

The main components of the system are Sun Java System RFID software, RFID readers, RFID printers and applicators, integration middleware, electronic pedigree application, and product authentication services. Due to the fact that RFID technology is still in the development phase, a few years are needed in order to fully benefit from RFID [19].

Rapid Intelligent Sensing and Control of Forest Fires-RiscOFF (2003): The project studies and tests a sensor network system for fire detection and alarm signalling. Its two main targets are to raise an alarm when the dimensions of the fire are still small (about tens of meters in size) and to locate the fire as best as possible to minimize spreading (the spatial resolution in localization of the detected fire should be about 200 meters). The cells of the wireless sensor network will be communicating via a wireless data transmission system with a central control or data collection point connected to the warning system of the emergency services, thus raising an immediate response fire alarm for a wide area of forest or grass [1]. Currently, the project has been focusing on the type of sensors to be used. Considering the application area, it must be multi-hop and support scalability. Also, it is desired that responsible authorities take necessary measurements against fire as quick as possible, therefore, end-to-end delay must be low. Mobility has not been mentioned in the project yet, however, there may be some mobile extinguisher robots in the monitored forest. Furthermore, the need for robustness and fault tolerance are apparent due to the harsh environmental conditions. Apart from those characteristics, efficient power management strategies are necessary for prolonging the network lifetime.

UbiBus (2003): Bus networks work in a similar way in different countries. To take a bus we just have to go to the closest bus stop and make a sign to the bus driver when the bus arrives. But this simple task is complicated for a blind or partially blind person. The objective of the project, developed by INRIA, is to design an application that helps blind people to benefit from public transportation. The

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UbiBus user can say to the bus that he needs to get on in advance to stop and be warned when his/her bus has arrived. This application should be easy to adopt and not disturb the service for other users and bus drivers.

UbiBus scenario is demonstrated as follows:

Three types of entities will interact: the bus riders (say Peter), the bus stop, and the bus. Peter has a mobile phone equipped with a short range communication interface such as Bluetooth or WiFi. Peter interacts with UbiBus via speech recognition. The only thing he has to do is to say the line number. Once Peter has said which bus he wants to take, he walks towards the bus stop. When he is close enough from the bus stop, his phone notifies him with the estimated time to wait (6 minutes for instance), received from the bus stop. Peter walks slowly to the bus stop, having plenty of time. At the bus stop, a non-blind girl is also waiting for a bus. Her attention is captivated by an ad on the bus stop for a new movie which interests her. To know more about it, she gets her device: the screen already shows the same poster as on the bus stop. Touching the screen makes her "dive" into poster as the device plays the movie trailer. Two minutes later, a bus arrives and the girl gets inside. Peter stays sit down. A man gets out of the bus and looks around, he seems to be lost. He looks at his device, just as he would look at his watch: the device spontaneously displays a map of the area. Peter is still waiting for his bus. Another bus is approaching, but Peter cannot see it. However, inside the bus, the driver notices a flashing "stop request" message displayed on the screen of device installed on the dashboard. The driver stops the bus, opens the door and Peter is notified by a vocal message that his bus has arrived.

MyHeart (2003): Cardio-vascular diseases (CVD) are the main reason of death in the western world. The MyHeart is an EU project aiming at empower citizens to fight cardio-vascular diseases by preventive lifestyle and early diagnosis. The first step of the project is to obtain knowledge on a citizen's actual health status. In order to gain this information, continuous monitoring of vital signs is a must. The approach is therefore to integrate system solutions into functional clothes with integrated textile sensors. With the combination of functional clothes and integrated electronics and processing them on-body, intelligent biomedical clothes will be used in order to fight with CVD. The MyHeart will bring about the solutions that will continuously monitor vital signs and context information, diagnose and analyze the health status and acute events, provide user feedback and seamlessly provide access to clinical and professional expertise if required. The main technical challenges of the project are continuous monitoring, continuous personalized diagnosis, continuous therapy, feedback to user, and remote access and professional interaction. There are no public results available yet for real-world applications of the project [48].

CROMAT (2003): It is a project funded by the Spanish National Research and Technology Development Programme. The main objective is the development of new methods and techniques for the cooperation of aerial and ground mobile robots [14]. It is intended to develop technologies that could be used in applications such as inspection of utilities, infrastructure and large buildings, disaster detection and monitoring (fires, floods, volcano eruptions, earthquakes), exploration, surveillance, urban safety, humanitarian demining. CROMAT is a project coordinated by the University of Seville with three Subprojects that share the design and development of a new control architecture for the coordination of aerial and ground mobile robots. The first Subproject is devoted to the development of an autonomous helicopter and its cooperation with a ground mobile robot. The second deals with teleoperation and cooperation of mobile robots, and the third one is devoted to the development of helicopter control techniques.

Smart Surroundings (2004): The overall mission of the Smart Surroundings project which is funded by EU, is to investigate, define, develop, and demonstrate the core architectures and frameworks for future Ambient Systems [11] which are networked embedded systems integrated with everyday environments and supporting people in their activities. As a result of Ambient Systems, a Smart Surrounding will be created for people to facilitate and enrich daily life and increase productivity at work. They will be quite different from current computer systems, as they will be based on an unbounded set of hardware artifacts and software entities, embedded in everyday objects or realized as new types of device. Over the last 10 years, the ubiquitous computing vision has inspired research into computing systems and applications that become pervasively embedded in our everyday environments, and that bring the unique flexibility of digital technology to the activities around which our lives evolve. Caused by rapid progress in technology, this early research tended to focus on experimental prototypes of infrastructure, devices, and applications. As the field is progressing, the most important research challenge and focus of this project is to develop the fundamental architecture of ubiquitous computing environments. It is this project's ambition is to move beyond prototypes toward sustainable systems for implementation of the ubiquitous computing vision. The ubiquitous computing research community at large has been very successful in advancing the infrastructure components for pervasive systems, and in exploring the design opportunities for novel applications. This work is compelling but has mostly remained centered around single devices as opposed to distributed systems composed of many devices. It is still observed that there is a very wide gap between the new design materials at hand (e.g. smart artifacts, ad hoc networks, location technologies) and the potential applications. For example, microprocessors and wireless radio can now be built into practically everything to create smart networked objects, but we lack the technology to integrate these in an open platform for a wide range of applications. Likewise, the components are in place for prototyping and exploring application ideas, but we lack the foundations for the principled study of ubiquitous systems and application designs.

CoBIs (2004): It is an EU project and aims at using smart sensor technology in industrial/supply chain/sensitive settings. It will make it possible to implement networked embedded systems technologies in large-scale business processes and enterprise systems by developing the technologies for directly handling processes at the relevant point of action rather than in a centralized back-end system. Modelling embedded business services, developing the collaborative and technology frameworks for CoBIs with necessary management support, and investigating and evaluating CoBIs in real-world application trials in the oil and gas industry are the main objectives of the project. The collaborative items are physical entities in enterprise environments, with embedded sensing, computing and wireless short-range communication. Items have unique digital IDs, embody sensors to monitor their state and environmental conditions, able to communicate peer-to-peer, collaborate in order to fulfill collective services such as observation of conditions that no single item could obtain independently, and interface back-end systems to make their service integral with overarching business processes [45].

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GoodFood (2004): Agriculture is a challenging area where newly emerged wireless sensors based on Micro and Nano technologies can be applied in order to increase the safety and quality of food products. The implementation of micro and nano technology into the agriculture is called Precision Agriculture where a number of distributed elementary sensors communicating wirelessly are used to monitor the processes of food production and to detect the remainder chemical substances in products. Wireless sensor networks can monitor every steps of food chain from farmer to consumer and introduce smart agro-food processing. Precision agriculture is a multidisciplinary application that includes the cooperation of microelectronics, biochemistry, physics, computer science and telecommunications areas [10], [25]. The Integrated Project GoodFood is a Precision Agriculture project that aims at assuring the quality and safety of food chain. Principally, it is based on the massive use of tiny detection systems capable of being close to the foodstuff and merged in Ambient Intelligence (AmI) paradigm. In GoodFood, high density sensors are deployed in the agricultural area wanted to be monitored and wirelessly interconnected, capable of implementing locally some computations based on some predetermined mathematical models and forwarding information to a remote site. First GoodFood application scenario is planned to be implemented in spring 2005 in a pilot site in a vineyard at Montepaldi farm, a property of the University of Florence. Based on MICA motes and TinyOS, a wireless sensor network (WSN) will be disseminated in the area and it will primarily be used for detection of insurgence toxins in the vineyard. The main characteristics of the GoodFood scenario are network lifetime and power efficiency, synchronization, security, localization, address and data centric communications, scalability, fault tolerance and node heterogeneity. Actually, each characteristic is a challenging area for the scenario and requires researches in order to provide proper operation.

Hogthrob (2004): This project is developed by Technical University of Denmark and aims at monitoring sows. Consider sows wearing sensor nodes incorporating movement detectors as well as a micro-controller and a radio. A sensor node with an integrated radio placed on each sow could transmit the sow's identification to the farmer's hand-held PC thus alleviating the need for a tag reader. The use of sensor nodes on the animals could facilitate other monitoring activities: detecting the heat period (missing the day where a sow can become pregnant has a major impact on the pig production) and possibly detecting illness (such as a broken leg) or detecting the start of farrowing (turning on the heating system for newborns when farrowing starts). Sows carrying sensor nodes directly communicates with the farmer's hand-held PC hence, the network is single-hop. Besides, the system must support mobility. Locating the pigs may also be an issue and furthermore, farmers cannot afford to buy an expensive technology; therefore, its product and maintenance costs must be feasible.

Safe Traffic (2004): This project, developed in Sweden, aims to build a novel communication system which will provide all vehicles, persons and other objects close to the road with the necessary information for establishing safer traffic. Furthermore, all road-users must be provided with an accurate positioning device. As a result, the futuristic plan of the Safer Traffic is that each road-user is equipped with a small unit including a transceiver and a positioning device. Also, wireless tiny low-power, low-cost sensors will be used for traffic monitoring, traffic-light coordination, emergency services and highway surveillance. The proposed system could also offer the Internet access and multimedia services such as video-on-demand and real-time games for commercial and personal benefits. The project is currently focusing on the major components of the physical and network layers of the wireless communications system that will become the platform for all related traffic safety applications [40].

5 Taxonomy of CO Applications

CO projects surveyed in Section 4 can be classified in many different ways as all applications have some common features with others. However, sectoral classification clearly highlights the application domains which can benefit from the CO paradigm to improve the social and economic life. Therefore, it is preferred. Considering current research trends, areas which can benefit from cooperating objects are determined as follows: control and automation, healthcare, environmental monitoring, security&surveillance, logistics, home&office, transportation, tourism and education&training. Other sectors such as entertainment is not included in the categorization since there is hardly any ongoing project in this domain yet that best characterize the requirements. Common characteristics and requirements of each sectoral area are summarized below. In the following tables, requirements written in red color represent challenging issues.

5.1 Control and Automation (CA)

Networked embedded systems decrease the need for human power. The applications that fall into this category may be used in indoor or outdoor environments and they should provide the ability to enable distributed process control with ad hoc and robust networking in challenging environments. They include robotics, control and automation technologies, and artificial intelligence studies. The benefits of those applications may be explained by giving examples in the process manufacturing area where continuous research and implementation of new production technologies must be done in order to reduce waste, reduce time of operations and improve volumes. Through the use of networked sensors, robots, and process control algorithms, the performance of manufacturing process is readily increased.

In many control and automation applications, apart from basic sensor nodes, there are transportation systems and other entities which capable of making autonomous decisions. Also, those applications are mostly event-driven.

The applications in this category are certainly required to be working in real-time. Hence, having support for fault tolerance, end-to-end delay and synchronization of the components are very important. Those applications are expected to decrease the need for interference of a human as much as possible, which is a fact that points to the importance of degree of automation. Also,the components in such a system may not be identical. Other issues are very dependent on the applications and their scenarios. So, some characteristics, like security, can be very important for some applications, while they are not an issue for some other applications. Table 1 summarizes the common and application-dependent characteristics of control and automation applications.

To the best of our knowledge there is no CO prototype or demo system worth to mention here that reflects the common requirements of control and automation applications.

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Common Characteristics and Requirements	Application Dependent Characteristics and Requirements
• Degree of Automation • Fault Tolerance • Heterogeneity • Production and Maintenance Cost • Real Time • Time Synchronization	• Context Awareness • Localization • Mobility • Packaging • Power Awareness • Scalability • Security

Table 1: Characteristics of control and automation applications

5.2 Home and Office (HO)

Traditional life styles and habits have been changing with the emerging applications of embedded systems in home or office environments. Networked sensors with different tasks may arrange the room conditions such as temperature and light according to the needs of person. Furthermore, carbon monoxide sensors may be used to detect unsafe levels emitted from the heating systems. The security of an indoor environment may be increased as well by linking the home to private security companies. Those applications change the way that people live. In home and office applications, the components of the system behave depending on the state of the environmental context. Since almost all of the applications will be very personalized, the security and privacy is highly important. Since the main inputs of the system will be originated from the human, localization is also important to state the location of the input to determine what to do. Such systems are inevitably designed to be context aware. The data to be processed or the feedback data of the system are expected to require a high bandwidth. Also, the system must be affordable by many people. A multi-hop network may not be necessary, also the topology and the routing will probably not be changed hence, mobility does not seem to be a challenging issue for this category. Table 2 summarizes the common and application-dependent characteristics of home and office applications.

Common Characteristics and Requirements	Application Dependent Characteristics and Requirements
• Context Awareness • High Bandwidth • Indoor • Localization • Production and Maintenance Cost • Security	• Degree of Automation • Fault Tolerance • Heterogeneity • Mobility • Power Awareness • Real time • Time Synchronization

Table 2: Characteristics of home and office applications

Some state-of-art projects in this category are; **Oxygen** [18] is an integrated vision and speech system uses cameras and microphone arrays to respond to a combination of pointing gestures and verbal commands

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developed by MIT Lab for Computer Science and Artificial Intelligence Lab. When you arrive at home, you say "I'm home", and the space comes alive. Lights flip on and music starts up on the stereo. **ActiveBat** [22] is a context-aware ultrasonic indoor positioning system, developed by ATT Labs, Cambridge. ActiveBat transceivers are mounted on walls. They communicate with ActiveBat tags carried by objects in the environment and determine their positions. The principal of the location-finding system is the trilateration and speed-of-sound is used to estimate the distance between the objects and reference points from TOA measurements. **Ubisense** is another location-finding systems used for creating smart spaces. Ubisensors mounted on walls use UWB signals to communicate with Ubitags carried by objects in the environment. As a result of this communication, the Ubisensors locate those objects [21]. **CORTEX's Smart room** [5] is an EU project. When someone enters into the sentient room, her identity is captured by some device in the room and it starts to behave intelligently in her preferred way. **EasyLiving** [34] is a ubiquitous computing project developed by Microsoft Research. It aims at developing architecture and technologies for building intelligent environments. **Smart Surroundings** [11], [26] is an EU project and the aim is to investigate, define, develop, and demonstrate the core architectures and frameworks for future ambient systems. It projects that people will be surrounded by embedded and flexibly networked systems that provide easily accessible yet unobtrusive support for an open-ended range of activities, to enrich daily life and to increase productivity at work. This idea requires ubiquitous computing. Although ActiveBat and Ubisense only provide location information to the users and do not promise to create an intelligent information, they are mentioned in this category in order to give some examples of the first home/office ubiquitous computing applications. Characteristics and requirements of the given scenarios are summarized in Table 3. There is no conflict in the common features dictated by the application domain. Some application-dependent features such as fault tolerance requirement seem also to be common. Additionally, varying requirements such as heterogeneity exist in the scenarios.

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	Oxygen	Smart Surroundings	ActiveBat	Easyliving	CORTEX Smart Room	Ubisense
Network Topology	Single	Single	Single	Single	Single	Single
Indoor/Outdoor	Both	In	In	In	In	In
Scalability	Low	Low	Low	Low	Low	Medium
Packaging	Low	Low	Low	Low	Low	Low
Fault Tolerance	Low	Low	Low	Low	Low	Low
Localization	High	High	High	High	High	High
Time Synch.	Medium	Medium	Medium	Medium	Medium	Medium
Security	Medium	Medium	Medium	Medium	Medium	Medium
Infrastructure	Ad Hoc	Yes	Yes	Yes	Yes	Yes
Prod-Maint.cost	High	High	High	High	High	High
Mobility	Low	Low	Low	Low	Low	Low
Heterogeneity	High	High	Low	High	High	Low
Data Traffic Flow	High	High	Low	High	High	Medium
Automation	High	High	Low	High	High	Low
Power Awareness	Medium	Medium	Medium	Medium	Medium	Medium
Real Time	Medium	Medium	Medium	Medium	Medium	Medium
Context-awareness	High	High	High	High	High	High
Reliability	Medium	Medium	Medium	Medium	Medium	Medium
Start Date	Early 2000s	Early 2000s	Late 1990s	Late 1990s	Early 2000s	Early 2000s
Current Stage	Testbed	Design Step	Testbed	Testbed	Testbed	Available

Table 3: Home and office scenarios and their characteristics

5.3 Logistics (L)

Logistics is a hot research field for new micro and nano technologies. By the use of distributed networked sensors, a product can readily be followed from production step until it is delivered to the end user. For this purpose, it may cover a large geographical area and many diverse entities in order to establish communication between entities involved in the application. Therefore it may require high degree of distribution. Also, a manufacturer or company would like to minimize its expenses in order to increase its profit. For a corporation, especially the maintenance cost of a logistics application is a significant parameter in order to decide to establish it or not.

In logistic applications, it is not easy to let humans be able to interfere with individual components of the system at any time for maintenance purposes. Therefore providing a fault tolerant system is important for this class. The system must also be able to serve to a scale of hundreds or thousands of inventories as well as it serves to tens of them. Mobility and localization of the components are basic requirements of the applications in this category. Table 4 summarizes the common and application-dependent characteristics

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of logistics applications.

Common Characteristics and Requirements	Application Dependent Characteristics and Requirements
• Degree of Automation • Fault Tolerance • Localization • Mobility • Power Awareness • Production and Maintenance Cost • Reliability • Scalability	• Heterogeneity • Packaging • Real Time • Security • Time Synchronization

Table 4: Characteristics of logistics applications

Due to the fact that many logistics applications benefit from the RFID technology, there are only a few scenarios mentioned in this category; **CoBIs-Collaborative Business Items** [45] aims the usage of smart sensor technology in industrial/supply chain/sensitive settings. It will make it possible to implement networked embedded systems technologies in large-scale business processes and enterprise systems by developing the technologies for directly handling processes at the relevant point of action rather than in a centralized back-end system. Modelling embedded business services, developing the collaborative and technology frameworks for CoBIs with necessary management support, and investigating and evaluating CoBIs in real-world application trials in the oil and gas industry are the main objectives of the project. **Zebra RFID (Radio Frequency Identification) Product Tracking** [51] is a method of remotely storing and retrieving data using devices called RFID tags. An RFID tag is a small object, such as an adhesive sticker, that can be attached to or incorporated into a product. RFID tags contain antennas to enable them to receive and respond to radio frequency queries from an RFID transceiver. **Smart Dust Inventory Control (SDIC)** [31] project can be described with a simple scenario, based on a communication sequence. The carton talks to the box, the box talks to the palette, the palette talks to the truck, and the truck talks to the warehouse, and the truck and the warehouse talk to the internet. Know where your products are and what shape they're in any time, anywhere. Sort of like FedEx tracking on steroids for all products in your production stream from raw materials to delivered goods. In **Sun RFID Industry Solution Architecture** [19], the aim is to monitor the pharmaceutical supply chain in order to prevent drug counterfeiting and improve the health and safety of the people. It is based on the RFID technology.

In this category, several requirements such as localization, scalability, end-to-end reliability are still challenging research issues. Characteristics and requirements of the readily available scenarios are given in Table 5.

	Zebra RFID Product Tracking	CoBIs	Smart Dust Inventory Control	Sun RFID Industry Solution Architecture
Network Topology	Single	Multi	Single	Single
Indoor/Outdoor	Both	Both	Both	Both
Scalability	High	High	High	High
Robustness	Medium	Medium	Medium	Medium
Fault Tolerance	Medium	Medium	Medium	Medium
Localization	High	High	High	High
Time Synch.	Medium	Medium	Medium	Medium
Security	Medium	Medium	Medium	Medium
Infrastructure	Yes	Ad Hoc	Ad Hoc	Ad Hoc
Prod-Maint.cost	High	High	High	High
Mobility	High	High	High	High
Heterogeneity	Low	High	Low	Low
Data Traffic Flow	Medium	Medium	Medium	Medium
Automation	Low	Low	Low	Low
Power Awareness	High	High	High	High
Real Time	Medium	Medium	Medium	Medium
Context-awareness	Low	Low	Low	Low
Reliability	High	High	High	High
Start Date	Early 2000s	Early 2000s	Late 1990s	2003
Current Stage	Available	Design Step	Testbed	Testbed

Table 5: Logistics scenarios and their characteristics

5.4 Transportation (TA)

Applications of this class aim at providing people with more comfortable and safer transportation conditions. They offer valuable real-time data for a variety of governmental or commercial services. It is possible to design different scenarios of transportation applications. For instance, in one scenario cars may communicate with each other in order to organize traffic, whereas in another one traffic organization may be done by installing static entities along highways and monitoring traffic conditions of roads. The desired result of these kinds of applications is to attain human-independent transportation.

The nature of transportation applications starts from being ad hoc, hence infrastructureless and mobile. One vital issue for those mobile components is localization. The systems like car control or traffic applications are highly required to run in real-time. So, the synchronization of the components and the end-to-end delay of the whole system are quite critical for such systems. Another issue that affects all these requirements is scalability. All the characteristic requirements we state here should be handled by taking care of different scales of the network. Table 6 summarizes the common and application-dependent characteristics of transportation applications.

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Common Characteristics and Requirements	**Application Dependent Characteristics and Requirements**
• Heterogeneity • Infrastructureless • Localization • Mobility • Real Time • Scalability • Time Synchronization	• Degree of Automation • Fault Tolerance • Packaging • Power Awareness • Security

Table 6: Characteristics of transportation applications

There are many projects that aim at providing safer public transport. We have covered only following applications since the field of action does not necessarily involve a sensor network in the scenarios: **The Traffic Pulse** is developed by Mobile Technologies, USA. This project is the foundation for all of Mobility Technologies applications. It collects data through a sensor network, processes and stores the data in a data center and distributes that data through a wide range of applications. Digital Traffic Pulse Sensor Network has installed along major highways, the digital sensor network gathers lane- by- lane data on travel speeds, lane occupancy and vehicle counts. These basic elements make it possible to calculate average speeds and travel times. The data will then be transmitted to the data center. In **CORTEX's Car Control Project** [37], the implemented system will automatically select the optimal route according to desired time for reaching the destination, distance, current and predicted traffic, weather conditions, and any other information that will be necessary for the purpose. Cars cooperate with each other to move safely on the road, reduce traffic conditions and reach their destinations. Cars slow down automatically if there are some obstacles or they are approaching to other cars, speed up if there are no cars or obstacles. Cars automatically obey traffic lights. The principal target of this application scenario is to present the sentient object paradigm for real-time and ad hoc environments. It needs decentralized (distributed) algorithms. **Safe Traffic** [40] project aims the implementation of an intelligent communication infrastructure. This communication system would provide all vehicles, persons and other objects located on or near a road with the necessary information needed to make traffic safer. In addition, all road-users should be provided with an accurate positioning device. The idea is simple: reducing the number of traffic-related deaths and injuries. **CarTALK 2000** [42] is a European Project focusing on new driver assistance systems which are based upon inter-vehicle communication. The main objectives are the development of co-operative driver assistance systems and the development of a self-organising ad-hoc radio network as a communication basis with the aim of preparing a future standard. To achieve a suitable communication system, algorithms for radio ad-hoc networks with extremely high dynamic network topologies are developed and prototypes will be tested in probe vehicles.
These are mostly ad hoc applications with high mobility requirements. The characteristics of scenarios are illustrated in Table 7.

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	Traffic Pulse	CORTEX Car Control	Safe Traffic	CarTALK 2000
Network Topology	Multi	Multi	Multi	Multi
Indoor/Outdoor	Out	Out	Out	Out
Scalability	High	High	High	High
Robustness	High	Low	High	Low
Fault Tolerance	High	Medium	Medium	Medium
Localization	High	High	High	High
Time Synch.	High	High	High	High
Security	Medium	Medium	Medium	Medium
Infrastructure	Yes	Ad Hoc	Ad Hoc	Ad Hoc
Prod-Maint.cost	Low	Low	Low	Low
Mobility	Low	High	High	High
Heterogeneity	Low	High	High	High
Data Traffic Flow	Low	High	High	High
Automation	Low	High	High	High
Power Awareness	High	Low	Low	Low
Real Time	High	High	High	High
Context-awareness	High	High	High	High
Reliability	Low	High	High	High
Start Date	Early 2000s	Early 2000s	Early 2000s	Early 2000s
Current Stage	Available	Testbed	Design Step	Testbed

Table 7: Transportation scenarios and their characteristics

5.5 Environmental Monitoring for Emergency Services (EM)

Environmental monitoring applications have crucial importance for scientific communities and society as a whole. Those applications may monitor indoor or outdoor environments. Supervised area may be thousands of square kilometers and the duration of the supervision may last years. Networked microsensors make it possible to obtain localized measurements and detailed information about natural spaces where it is not possible to do this through known methods. Not only communications but also cooperation such as statistical sampling, data aggregation are possible between nodes. An environmental monitoring application may be used in either a small or a wide area for the same purposes.

One of the first ideas of wireless sensor network concept is to design it to use the system to monitor environments, where humans cannot exist all the time. The main issue is to determine the location of the events. Such systems are to be infrastructureless and very robust, because of the inevitable challenges in the nature, like living things or atmospheric events. Since the nodes are untethered and unattended in this class of applications, the system must be power efficient and fault tolerant. Long lifetime of the network must be preserved while the scale increases in order of tens or hundreds. Table 8 summarizes the common and application-dependent characteristics of environmental monitoring for emergency services applications.

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Common Characteristics and Requirements	Application Dependent Characteristics and Requirements
• Fault Tolerance • Infrastructureless • Localization • Packaging • Power Awareness • Production and Maintenance Cost • Scalability	• Degree of Automation • Heterogeneity • Mobility • Real Time • Security • Time Synchronization

Table 8: Characteristics of environmental monitoring for emergency services applications

Environmental monitoring for emergency services is a typical domain which can benefit from networked tiny sensors. Several projects are underway: **GoodFood** [10] [25] project aims to develop the new generation of analytical methods based on Micro and Nano technology (MST and MNT) solution for the safety and quality assurance along the food chain in the agro-food industry. **Hoghtrob** aims the monitoring of sensor wearing sows. The use of sensor nodes on the animals could facilitate other monitoring activities: detecting the heat period (missing the day where a sow can become pregnant has a major impact on the pig production) and possibly detecting illness (such as a broken leg) or detecting the start of farrowing (turning on the heating system for newborns when farrowing starts). The objective of **WaterNet** [49] was to provide the users, namely drinking water authorities, with a suitable technology and it has demonstrated the usability and appropriateness of newly developed methods in real-life applications. **GlacsWeb** [46] project is being developed in order to be able to monitor glacier behaviour via different sensors and link them together into an intelligent web of resources. Probes are placed on and under glaciers and data collected from them by a base station on the surface. Measurements include temperature, pressure and subglacial movement. The main goal of **Sustainable Bridges** [28] [9] is to develop a cost effective solution for detection of structural defects and to better predict the remaining lifetime of the bridges by providing the necessary infrastructure and algorithms. Meteorology and Hydrology in Yosemite National Park is monitored by **Smart Mesh Weather Forecasting (SMWF)** system. Results are showing how, in some years, snowmelt may occur quite uniformly over the Sierra, while in others it varies with elevation.

The number of commercial applications will increase when algorithms and paradigms satisfy challenging requirements such as scalability, robustness or power efficiency. The characteristics and the requirements of the above scenarios are summarized in Table 9.

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	GoodFood	Hoghtorb	WaterNet	GlacsWeb	Smart Mesh Weather Forecasting	Sustainable Bridges	Wildfire Monitoring
Net. Top.	Multi	Single	Multi	Multi	Multi	Multi	Multi
In/Out	Out	Both	Out	Out	Out	Out	Out
Scal.	High	Medium	High	High	High	High	High
Pack.	High	High	High	High	High	High	High
F. Tol.	High	High	High	High	High	High	High
Loc.	Medium	High	Low	High	Medium	High	High
T. Synch.	Medium	Low	Low	Medium	Medium	High	High
Sec.	Medium	Low	Medium	Medium	Low	Medium	Medium
Infr.	Ad Hoc	Ad Hoc	Ad Hoc	Ad Hoc	Ad Hoc	Ad Hoc	Ad Hoc
Pr.-Ma.cost	High	High	High	High	High	High	High
Mob.	Low	High	Low	Low	Low	Low	Low
Heter.	High	Low	Medium	Medium	Low	Medium	High
D. Tr. Flow.	Medium	Low	Low	Medium	Medium	Medium	Medium
Aut.	Low	Low	Low	Low	Low	Low	Low
P. Aw.	High	Medium	High	High	High	High	High
R. Time	Medium	High	Medium	Medium	Medium	High	High
Cont.-aw.	Low	Low	Low	Low	Low	Low	Low
Reli.	Medium	Medium	Medium	Medium	Medium	High	Medium
St. Date	Early 2000s	Early 2000s	Early 2000s	Early 2000s	Early 2000s	Early 2000s	Early 2000s
Cur. Stage	Pilot Application	Available	Pilot Application	Pilot Application	Pilot Application	Design Step	Testbed

Table 9: Environmental monitoring for emergency services scenarios and their characteristics

5.6 Healthcare (H)

Applications in this category include telemonitoring of human physiological data, tracking and monitoring of doctors and patients inside a hospital, drug administrator in hospitals etc. Merging wireless sensor technology into health and medicine applications will make life much easier for doctors, disabled people and patients. They will also make diagnosis and consultancy processes faster by patient monitoring entities consisting of sensors which provide the same information regardless of location and transition automatically

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from one network in a clinic to the other installed in patient's home. As a result, high quality healthcare services will get closer to the patients.

Health applications are critical, since vital events of humans will be monitored and automatically interfered. Heterogeneity is an issue, because the sensed materials will be various. Localization is important because it is critical to determine where exactly the person is; if he carries a heart rate control device and it detects a sudden heart attack, there must be no mistake or no incapability for finding his location. However, since in most cases single-hop networks will be used and neither topology, nor the routing will be changed, mobility is not considered to be a challenging issue for this kind of applications. The delay between the source of the event, and the other end-point of the system is also important. The data has to be conserved as original, which points to reliability of transmission. Also the context is important. Supposing a sensing node must take into account that if a person is doing sports at that moment in order to tolerate higher heart rate differences. Although the idea of embedding wireless biomedical sensors inside human body is promising, many additional challenges exist; the system must be safe and reliable; require minimal maintenance; energy-harnessing from body heat. With more researches and progresses in this field, better quality of life can be achieved and medical cost can be reduced. Table 10 summarizes the common and application-dependent characteristics of healthcare applications.

Common Characteristics and Requirements	**Application Dependent Characteristics and Requirements**
• Context Awareness • Heterogeneity • Localization • Real Time • Reliability	• Degree of Automation • Fault Tolerance • Infrastructureless • Mobility • Power Awareness • Security • Time Synchronization

Table 10: Characteristics of healthcare applications

The projects, examined in this category are as follows: **MyHeart** [48] aims empowering the citizens to fight cardio-vascular diseases by preventive lifestyle and early diagnosis. The first step is to obtain knowledge on a citizen's actual health status. In order to gain this information, continuous monitoring of vital signs is a must. The approach is therefore to integrate system solutions into functional clothes with integrated textile sensors. The combination of functional clothes and integrated electronics and process them on-body, we define as intelligent biomedical clothes. The processing consists of making diagnoses, detecting trends and react on it. MyHeart system is formed together with feedback devices, able to interact with the user as well as with professional services. In **Ubiquitous Support for Medical Work in Hospitals (US-MW)** [2] project, clinics can access relevant medical information and collaborate with colleagues and patient independent of time, place and whatever they are doing. Supposing a patient is lying on an interactive bed and on the other side there is a public wall-display in another room, clinic or hospital and

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a nurse will be having a real-time conference with a radiologist in this project. In **AUBADE**, the aim is to create a wearable platform consisting of biosensors to ubiquitously monitor and recognize the emotional state of those kind of people in real time.

Healthcare projects are summarized in Table11 regarding their characteristics and requirements.

	MyHeart	Ubiquitous Support for Medical Work in Hospitals	AUBADE
Network Topology	Single	Single	Single
Indoor/Outdoor	Both	Indoor	Indoor/Outdoor
Scalability	Low	Medium	Low
Packaging	Low	High	Low
Fault Tolerance	Low	Low	Low
Localization	High	High	High
Time Synch.	Medium	High	Medium
Security	Medium	Medium	Medium
Infrastructure	Yes	Yes	Yes
Prod-Maint.cost	Low	Low	Low
Mobility	Low	Low	Low
Heterogeneity	High	High	High
Data Traffic Flow	Low	High	Low
Automation	Low	Low	Low
Power Awareness	Medium	Medium	Medium
Real Time	High	High	High
Context-awareness	High	High	High
Reliability	Medium	Medium	Medium
Start Date	Early 2000s	Early 2000s	2003
Current Stage	Design Step	Design Step	Design Step

Table 11: Healthcare scenarios and their characteristics

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5.7 Security and Surveillance (SS)

Sensors and embedded systems provide solutions for security and surveillance concerns. These kinds of applications may be established in varying environments such as deserts, forests, urban areas, etc. Communication and cooperation among networked devices increase the security of the concerned environment without human intervention. Natural disasters such as floods, earthquakes may be perceived earlier by installing networked embedded systems closer to places where these phenomena may occur. The system should respond to the changes of the environment as quick as possible.

Security and surveillance applications have the most number of challenging requirements. Almost all issues must be covered to develop such systems. These applications require real-time monitoring technologies with high security cautions. The mediums to be observed will mostly be inaccessible by the humans all the time. Hence, robustness takes an important place. Maintenance may not be possible also. So, Power efficiency and fault tolerance must be satisfied. Table 12 summarizes the common and application-dependent characteristics of security and surveillance applications.

Common Characteristics and Requirements	**Application Dependent Characteristics and Requirements**
• Fault Tolerance • Infrastructureless • Localization • Packaging • Power Awareness • Real Time • Scalability • Security • Time Synchronization	• Degree of Automation • Heterogeneity • Mobility • Production and Maintenance Cost

Table 12: Characteristics of security and surveillance applications

Sample projects we covered in this category are: **Bio Watch** [36] aims at providing early warning of a mass pathogen release, including anthrax, smallpox and plague. The primary goal of **FloodNet** [46], is to demonstrate a methodology whereby a set of sensors monitoring the river and functional floodplain environment at a particular location are connected by wireless links to other nodes to provide an "intelligent" sensor network. **Vehicle Tracking and Autonomous Interception (VT-AI)** [35] is a networked system of distributed sensor nodes that detects an uncooperative agent called the evader and assists an autonomous robot called pursuer in capturing evader developed by University of California at Berkeley. **Monitoring Volcanic Eruptions with a Wireless Sensor Network (MVE-WSN)** [41] is a wireless sensor network to monitor volcanic eruptions with low-frequency acoustic sensors developed by University of Harvard and University of North Carolina. The **PinPtr** [27] system uses a wireless network of many low-cost sensors to determine both a shooter's location and the bullet's trajectory by measuring both the muzzle blast and the shock wave. The **COMETS Project** [13,30] (EU funded, IST-2001-34304) on real-time coordination and control of multiple heterogeneous UAVs includes the experimentation and demonstration of the system in

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forest fire detection and monitoring. The **CROMAT Project** [14] on the cooperation of aerial and ground robots also considers applications in disaster scenarios. And lastly, **RISCOFF** project studies and tests a sensor network system for forest fire detection and alarm signalling.

The results of requirement analysis are shown in Table 13.

	PinPtr	Vehicle Tracking	COMETS and CRO-MAT	Flood Net	Bio Watch	RISCOFF	Monitoring Volcanic Eruptions
Network Topology	Multi	Multi	Multi	Multi	Multi	Multi	Multi
Indoor or Outdoor	Out	Out	Out	Out	Out	Out	Out
Scalability	High	High	High	High	High	High	High
Packaging	Low	High	High	High	High	High	High
Fault Tolerance	High	High	High	High	High	High	High
Localization	High	High	High	High	High	High	High
Time Synch.	High	High	High	Medium	High	High	High
Security	High	High	Medium	Medium	High	Medium	Medium
Infrastructure	AdHoc	AdHoc	AdHoc	AdHoc	AdHoc	AdHoc	AdHoc
Prod-Maint.cost	High	High	High	High	High	High	High
Mobility	Low	High	High	Low	Low	Low	Low
Heterogeneity	Low	Low	High	Low	High	High	Low
D. Tr. Flow	Low	High	High	Low	Low	Medium	Low
Automation	Low	High	High	Low	Medium	Low	Low
Power Awareness	High	High	High	High	High	High	High
Real Time	High	High	High	High	High	High	High
Context-awareness	Low	Low	Low	Low	Low	Low	Low
Reliability	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Start Date	Early 2000s	Early 2000s	Early 2000s	Early 2000s	Early 2000s	Early 2000s	Early 2000s
Current Stage	Testbed	Testbed	Pilot appl	Pilot appl	Available	Design step	Testbed

Table 13: Security and surveillance scenarios and their characteristics

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5.8 Tourism (T)

Everybody wants to feel safe and comfortable when he is in a new environment. When you visit a new country you want to find wherever you like to go without much effort. New micro and nano technologies may help tourists in a foreign environment. For example, sensors and hand-held devices may be a city guide, or may help people in an art museum. Location of the museums, restaurants and information about weather should be provided to the tourists.

Tourism oriented applications do not have high dependencies on the characteristics we mention here. However, they must be personalized. Those applications must be service and context aware and cost effective. They must also support mobility of the user. Table 14 summarizes the common and application-dependent characteristics of tourism applications.

We present two sample studies: **Smart Sight** [52] project is intended to translate from and to local language, handle queries posed and answer in spoken language, and be a navigational aid. The assistant is a "wearable computer" (consisting of a Xybernaut MAIV and a Thinkpad 600) with microphone, earphone, video camera, and GPS to determine users location. The system would have better knowledge of the environment than the tourist with accessing local database and the Internet. The goal of **Cyber Guide** [43] is to provide information to a tourist based on her position and orientation. Initial prototypes of the Cyberguide were designed to assist visitors on a tour of the Graphics, Visualization and Usability Center during monthly open house sessions. The user will be able to see her current location and the demonstrators in her surroundings on a map. The characteristics and challenging requirements of the applications in this domain are given in Table 15 . As there are only few applications, it is difficult to make common conclusions from the summary table.

Common Characteristics and Requirements	**Application Dependent Characteristics and Requirements**
• Context Awareness • Mobility • Production and Maintenance Cost	• Degree of Automation • Localization • Fault Tolerance • Packaging • Power Awareness • Real Time • Scalability • Security • Time Synchronization

Table 14: Characteristics of tourism applications

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	Smart Sight	Cyber Guide
Network Topology	Single	Single
Indoor/Outdoor	Both	Both
Scalability	Low	Low
Packaging	Low	Low
Fault Tolerance	Low	Low
Localization	High	High
Time Synch.	High	High
Security	Low	Low
Infrastructure	Ad Hoc	Ad Hoc
Prod-Maint.cost	High	High
Mobility	Low	Low
Heterogeneity	Low	Low
Data Traffic Flow	Medium	Medium
Automation	Low	Low
Power Awareness	Medium	Medium
Real Time	High	High
Context-awareness	High	High
Reliability	Medium	Medium
Start Date	Late 1990s	Late 1990s
Current Stage	Available	Available

Table 15: Tourism scenarios and their characteristics

5.9 Education and Training (ET)

Another emerging application area of embedded systems is the education. It is possible to provide more attractive lab and classroom activities involving cooperating objects. Current activities aim at merging embedded systems into the education methods.

Although the requirements of education and training applications are highly dependent on the context, they all must be cost effective and affordable by many users. Since these applications are meant to ease the training of users by taking place of a living educator, they must have a high degree of automation. The other issues may be required more or less by the concept, context or type of the application. Table 16 summarizes the common and application-dependent characteristics of education and training applications.

Two projects are briefly introduced in Section 4 for education and training category. The first project is Smart Kindergarten [39] which builds a sensor-based wireless network for early childhood education. It is envisioned that this interaction-based instruction method will soon take place of the traditional stimulus-responses based methods. Probeware [38] is the other education and training project example which is an educational hardware and software tool used for real-time data acquisition, display, and analysis with a computer or calculator. It is also known as Microcomputer-Based Labs (MBL). When it is used with a

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calculator, it is known as Calculator Based Labs (CBL). The characteristics and challenging requirements of the applications in this domain are given in Table 17

Common Characteristics and Requirements	**Application Dependent Characteristics and Requirements**
• Degree of Automation • Production and Maintenance Cost	• Fault Tolerance • Heterogeneity • Localization • Mobility • Packaging • Power Awareness • Real Time • Scalability • Security • Time Synchronization

Table 16: Characteristics of education and training applications

	Probeware	Smart Kindergarten
Network Topology	Single	Single
Indoor/Outdoor	Indoor	Indoor
Scalability	Low	Low
Packaging	High	High
Fault Tolerance	Low	Low
Localization	Medium	Medium
Time Synch.	Medium	Medium
Security	Low	Low
Infrastructure	Ad Hoc	Ad Hoc
Prod./Maint.cost	High	High
Mobility	Low	Low
Heterogeneity	Medium	Medium
Data Traffic Flow	Medium	Medium
Automation	Low	Low
Power Awareness	Medium	Medium
Real Time	Medium	Medium
Context-awareness	High	High
Reliability	Medium	Medium
Start Date	Early 2000s	Early 2000s
Current Stage	Testbed	Testbed

Table 17: Education and training scenarios and their characteristics

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6 Scenario Description Structure

As stated cooperating objects and wireless sensor networks are applicable to a wide range of environments and in various conditions. Also, each sensor network may have assorted roles depending on the task and the scenario. Therefore, each different task may be fulfilled by a set of different entities. Below, there exists a set of symbols, to define the objects and to define the media, used to describe scenarios.

However, human acting devices in a scenario, such as a fire truck with a GPS, will be an end-point. Characteristics of end points based on human behavior will not be detailed further in the scenarios. These end-points are named as *Facilities* where human beings meet the whole system.

In Table 18, we state the symbol set for objects that are used in the scenario decompositions.

Basic Sensor Node collects information about the environment and transmits it to the collection point (maybe sink or base station, depending on the application). It may have different tasks and operational environments. Basically, there are two types of sensors. The first one is called proactive (identified by a 'periodic send' symbol) which monitors the environment continuously. On the other hand, reactive sensors (identified by a 'event-based send' symbol) need to transmit data to the collection point only when the variable being monitored increases beyond a pre-determined threshold. A sensor node is also expected to carry some sensors embedded on it. To indicate which types of sensors the node contains, one Latin character for each sensor will be placed around the figure. For example, a sensor node which senses temperature (T), acoustic (Q), photo (P) and also contains a barometer (B) on it, is figurized below:

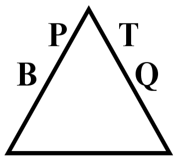

Figure 1: Node with Sensors

Letters to indicate sensor types are:

P: Photo
T: Temperature
A: Acoustics
X: Accelerometer
M: Magnetometer
H: Humidity
B: Barometer

Sink's task may vary from one application to another. It may be an actuator, a collection point or a base station. Various local sink nodes may collect data from a given area and create summary messages. It has more power and longer lifetime.

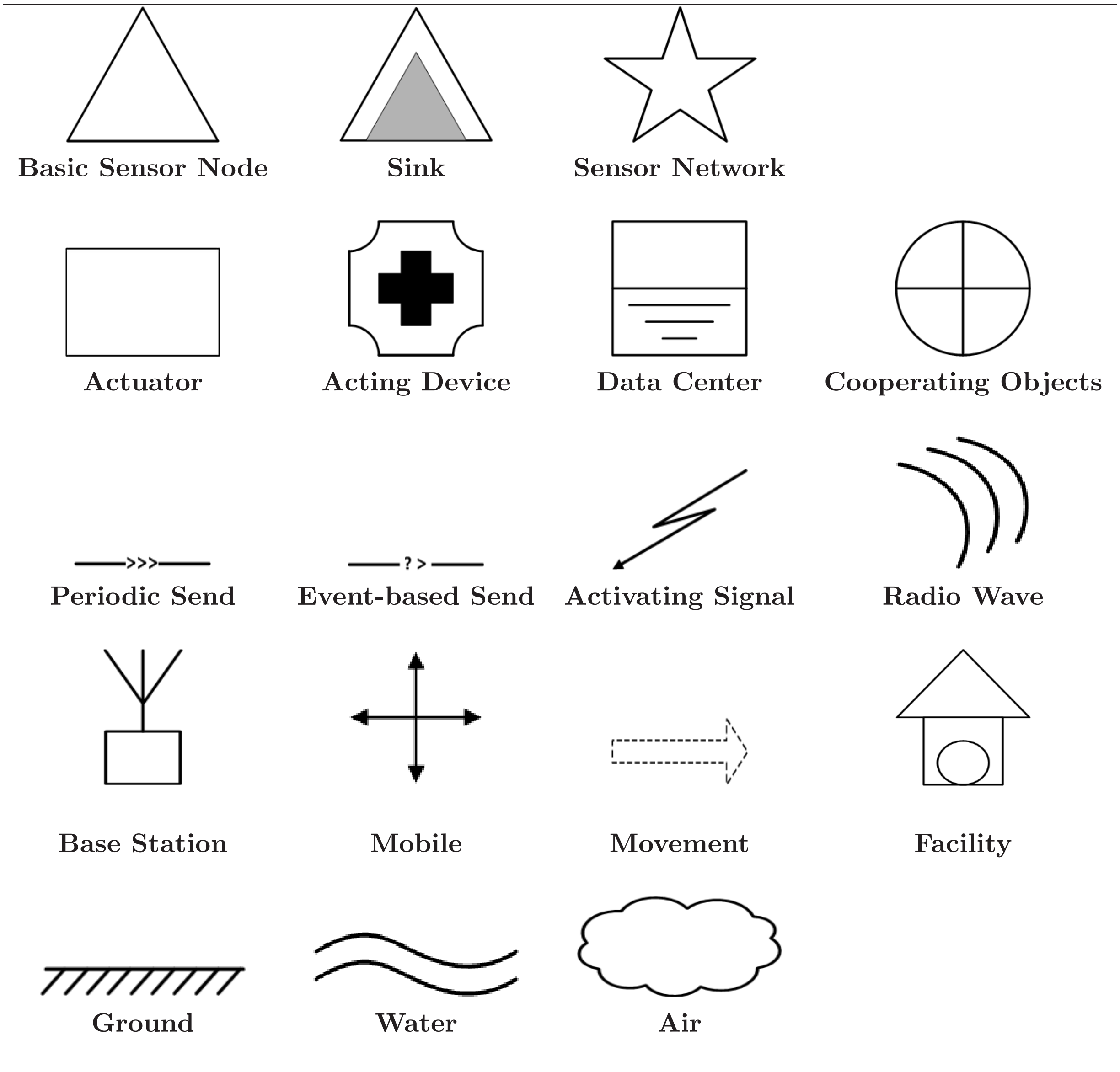

Table 18: Symbol Set

Sensor Network may consist of hundreds or thousands of tiny nodes. Some of those nodes may be mobile. They do not have to be identical. Some of them may be superior to the rest in terms of lifetime, energy source, etc.

Actuator does not have to be included in all ubiquitous computing wireless sensor network applications. However, if we need to activate some devices according to the readings coming from sensor nodes, actuator node is essential. It is worthy to briefly introduce fire detection scenario as an example.

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Suppose that hundreds or thousands of sensor nodes are scattered in a forest and they measure the temperature of the environment continuously. If there were a sudden increase in the temperature of the environment, they send an emergency data to the actuator node as quick as possible, and then it activates the *acting device*. To sum up, actuators extend control from cyber space into the physical world.

Acting Device is the device which is activated by the actuator. On decision of acting, the actuator sends activation signals to the acting device to interfere the related event. An acting device can be a fire distinguisher or a traffic light.

Data Center stores the data which is received from base stations for further analysis.

Cooperating Object defines an object that may include all components given above. In order to explain what cooperating object means, it is worthy to take a closer look in car control scenario. In this example, each car is a cooperating object and cars cooperate and exchange information in order to provide more secure and less dense traffic conditions. Here, each car has a few sensors and actuator. These sensors may have different tasks. Actuator makes car behave according to information collected by sensors and sent by other cars. As a result, there is a cooperation between two or more entities and each entity is named as a cooperating object. The figure must be thought as slices of a pie. Figures of objects that are in cooperation will be inserted into the equally divided slices of the CO symbol.

Periodic (Continuous) Data Sending is done by proactive sensor nodes that monitor the environment continuously and send periodic data to the parent nodes. This kind of communication is mostly seen in environmental monitoring applications. The direction of the arrow indicates the direction of the transmission.

Event-based Data Sending occurs when the variable being monitored increases beyond a threshold. Fire-detection application is an example where sudden temperature increase may happen and sensor nodes send an emergency signal to the actuator. It is a kind of event-based data transmission. The direction of the arrow indicates the direction of the transmission.

Activating Signal is sent by actuator to the entity that is to be activated.

Radio Wave symbol describes an object having the ability of communicating via RF signals.

Base Station can have more power and longer lifetime than ordinary nodes. It may have longer communication range in order to make it possible to communicate with remote sites. It gets sensor node readings and stores data.

Mobility can be a property of some objects in the scenario. For a mobile sensor node, this symbol will be added to the inbounds of the sensor symbol.

Movement and the direction of the movement can be predetermined or illustrated. The dotted thick arrow expresses that the object on the edges is moved in the direction of the arrow points. The moved object is also symbolized as a dotted form of it.

Facility is the end point of the whole system. The human meets with everything at this level.

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For example; suppose a scenario, which contains an object that is an actuator node that can work as a sink, and also mobile and has already moved in the right direction. Such an object will be described by a figure that is composed of all of the attributes of itself, as shown in Figure 2:

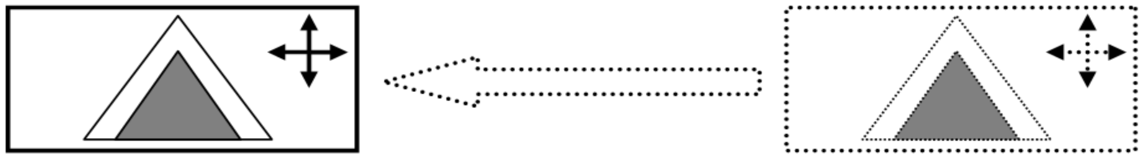

Figure 2: The Usage of Symbol Set

In a scenario, devices and related entities can all be in the same medium, or each one can be in a different medium. Whenever the medium of presence is needed to be referred, the *medium* symbols will be used to express that medium to be in **air**, on the **ground**, or in the **water**.

7 Application Scenarios

As noted, few readily available scenarios exist today if academic test-beds do not count. Many projects still at testing stage determine the characteristics and requirements. Therefore, real requirements are not available for many scenarios yet. In this section, we present six scenarios ranging from readily available to scenarios at design stages. The selected scenarios cover a wide spectrum of domains with different characteristics such as scalability, mobility, robustness etc. In studying the readily available scenarios the following information is provided: user requirements, object decomposition, functional specification of each object in the scenario, architectural description, general characteristics and the current state. For the scenarios in early stages, basically, motivation behind the scenario and currently available object decomposition information are given. The scenarios given below are forest fire detection, precision agriculture, safe transport, sow monitoring, intelligent surrounding, and bridge monitoring.

7.1 Forest Fire Detection Scenario

7.1.1 Introduction

Consider a scenario for forest surveillance and protection such as a natural park, with important ecological value, in fire-prone season. The park has interfaces with urban settlements. The full scenario has three different stages:

- Forest surveillance involving the detection of dangerous activities and the determination of the conditions that involves high forest fire risk
- Fire detection and localization
- Fire monitoring and aids to forest fire extinguishing

In the following, only the second stage will be detailed.

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Traditional forest fire detection is done by means of non-automatic procedures, and particularly by human surveillance from watch-towers. The main drawbacks are the errors originated by subjectivity of the operators, as well as the tiredness and de-motivation of this personnel, the considerable detection delay (especially during the night) and errors in localization. Despite these drawbacks, these manned procedures are today the most used operational technique. Several systems for automatic forest fire detection have been developed and some few of them are used in operational conditions.

The use of wireless sensor networks could contribute to overcome some of the above mentioned drawbacks. Assume that a network of low-cost wireless sensors has been deployed in the natural park. Sensors could be also installed in vehicles or even can be carried out by personnel involved in surveillance and fire extinguishing activities. Then, mobile sensor issues are relevant in the scenario.

The application of wireless sensor networks to fire detection has been proposed by different authors. In fact sensor nodes capable of detecting high temperature or heat exist. It could be also possible to use other sensors (i.e. carbon monoxide) to detect physical phenomena related to the presence of a forest fire. Then, dropping hundreds or thousands of these nodes in the fire-prone forest-park seems an automatic detection alternative. Fire detection has been considered in the FireBug project [4, 6, 8]. The objective of this project is the Design and Construction of a Wildfire Instrumentation System Using Networked Sensors.

On the other hand, it should be noted that the scenario involves different kind of cooperating objects of different size and characteristics. Thus, for example, Personnel Device Assistants (PDAs) can be used to have updated information from the environment and to guide the operational extinguishing personnel. Portable field computers and laptops on board vehicles are useful for surveillance and fire fighting. Satellite positioning systems, can also be used integrated with PDAs, portable computers and laptops to know in real time the absolute position of people and vehicles.

Moreover, the application of autonomous objects is useful to provide information of the areas poorly covered by the sensor network in the natural park and to calibrate the sensor nodes. Different autonomous systems can be used for surveillance, detection, localization and fire monitoring and measurement. These include computer vision systems for detection and monitoring [29], autonomous vehicles and robots to acquire information or even to actuate in the extinguishing operations.

Autonomous ground vehicles can have significant sensing, communication and power infrastructure onboard. However, they have significant mobility constraints in the forest scenario. Then, it could be very difficult to access to the desired locations to acquire information or to actuate. Then, the application of unmanned aerial vehicles is also useful for the surveillance, detection and extinguishing activities since it may be difficult to deploy the sensors in the whole area. The COMETS project of the European Commission (IST-2001-34304) on multiple heterogeneous unmanned aerial vehicles considers the application of multiple unmanned aerial vehicles for the forest fire detection and monitoring.

7.1.2 Scenario Characteristics

Three main platforms can be used for automatic forest fire detection: ground platforms, platforms on aerial means, and satellite based systems.

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Several automatic forest-fire ground detection systems have been developed in the last 10 years. In most cases they are based on the computer processing of the images provided by infrared and/or visual cameras mounted on surveillance towers and other locations with good visibility conditions. Their main advantages when comparing to satellite based systems are the detection delay and the resolution.
Infrared cameras provide estimations of the radiation intensity of the scene. For fire images in natural environment, fire is the source that originates the highest infrared radiation intensity. The main infrared band used for forest fire detection is the mid-infrared [3-5] m, but also the far-infrared band ([8-12] m) or thermal infrared are used for detection and false alarm discrimination. Detection systems using infrared cameras have demonstrated the ability to detect small fires (about 1m) up to several kilometres (between 10 and 20). There are various commercial detection systems that have been in operation for several years in Spain and Italy using infrared technology (i.e. BOSQUE system, BSDS system). Early detection can be achieved when there is direct visibility of the fire. However, the application infrared systems have problems in detection of forest fires in areas with dense vegetation and when the topography precludes the direct see of all possible sources of early fires.
Wildfire-detection systems using visual cameras have also been developed, including automatic detection systems such as ARTIST-FIRE fire which has been operational in France in the last years. These systems are usually based on the smoke plume detection. The adequate selection of the optical system of the cameras is very important. Furthermore, the compensation of the variation of lighting conditions and the lack of contrast between the smoke and the background play an important role in automatic detection systems. Moreover, smoke plume detection by means of visual cameras cannot be applied by night.
Precise localization of the alarm is not easy if the number of observatories is low. Thus, if the fire is only detected from one observatory, the localization of the alarm relies on the accuracy of the available map and the modelling of the optical system. The accuracy also depends on the characteristics of the terrain and the relative position of the observatory. Moreover, in case of smoke detection, when there is no direct vision of the fire, only the direction can be determined.

7.1.3 Functional Specification

The use of sensors networks to cover large forests requires that nodes use multi-hop communication. If a node detects a fire, it should send an alarm message (along with its location) to a forest monitoring and control center.
The main practical problems are similar to other encountered in environment monitoring plus others related to:

- Fire should be detected early enough otherwise the system will be useless
- False alarms should be avoided. That depends on the sensor and also another parameter or information (i.e images) can be used to validate the event.
- Localization should be provided. The use of GPS and transmission of the position information along with the alarm still a costly solution.

Then, hybrid alternatives, combining wireless sensor networks (low cost and low energy consumption nodes) with cameras and other communication systems, seems to be a currently attractive solution.

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Some of the nodes should be mobile to overcome the coverage limitations and should have power and communication resources to support cameras.

The main problems related to the application of autonomous systems are also related to coverage. One solution could be to use one long-endurance UAV for patrolling looking for fire detection in critical seasons. However, in the current state of the technology this is an expensive solution. Another alternative would be to use several low cost aerial vehicles with appropriated coordination capabilities as in the COMETS project. The combination of autonomous systems with wireless sensor networks for environment monitoring and detection seems to be an attractive solution. The robotic nodes have much higher capabilities than the sensor nodes in terms of both hardware functionalities and networking throughput, overcoming the difficulties of the wireless sensor networks mentioned above. Particularly, a limited number of mobile robotic nodes can cover a large scale sensor network.

7.1.4 Object Decomposition

Wireless Sensor Network: The scenario requires the deployment of a wireless sensor network composed by a large number of cooperative sensor nodes.

There are different types of sensor nodes in the market. The Berkeley motes are the most widely known. These sensor nodes have the advantage that there is a complete information about its software and hardware; furthermore, the software is developed under the open source license and there is enough information to develop sensor nodes or sensor expansion boards for particular applications. The main characteristics of these sensor nodes are:

- Bidirectional communications in RF: at 400, 900 MHz and 2.4 GHz using technologies of spread spectrum and frequency hopping.
- TinyOS operating system: it is under an open source license, and it is implemented in NesC. This operating system has a small size, modular structure, allowing to implement light threads and implementing communication protocols designed for sensor networks.
- Based on microcontrollers of 8 bits with low calculation power
- Opportunity of over-the-air reprogramming.
- Modular hardware system for its easy expansion. This expansion is made with sensor boards as the Mica Weather Board which provides sensors that monitor changing environmental conditions with the same functionality as a traditional weather station. The Mica Weather Board includes temperature, photo-resistor, barometric pressure, humidity, and passive infrared (thermopile) sensors

The thermopile may be used in conjunction with its thermistor and the photoresistor to detect cloud cover. The thermopile may also be used to detect occupancy, measure the temperature of a nearby object, and sense changes in the object's temperature over time. If the initial altitude is known, the barometer module may be used as an altimeter. Strategically placed sensor boards with barometric pressure sensors can detect the wind speed and direction by modelling the wind as a fluid flowing over a series of apertures.

It should be noted that new COx and NOx sensors have been recently developed. These sensors could be used to monitor the smoke concentration precluding harmful effects on the fire fighters

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and population in general. Both static nodes and mobile nodes carried by the fire fighting personnel could be used.

Ground Vehicles: The use of ground vehicles is an alternative to provide mobility to the nodes. In fact these vehicles can have significant communication and power infrastructure. The interest of unmanned vehicles can be justified by the risk involved in fire fighting operations.

Autonomy of the vehicles in the natural terrain poses significant challenges. In fact, we may not be able to provide it with accurate models of terrain. If maps are available, they may lack local detail, and in any case will not represent the changes that can occur in dynamic situations where transient obstacles (such as other mobile vehicles and humans) will be encountered, or where activities of the autonomous ground vehicle itself might alter its environment during accomplishment of tasks. On the basis of information obtained from its own sensors, the autonomous ground vehicle must be capable of building its own maps to represent the environment and flexibly support its own reasoning for navigational planning and, if necessary, re-planning. Moreover, as the world around the vehicle can change quickly, we want the software which implements control to be computationally efficient and supportive of real-time response to events. In spite of the progress achieved in autonomous ground vehicles, it is clear that autonomy is still very difficult to achieve in operational conditions.

Unmanned Aerial Vehicles: Unmanned air vehicles (UAVs) are self propelled air vehicles that are either remotely controlled or are capable of conducting autonomous operations. Three different types of Unmanned Aerial Vehicles can be considered: airplanes, helicopters and airships.

Airships are interesting for surveillance missions in general. However, the use of airships is strongly constrained by the wind velocity. It should be noted that the deployment of unmanned aerial vehicles for early detection could be recommended when the weather conditions favour the rapid propagation of the fire, which are strongly related to the wind velocity. Then, airships do not offer good characteristics to be used in this scenario.

Furthermore, unmanned airplanes are preferred to helicopters for surveillance and forest-fire detection tasks due to the greater flying range, coverage, ability of autonomous flight and less difficult teleoperation in case of failure of on-board automatic control systems. In case of large areas, the use of several UAVs can be of interest. Multi-UAV surveillance strategies require appropriate planning and coordination algorithms.

7.1.5 Step by Step Scenario Description

The scenario involves the application of the following objects:

- Wireless sensor network with nodes providing measures of temperature, humidity, NOx and COx
- Autonomous low cost aerial vehicles: airplane and helicopter
- Conventional ground and aerial vehicles for patrolling and fire extinguishing
- Mobile computing objects: PDAs, laptops and portable computers
- Computer vision systems

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One sensor is giving conditions near the limit of the alarm, but the threshold is not over passed. There are also coverage problems, then the managers have uncertainties about the existence of a fire.

One of the cameras sees a small smoke plume. However, due to the vegetation and terrain characteristics, the hot spot is not seen from the infrared camera and there are strong uncertainties about the location of the possible fire.

The patrolling ground vehicle cannot access to good observation points. Then, the managers decide to fly the autonomous airplane over the suspicious area.

The autonomous airplane has infrared and visual cameras, satellite positioning systems and software to determine the location of objects in the images by using the positioning and navigation sensors.

The autonomous airplane confirms the alarm and locates the fire. It is in an inaccessible area with very high risk of propagation due to vegetation, slope and wind conditions.

The managers activate the fire extinguishing means.

The fire detection and localization scenario depicted by standard symbol set is given in Figure 3.

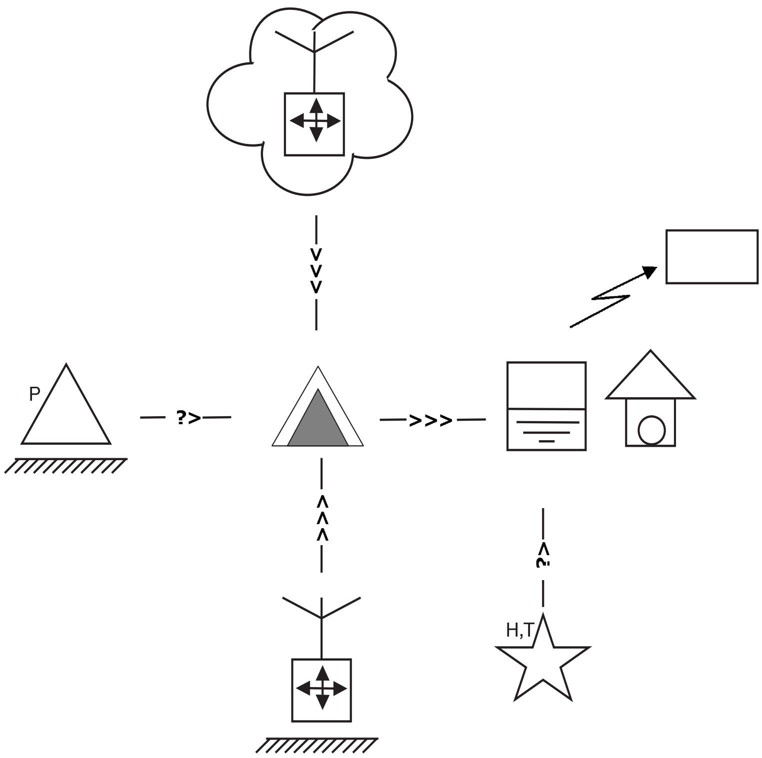

Figure 3: Fire Detection and Localization

7.1.6 System Requirements

Some relevant system requirements in this application scenario are:

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Scalability: Due to the fact that sensors have a small transmission range on the order of a few meters, the number of nodes in the network may be on the order of thousands to cover a large area. Therefore, scalability is another issue that needs to be solved in order to provide proper work of the algorithms without affecting the application performance.

Mobility: Due to the fact that the system will have a number of wireless mobile robots, it must support mobility and ad hoc (infrastructureless) communication. The mobility leads to the frequent changes in the number of nodes and the topology of the network and also affects other requirements such as localization.

Fault tolerance: The need for robustness is apparent due to the harsh operational conditions in an outdoor environmental monitoring application. Even when robustness is provided, there will be some nodes failures, so fault tolerance should be provided for accurate monitoring.

Power Awareness: Efficient power management strategies are necessary for prolonging the network lifetime, especially in an application designed for environmental monitoring, since it is not usually easy to access that environment and replace the network with a new one. The network lifetime also depends on the communication range of a single node, the total number of nodes, and the total size of the area to be surveyed.

Real-time: It is desired that responsible authorities take necessary measurements against fire as quick as possible, therefore, end-to-end delay must be low.

Localization: Event localization, such as fire or smoke detection, is a significant requirement in this scenario. Some nodes may have GPS receivers and geometrical and mathematical methods could be applied to estimate the locations of other nodes without GPS. Furthermore, the vehicles (aerial or ground) considered in this scenario are usually equipped with GPS and several algorithms have been recently proposed for the localization of the nodes of a WSN by using certain information from robots moving near their locations.

Those robots and other CO considered in this scenario are also provided with sensors (such as visual and/or infrared cameras) and algorithms that allow them to detect and locate the fire if direct visibility is available.

Synchronization: In this scenario, it is usually required to associate data coming from different CO to the same event, so data aggregation and data fusion techniques are relevant. Furthermore, a detection task over a broad area requires the cooperation among different CO such as nodes of a WSN and UAVs patrolling over the forest. Therefore, time synchronization is a relevant issue in this application scenario.

Heterogeneity: It is practically impossible to have all nodes identical in a wireless sensor network application. In fact, some nodes may be mobile whereas others can be static, and different sensors measuring different parameters are possible in this scenario. Furthermore, autonomous systems, and particularly aerial vehicles, with different architectures and levels of decisional autonomy are considered. It has also been mentioned that those robots can be ground or aerial robots. Therefore, the system should support a high level of CO heterogeneity.

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7.2 The GoodFood

7.2.1 Introduction

[10], and [25] are the main resources of the scenario. Recent developments in wireless sensor technology have provided people with being aware of environment changes and tackling properly with them. AmI (Ambient Intelligence) paradigm explains the case where the user is surrounded by intelligent and intuitive interfaces able to recognize and respond to his/her needs. It is possible to integrate AmI and wireless sensor network technology in order to monitor different environments and control sudden changes.

Agriculture is a challenging area where newly emerged wireless sensors based on Micro and Nano technologies can be applied in order to increase the safety and quality of food products. The implementation of micro and nano technology into the agriculture is called Precision Agriculture where a number of distributed elementary sensors communicating wirelessly are used to monitor the processes of food production and to detect the remainder chemical substances in products. Wireless sensor networks can monitor every steps of food chain from farmer to consumer and introduce smart agro-food processing. Precision agriculture is a multidisciplinary application that includes the cooperation of micro electronics, biochemistry, physics, computer science and telecommunications areas.

Precision agriculture applications aim at monitoring and controlling the parameters that affect the plant growth. Various nutrients (zinc, poshphorus, nitrogen, etc...), soil moisture, temperature, pH, soil organic matter content, rooting depth, weed pressure, and pathogens have significent influence on food production. These soil parameters change within fields, therefore plant growth also varies within a field. The term "spatial variability" defines the variability of a parameter within a field and a precision agriculture application should obtain spatial variability maps of a field.

The Integrated Project GoodFood is a Precision Agriculture project that aims at assuring the quality and safety of food chain. Principally, it is based on the massive use of tiny detection systems capable of being close to the foodstuff and merged in Ambient Intelligence (AmI) paradigm.

In GoodFood, high density sensors are deployed in the agricultural area wanted to be monitored and wirelessly interconnected, capable of implementing locally some computations based on some predetermined mathematical models and forwarding information to a remote site.

First GoodFood application scenario is planned to be implemented in spring 2005 in a pilot site in a vineyard at Montepaldi farm, a property of the University of Florence. Based on MICA motes and TinyOS, a wireless sensor network (WSN) will be disseminated in the area and it will primarily be used for detection of insurgence toxins in the vineyard.

7.2.2 Scenario Characteristics

The main characteristic requirements of the GoodFood scenario are network lifetime and power efficiency, synchronization, security, localization, address and data centric communications, scalability, fault tolerance and node heterogeneity. Actually, each characteristic is a challenging area for the scenario and requires

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researches in order to provide proper operation. They will be investigated further in the system requirements section.

7.2.3 User Requirements

A precision agriculture application aims at monitoring and controlling the quality and safety of food products. It is crucial to measure not only the conditions of agricultural area but also the percentage of chemical substances in food.

First of all, users of the system wants to obtain some information about the of the soil such as nutrients (zinc, poshphorus, nitrogen, etc...) and organic matter included in soil, moisture, temperature, and pH of soil. By using this data, it can be determined which food fits best this soil. Another user requirement is to determine remaining chemical substances in products. By this information, hazardous foods are indicated and end-user knows that those marked foods may cause severe health problems.

7.2.4 Functional Specification

In general, there are four main components of the GoodFood; wireless sensor network, sink node, base station and data center. The wireless sensor network is composed of hundreds or thousands of basic sensor nodes deployed close to the event. Each sensor node may have several nodes with different tasks. They measure the parameters related to the quality and safety of food and send this information to the sink node which is more powerful than elementary sensors. A sink node has computational capability and it runs distributed algorithms. The data sent by sensor network are sorted and classified according to the measured parameters. It also has data aggregation capability. The base station acts as a relay between the sink node and the data center. In other words, it is like a gateway that delivers the information coming from the field to the remote side. The data center is a data pool where all information related to the food safety and quality are collected. The users accessing the data center may be food specialists, nutritionists, manufacturers, ordinary people, etc. The quality and safety of produced food is evaluated by users at this step.

7.2.5 Object Decomposition

Generally, the scenario requires the cooperation of three different technologies that are given below:

The High Density Wireless Sensor Network that consists of a large number of low power, low bandwidth components that collect the information about the parameters affecting the safety and quality of food. The network will consist of hundreds to thousands of nodes designed for unattended operation. It is possible to have a few mobile nodes for better coverage. The data rate is expected to be low (on the order of kbits). The wireless sensor network is divided into groups and each group is called cluster where each cluster has a cluster head. The cluster head is also called sink node. It is more powerful than basic elementary sensor nodes and has data aggregation capability. It also runs distributed algorithms.

Wireless Base Network that acts as a relay between the sensor network and the fixed base network and consumes high bandwidth. It is not far from the agricultural area. Wireless sensor network is deployed in the area. The larger the distance that sensors have to send data over, the less efficient is the power consumption strategy, therefore, the distance between the sensor network and the base station should be as small as possible.

Fixed Base Network that has high performance computing platform to support truly scalable data processing. It is called the data center. The information coming from the source are stored and retrieved for the evaluation of the food safety and quality. Also, users may send various queries to the wireless sensor network.

7.2.6 Step-by-Step Scenario Description

The GoodFood project scenario mainly consists of three components. The networked sensor nodes that include various sensors disseminated close to the area are the first part. Base station that relays information coming from sensor network to the remote data center is the second and the data center that collects whole data sent by WSN is the last component. The layered structure of the GoodFood scenario is given in Figure 4. The facility in the figure may be food analysts, nutrition specialists, etc who can access to the data center and evaluate the quality and safety of food.

Wireless Sensor Network: It is based on MICA motes and run by TinyOS. Each sensor node may consist of several sensors varying from sensors measuring ambient conditions such as humidity and temperature of soil to sensors measuring chemical substances in food and pathogens that harm food products. Once sensors are deployed to the area, they construct a multihop wireless sensor network and start to monitor the environment. Sensor nodes collect temperature, pressure, moisture, and pesticies (bacteria, fungi, insects) data, that is, each sensor node includes several sensors on board. They also attach time and location information to those data and send them to their sink node that is capable of analyzing data. They have computational capability and can interpret the information sent by sensor nodes. Each sink node has data aggregation and computational capabilities. They collect raw data from sensor nodes, process and aggregate them, then forward it to data center via base station. The wireless sensor network established in the field is called monitoring infrastructure. Information collected by monitoring infrastructure will be used to develop mathematical models for predicting the insurgence of pathogens such as botrys and pheronospera or food toxins such as ochratoxin. Distributed mathematical models and algorithms in WSN will be used to perform spatio-temporal correlations of data, detect the presence of mycotoxins and pathogens. This will make it possible to take quick and appropriate measurements. Clustering structure among sensors is used for more efficient power consumption strategy and and longer lifetime. According to clustering, the WSN is divided into small groups and each group has a leader called cluster head that is more powerful than other nodes in the group. By dividing large sensor network into small groups, communication range of each node is decreased, thus power resources are more effectively used, because it is well known that the longer the communication range, the more power needed to send data over that distance.

Base Station: It acts as a radio relay that delivers sensor readings to the data center. It may also control the autonomous operation of the network. Data coming from basic sensors deployed in the agricultural area are sent to the data center via base station. Also, users in data center may send various queries to the sensor network via base station.

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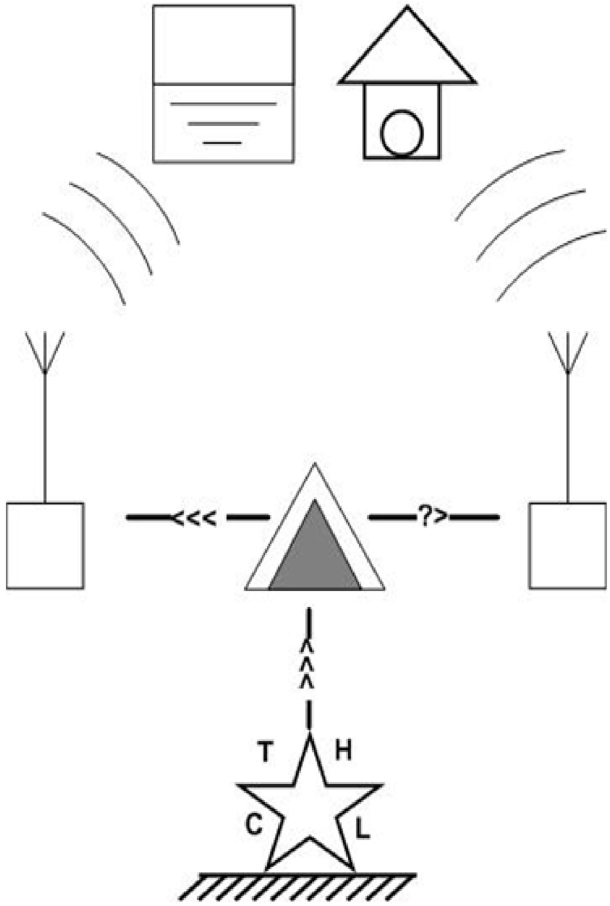

Figure 4: The Object Decomposition of the GoodFood

Data Center: All data coming from the agricultural area come to the data center. User can access and control the network via data center. Information sent by networked sensors are evaluated and the field conditions and remaining chemical substances in food products are determined, thus, each step of the food production is controlled and monitored. Some foods may have higher level of harmful chemical substances than pre-determined threshold. In such a case, those products are marked and people are warned about them.

Generally, GoodFood scenario has three phases named as sensing, processing and decision making, and acting. Distributed networked sensor nodes monitor the environment and parameters related to the quality and safety of food. Data evaluation is fulfilled by sink nodes. In other words, sensor readings are collected and aggregated by sink nodes where distributed algorithms and some mathematical models run on. It means that the information delivered to the data center are not raw data. Information sent by sink nodes via base station are stored in data center where acting phase occurs. Data storage is used, as name implies, for storing and retrieving information in a more organized way according to the sensors modelling

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language and the database model. Also, a data mining system for analyzing the information to find some demanding correlations is needed. What is more, users that have access right to the system may want to take any kind of decisions according to the obtained knowledge about the quality and safety of food products, therefore a decision support system is needed. The file system is necessary for storing data structured in files as well. Users such as food quality specialists, nutritionists, and consumers can develop strategies for the safety and quality of food according to those data. They may also send queries to the sensor network and demand specific information about the area such as what is the risk level of pathogens' attack on the field. As another example of data storage application, suppose that some kind of food has been monitored during the product process and any necessary information about the quality and safety of it has been obtained. The product may contain any chemical substance that is risky. Now, any user that has access right to database may introduce the community if the food has any risk or not. The picturised scenario is given in Figure 5.

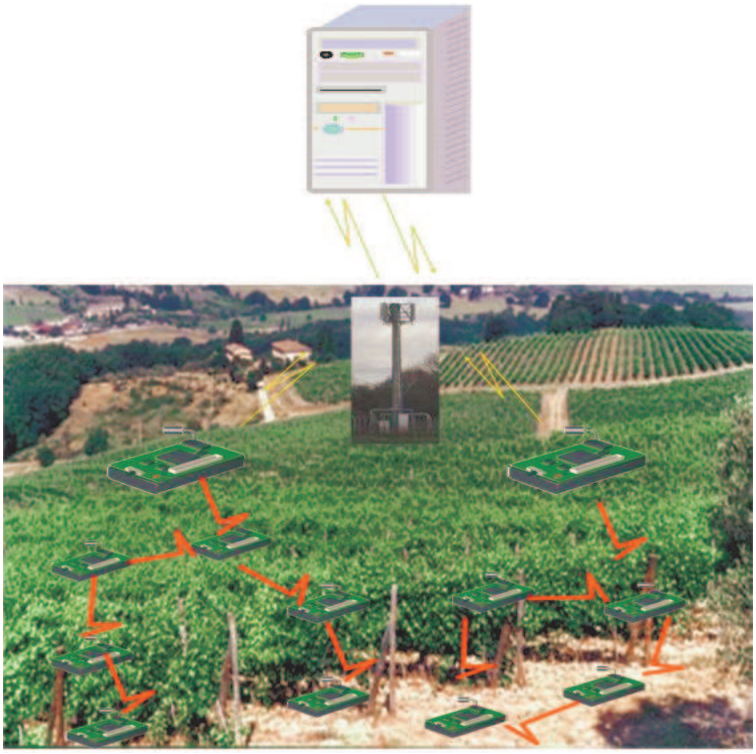

Figure 5: The GoodFood Scenario

7.2.7 System Requirements

The GoodFood project has several problems and requirements that need to be solved in order to provide proper operation. In order to present complete definition of system requirements, some specific information and details about the GoodFood project which has been implemented in pilot site in a vineyard are needed.

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For instance, the communication range of a single node, the number of nodes deployed in the vineyard, the total area of the pilot site, the planned system lifetime are among critical parameters that affect system requirements. Some important system requirements are as follows:

Network lifetime and Power Efficiency: The cost of radio communications in terms of energy is high. The larger the distance between two communicating entities, the higher the energy consumed. Therefore, in order to optimize energy consumption, clustering structure should be used and information should be exchanged between neighbor nodes. On the other hand, energy saving measurements bring about longer life-time. As a result, power efficient communication algorithms lead to a longer network lifetime. Due to the fact that a precision agriculture application scenario may be responsible to monitor a food's production process that lasts for several months, efficient power consumption algorithm is a must. The network lifetime of GoodFood is directly affected by communication range of a single node, total number of nodes, and total size of the area. Therefore, those information are needed for a precise definition of network lifetime.

Synchronization: Time synchronization among entities is a significant need in order to provide consistent coordination among nodes. The start and stop of the transmission between two devices should be defined correctly. In precision agriculture application, users can send queries to sensor nodes for some specific information. In this session, before starting communication, time synchronization is necessary. Besides, synchronization between sensors and sink node should be provided.

Security: Wireless sensor network applications face with security requirements on different levels of the network. Whereas the loss of one or more nodes due to failure or damage should be tolerated in a specific case, in another situation data may need protection against deliberate attacks or accidental alteration. On the other hand, security measurements should not make the system access harder for users.

In this precision agriculture application scenario, it is important to have some security mechanism that controls the access to the system and information. Also, authentication and authorization are necessary among nodes to prevent fake nodes. Besides, it is possible to encrypt data with encryption algorithms that bring about low overhead. In order to provide security of the system, efficient user and key management schedules are needed.

Localization: If the data sent by sensors do not include the location information of the event, it is not valuable for the user. After deployment phase, sensors should be able to estimate their locations in order to send reasonable data. It is possible to face insurgence toxins' attack on food in a specific region of the agricultural area. While sensor nodes notice this attack, they should give the position of the attack in order to provide responsible authorities with taking necessary and efficient measurements. The deployment procedure of networked sensors determines the localization method of the GoodFood scenario. They may be placed manually, or there may be a few nodes superior to the rest which are deployed randomly. Those superior nodes may have GPS receivers, thus they define their positions via GPS (Global Positioning System). Other nodes may estimate their locations with geometrical and mathematical methods by communicating with those nodes that know their positions a priori. As a result, minimum sensitivity of location information is mainly determined by deployment method of GoodFood project.

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Address and data centric communications: It is required that this precision agriculture scenario must support both address-centric and data-centric approaches. In the first model, each node has its unique logical address and communication is mostly point - to - point. This model will be used especially when queries for sensor readings are sent and configuration and diagnostic procedures are initiated. On the other hand, data-centric model is used when exchanged data is more important than the participants of the communication. For instance, interests are propagated within the network and information are collected from nodes whose data match the requests.

Scalability: The number of sensors in the initial network topology may be on the order of tens or hundreds. However, the agricultural area wanted to be monitored may be enlarged that requires thousands of sensors. Mathematical and computational methods and the software of the scenario must be capable of working with this extremely high number of nodes. The design should allow the system to work properly even when the number of sensors is increased.

Fault Tolerance: It is highly possible to lose some sensors of the network due to the environmental and operational conditions. However the network should maintain its operation even a few nodes fail to perform their task, that is, it should have a predetermined fault tolerance against possible errors.

Node Heterogeneity: It is practically impossible to have all nodes identical in a wireless sensor network application. Some of them should be more powerful than the others. Also, some nodes may be mobile while the others are static. For this precision agriculture application scenario, we need sink nodes that are more powerful than elementary sensor nodes. It also has various sensors measuring different parameters of the soil and food products. The system should support node heterogeneity.

7.3 CORTEX's Car Control

7.3.1 Introduction

[5], [37] are the main resources of the scenario. Car control scenario aims at demonstrating the feasibility of the sentient object paradigm for real-time ad hoc environments. In this scenario, cars are able to operate independently and cooperate with each other to avoid collisions. It has been searching for the feasibility of future car systems that will be able to transport people without human intervention. The final destination and optionally the desired time of arrival are the only two parameters needed to be provided. Thus, the car control system will automatically select the optimal route according to those information for reaching the destination. Cars will cooperate with each other to move safely on the road, reduce traffic conditions and reach their destinations.

The principal target of this application scenario is to present the sentient object paradigm for real-time and ad hoc environments. It needs decentralized (distributed) algorithms.

Each car is a cooperating object. However, they can be called sentient object as well. They are autonomous and proactive. Sentient objects sense their environment via sensors and react to sensed information via actuators. Various sensors mounted on cars are responsible for monitoring the environment and sensing related information. They should receive both periodic such as position information broadcasted by nearby

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cars and sporadic events such as emergency stop signals that provide information about unpredictable situations.

7.3.2 Scenario Characteristics

The car control scenario is an example of proactive applications relying on sensor-rich components. Each car is capable of acting based on the acquisition of information from the environment. Some of the main characteristic requirements of the scenario are sentience, autonomy, scalability, time and safety critical behavior and mobility. The scenario characteristics are introduced in the system requirements section.

7.3.3 User Requirements

The main requirement of the scenario is the cooperation between the cars on the road. It is desired that each car contributes to the determination of traffic conditions. They should also obey the traffic lights without human intervention. If a car senses an obstacle ahead, it should broadcast an emergency signal, thus, each car becomes aware of the situation. When there is a traffic jam in a particular region, other cars approaching to the jammed area know the situation and have an opportunity for finding alternative ways.

7.3.4 Functional Specification

In the car control scenario, each car is a cooperating object and includes several sensors with different tasks and an actuator working as a control logic engine. The functionalities of each component of the scenario are given below:

Sensors: Elementary sensor nodes are mounted on cars. They are not identical and each has different tasks. For instance, a sensor may collect information about traffic lights, while another one may measure the distance to another car or obstacle ahead. They do not interpret data, just sense their environment and send those data to the actuator.

Actuator: It can be said that it is the brain of the car. The reaction to sensed information is organized by actuator. Principally, it is a control logic engine and decision maker.

7.3.5 Object Decomposition

As stated above, the car control scenario is mainly composed of cars. In other words, each car is a cooperating object. Also, traffic lights and the data center are members of the system. Each car has several sensors each having different tasks and an actuator. The object decomposition of a car is given in Figure 6.

Sensors: They are mounted on car. Each sensor has different tasks. For instance, there may be distance sensor, speed sensor, etc. They just collect the information for which they are responsible. They are not capable of interpreting the collected information.

Actuator: It provides the car with being independent of human control. The information collected by sensors are evaluated by actuator. It determines the car's reaction to the sensed data. Also, it provides the communication with other cars.

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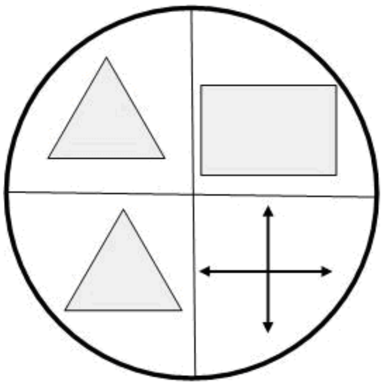

Figure 6: The Object Decomposition of Car Control Scenario

The Data Center: The car control scenario is based on decentralized algorithms run by cars on the road. However, there is a need for data center even when the operation is distributed. The data center may build strategies and statistics about the traffic of the roads for particular time segments of the day and disseminate those information to the cars. It may also send weather and news information.

7.3.6 Step-by-Step Scenario Description

The system mainly consists of cars where each car is a cooperating object. They include a number of sensors that receive various periodic and event-based information from the environment. Sensors' output is only an approximation to the value sensed in the real world. Due to the physical measurement, uncertainty is inevitable in data. Probabilistic sensor fusion scheme based on Bayesian networks can be used as a mechanism for measuring effectiveness of derivations of context from noisy data. Each car needs an actuator which is a control logic engine and interprets raw sensed data that needs to be transformed to meaningful information. Sensor readings also include context information such as the position of each car with respect to other cars and traffic lights. Each car needs to be aware of its safety zone and be able to detect any objects entering its safety zone. For instance, ultrasonic sensors fitted at each side of the car provide context awareness. The interaction between sentient objects differs from traditional interaction models. They communicate via an anonymous, generative communication abstraction. The messages are generated spontaneously rather than with request/response style. It leads to the unplanned and spontaneous interaction.

Obstacle detection may be a scenario example of CORTEX Car Control Application. In order to avoid of colliding with both obstacles on the road and other cars, they should be able to detect its position and the other cars' positions and take actions upon this information. If a car detects an obstacle ahead, it should rapidly apply an emergency stop and disseminate an emergency signal. Cars receiving an emergency stop signal from a car ahead should also apply an emergency stop themselves. The picturised scenario is given in Figure 7.

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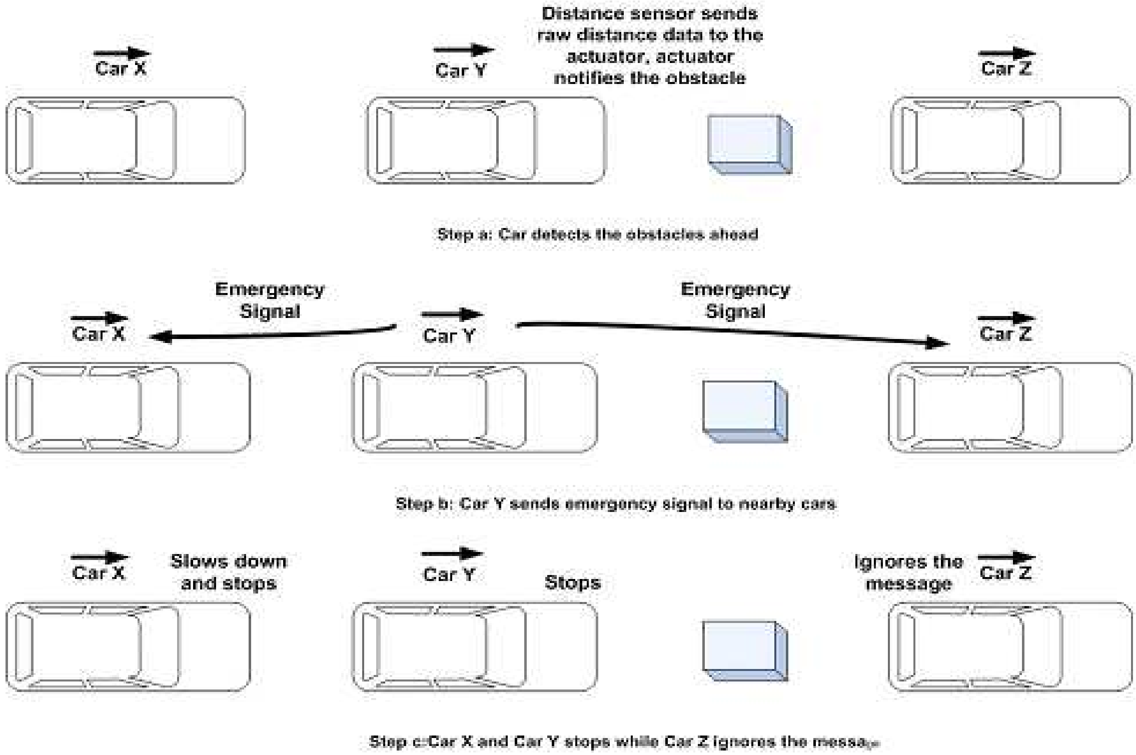

Figure 7: The Car Control Scenario

7.3.7 System Requirements

Autonomy: As stated before, this scenario aims at searching for possible ways of providing traffic control without human intervention. Cars need to make autonomous decisions such as deciding when to brake or change the car speed. Decision-making takes place based on current and past context information. A control logic engine is necessary to fulfill such autonomous behavior.

Cooperation: In order to avoid of human-based traffic control, some degree of cooperation between cars is required. Each car notifies other cars about the actions it takes by dissemination of events. The events are propagated to all cars in its proximity. Event dissemination should be as real-time as possible. For instance, a car suddenly slows down, and the car is followed by many other cars. The braking car should broadcast an event notifying brake action to cars which follow it, in a timely manner. The cars that have received the brake event on time, take necessary measurements to avoid collision of chain of cars. Disseminated events should also include context information such as location of braking car for the correct perception of the event.

Scalability: The system should be designed to deal with scenarios where there can be large number of cars. The number of participant cars, or sentient objects, has a varying nature and depends on the congestion of the road. The number of cars cooperating with each other will be potentially large and each car will communicate in a one-to-many fashion without aide of centralized servers. The cars and traffic lights must use wireless networks that use ad-hoc and multi-hop model for communication. For an effective scalability strategy, location aware communication should be used to avoid message propagation beyond the geographical area of interest.

Time Critical: CORTEX car control scenario needs timely dissemination of events whereby higher priority events obtain higher priority channels and higher priority threads. It should provide real-time guarantees for assuring that critical messages such as an emergency stop signal have bounded delays.

Safety Critical: In distributed systems based on wireless ad-hoc environments, there may be an unpredictable number of application components that compete for a limited amount of resources such as CPU and communication resource, thus leading to unpredictable delays for executions. Due to the fact that car control system has strict timeliness requirements, the system is only feasible if timing failure detection and QoS based adaptation is supported. A timing failure detection service can be used to detect timing failures, which enables to take fail safe actions upon timing failures.

Mobility: The CORTEX Car Control Scenario mainly includes both fixed and ad hoc structure. Traffic lights, and GPS services provided by satellites are some elements of fixed structure, while the scenario mainly depends on cars that create highly mobile environment.

7.4 Hogthrob

7.4.1 Introduction

Progressively, IT is finding its way into pig production, a leading industry in Denmark. Most farmers are now equipped with computer-based planning and control systems (including wireless networks and hand-held PCs). The use of IT for practical animal husbandry is still very limited, however a recent project conducted by the National Committee for Pig Production in collaboration with DTU explored the usage of microphones together with a tailored voice recognition software to identify coughing pigs. A new law requires pregnant sows to move freely in a large pen. This is a challenge for farmers. They need to identify the sows that should be placed in the smaller pens among all the pregnant sows. Sows are nowadays equipped with RFID tags. The farmer needs to use a tag reader (possibly physically applied on the RFID tag) to identify the sows. This solution is not practical in large pens.

7.4.2 Scenario Characteristics

A sensor node with an integrated radio placed on each sow could transmit the sow's identification to the farmer's hand-held PC thus alleviating the need for a tag reader. The use of sensor nodes on the animals could facilitate other monitoring activities: detecting the heat period (missing the day where a sow can become pregnant has a major impact on the pig production) and possibly detecting illness (such as a broken leg) or detecting the start of farrowing (turning on the heating system for newborns when farrowing starts).

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7.4.3 User Requirements

The farmer needs to be alerted when a sow is in hear. The farmer needs to be locate a sow given its identification.

The cost of a sensor node has to be in the order of 1 euro (due to the limited profit margin on a sow - note that a sensor node on a pig should not cost more than a couple of cents).

The lifetime of the sensor node should ideally be 2 years (the lifetime of a sow). A lifetime of 6 months and more is acceptable.

7.4.4 Functional Specification

Hogthrob is a research project. Functional specifications are thus a bit of an overkill. Here is a description of the three main challenges tackled in the context of the project:

- The current generation of sensor nodes is assembled from off the shelf components. The next step is to integrate all the components of a sensor node on a single chip in order to minimize energy consumption as well as production cost. We propose to build networked on-a-chip sensor nodes where processing, communication and sensing capabilities are integrated on a single chip. We opt for a system-on-a-chip design because the limited number of components guarantees a low production cost and because the small size of the device gives us room for robust packaging.
- Early work on sensor network has focused on demonstrating the potential of the technology. Only a couple of experiments have been led with actual applications. We propose to develop a sensor network infrastructure adapted to the needs of an actual application.
- The sow monitoring application will allow farmers to track sows in a large pen, to detect the start of the heat period and possibly to detect the start of farrowing as well as illness (such as broken legs). There is no such monitoring system available today.

7.4.5 Object Decomposition

The object decomposition of Hogthrob is given in Figure 8
The behavior of sows has been studied over the years. It is a well known fact that the behavior of sows changes when they are in heat and when they are close to farrowing. Sows in heat become more active and more exploring. If they are housed in a pen with contact to a boar pen, they more frequently approach the boar . Often sows will also mount each other when they are in heat. In the last hours before farrowing a sow exhibits a characteristic nest-building activity. The pattern is to a large extent prohibited by the fixation of the sow, but a more restlessness behavioral pattern remains. A first challenge is to design a predictive model of the heat period taking the movement of sows as input and providing as output the probability of the heat period. Validating such a model will require a body of statistical data about sow movements in relation with their heat period. To the best of our knowledge, such data do not exist. Field experiments will allow acquiring them. Similar models will also be built for predicting start of farrowing and for illness where the activity level is lower. Because illness events are rare our predictive model will be

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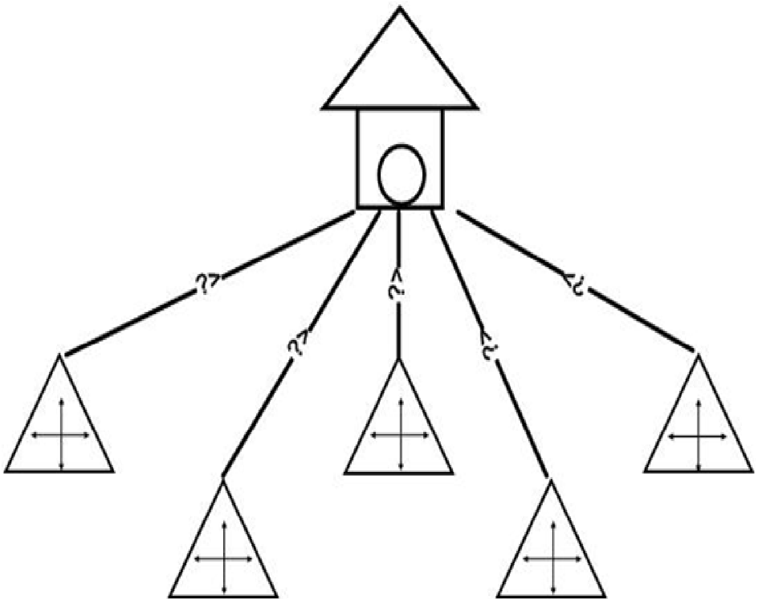

Figure 8: Object Decomposition of Hogtrhob

more speculative. It will have to be validated over a time period probably longer than the project. The second challenge is to capture the data needed to feed the model. What sensors should be installed on the sensor nodes? What kind of data should be collected from the sensor network? What kind of processing should be performed on the sensor nodes? What are the requirements in terms of response time? These questions are being tackled in close cooperation with the development of the sensor nodes and of the sensor network infrastructure.

7.4.6 Step-by-Step Scenario Description

1. Sow localization: " The farmer enters the pen with his PDA " He selects the ID of the sow he wants to locate " The sensor node on the selected sow emits a visual or acoustic signal that allows the farmer to locate the given sow.

2. Heat period: " The farmer gets an alarm whenever a sow enters the heat period
Technology has been developed for monitoring the heat period of cows (in particular University of Twente did some experiments in the context of the Eyes project). The technology developed for cows does not scale to sows in terms of cost, form factor and lifetime.

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7.5 Smart Surroundings

7.5.1 Introduction

[11, 23, 24] are the main resources of the study. The overall mission of the Smart Surroundings project is to investigate, define, develop, and demonstrate the core architectures and frameworks for future Ambient Systems. In this context, ambient systems are referred as; networked embedded systems which support people in their everyday activities by integrating with the environment. They are aimed to create a Smart Surrounding for people to increase their life standards and their productivity at work. These systems differ from traditional computing systems by being based on an unbounded set of hardware and software, which will be embedded in everyday objects or appear as new devices. In this project, the aspects of ubiquitous computing, which is a rapidly developing area, are planned to be detailed and aimed to be implemented. Currently, most of the new technologies can be practically built into many objects to create smart networked environments. However, integrating these technologies in an open platform to be used in a wide range of applications is still an issue to be solved.

Main objectives of this project can be explained as below:

1. Opening a platform for ubiquitous computing systems that integrates the required infrastructure components and provides an extensible set of universally installable tools, devices, and services for the developers, operators and users of Smart Surroundings. The platform development will be driven with an engineering ethos of providing solutions that are practical and sustainable in the face of real world, and effective in reducing the cost for development and installation. The ambition is to establish this platform as a standard for research and development of ubiquitous computing environments.

2. To lay the foundations for understanding interactions in ubiquitous computing with the conceptual frameworks, models and notations needed to describe the structure and behavior of system components from a variety of research perspectives. The work on foundations is aimed to overcome the current ad hoc nature of designs and evaluations. The expected result is a set of fundamental models and frameworks that will support evaluation and comparison of designs and systems.

3. To study ubiquitous computing in concrete and complex settings to ensure that development of platforms and foundations remains firmly grounded in reality. The concrete settings will investigate ambient system environments ranging from small and dense to large and sparse, and from digitally well provisioned to digitally impoverished. The scenarios explored in these settings will not be focused on selected applications as such but on the complex situations that arise from interaction of diverse stakeholders with many different threads of activity. The project target is to design and implement real world experiments that expose ubiquitous computing systems to the challenge of supporting a multitude of competing applications and user experiences.

7.5.2 Scenario Characteristics

Settings

At present the project is focusing on two main settings: *well-being* and *office*. The main application on the well-being setting is stress management, while in the setting the application is developing flexible office environments. Additionally, short time ago a sub-project started, *Home Care SenseNet*, to improve elderly care.

Stress Management: Stress is experienced by most people due to their work, sports, family responsibilities etc. People believe they can use some assistance in dealing with stress. Medically, stress is defined as a "perturbation of the body's homeostasis". The common indices of stress include changes in biochemical parameters (such as epinephrine and adrenal steroids), physiological parameters such as increased muscle tension, heart rate and blood pressure and behavioral effects such as anxiety, fear and tension. However, just as distress can cause disease, it seems plausible that there are good stresses that promote wellness. Stress is not always necessarily harmful. Increased stress at work for instance, may results in increase in motivation and awareness providing the stimulation to cope with challenging situations. However, long lasting periods of stress may result in negative stress. Excessive, prolonged and unrelieved stress can have a harmful effect on mental and physical conditions; for instance it is associated to cardiovascular diseases, immune system diseases, asthma and diabetes. Common signs of negative stress are tiredness, concentration and memory problems, changes in sleep patterns etc. People need to find an optimum between positive and negative stress. Since there is no single level that is optimum for all people, *personal stress-training systems* can assist in reducing elevated levels of stress. Controlling stress by means of this system contributes to the subjects well-being. Stress management should be individually adapted, able to learn from ongoing experiences, private, anywhere and anytime, active, continuously interacting with its surrounding to optimize feedback. This addresses the need for a wearable or private product (clothes, jewelry etc) so the subjects can and will be trained in a variety of settings which is not physically bounded.

Stress will be determined using different methods: measuring physiological data (e.g. muscle tension, heart rate), monitoring the user's interaction with the environment (e.g. preasure excerted when using the mouse, playing with a pen or pressing a ball) letting the user provide feedback about his stress level with tangible interfaces, and taking into account the context of the user (e.g. room temperature, light level, activity performed, agenda, etc.).

The feedback will be provided modifying the ambient (e.g. lights, sounds, music) where the user is at present (e.g. office, home, car), and using wearable and private products as PDA, watches, jewelry, clothes, etc.

Figure 9 provides a high-level picturized view of the stress management setting. The general hierarchical view of the Smart Surroundings' settings is figurized in Figure 11

Flexible Offices: Nowadays, the trend of working in a more flexible way both while traveling to various locations and countries and within their own company building becomes apparent. Governments and employers have already started seeing advantages of flexible office solutions. It saves expenses of building maintenance, parking costs, reduces intensity of traffic and increases effectiveness of employees. This trend will continue in the future. Such a change will be motivated by economical reasons as well as a way to enhance the quality of work.

Smart Surroundings envisions the future of working in offices different than what we experience today. Both the environment and the working itself will differ from today's style of working. International cooperation and global activities of business, industry and research will involve more and more people working abroad. The mobility and temporary residence of working people promotes the idea

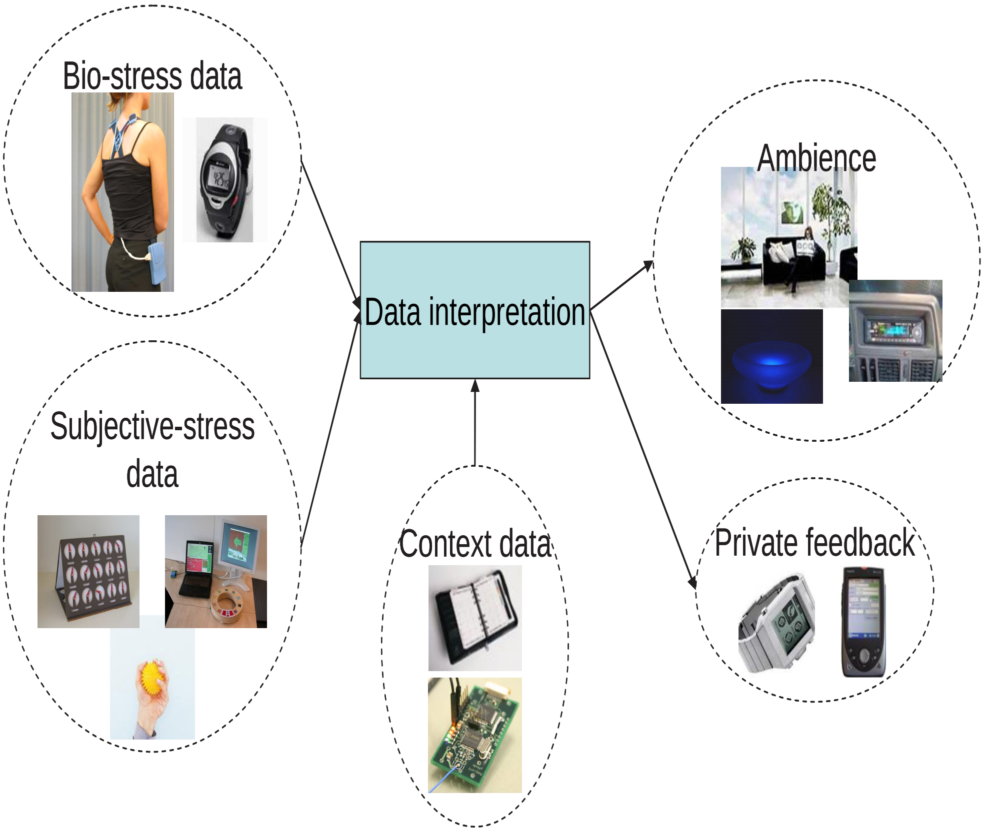

Figure 9: Picturized abstraction of Stress Management setting of Smart Surroundings

of renting offices for short and mid-term period instead of buying or continuously renting them. In this project, they picture the situation of a flexible office being rent for some weeks to some month for people that work abroad. This setting outlines requirements and possible solutions for such flexible offices. Special attention will be on the personalization of the office space as well as practical flexibility and usefulness of furniture and electronic equipment.

People will start working in more flexible ways not only while travelling abroad but also within their own company building. A growing number of companies switch to open workspaces and flexible working style. An example of such a transformation can be the Dutch insurance company - Interpolis. The biggest technical enabler for implementation of the flexible office concept was development and popularization of wide area networks, wireless communication and the Internet enabling remote access to the office. This change has an impact on technology as well as on the way teams work.

Smart Surroundings believe that flexible offices will be part of our future. It is clear that if not correctly implemented, it can result in a undesirable environment to work. Therefore, the project is involved in providing a flexible and yet friendly and efficient way of working. They picture the

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situation of a flexible office, where no employee has his/her own, static office space. Every person has means to work from any place within a company building as well as from another location (client, home, etc.). They outline requirements and possible solutions for such flexible offices. Special attention will be paid on the communication aspect as well as enablers for ad-hoc meetings.

At present they are working on an abstraction called 'Mini-ME'. Mini-Me is the user's doublet in the working and family life, providing and receiving information around the worlds from/to other Mine-MEs, and giving to employees desired data in order to take decisions, organize time, to get in contact with other people. Mini-ME will also allow to control the environment and personalize it to fit the preferences of the user, and control the devices in the offices and outside them (e.g. coffe machines, copiers, overhead projectors). Envisioned scenarios are also supporting workers to hold informal meetings in coffee rooms or corridors, and supporting formal meetings with unknown people. Figure 10 gives a high-level view of the functionality of Mini-ME.

Figure 10: Picturized abstraction of office setting of Smart Surroundings

Home Care SenseNet: The Home Care SenseNet (HCSN) [3] aims to improve the quality of the life of patients in need of care and their care-givers. It achieves that by enabling longer independent living, and automating routine administrative task of care-givers.

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The strength of the HCSN is its simple deployment in existing private flats/houses and care institutions because no expensive cabling infrastructure is necessary. Sensor nodes can be attached exactly where they are needed and can last for years without maintenance. Small ad-hoc mesh WLAN nodes, which require only a power outlet, provide the second layer infrastructure connections that extend the lifetime and reach of the network in large buildings. The whole network is largely auto-configuring and requires no or little IT knowledge for set-up and maintenance.

The wireless sensor network will monitor a part of the physical environment, physiological state, and current location of clients and, optionally, care-givers. The health-care application uses this context data to derive significant events, notify care-givers where appropriate, and log events for long-term analysis, administration, and accounting. Examples for significant events are "change diaper of client", "client's diaper was changed by care-giver", or "client sleeping uneasily". In case of potential emergencies (e.g. "client may have fallen"), the HCSN will use the location information to alert the closest care-givers. A significant use case can be the recognition and monitoring of behavioural patterns and the detection of changes in that pattern. For example, the HCSN may monitor "normal" wake-up times, when which room is used in the house, at what times the fridge is opened or medicine is taken etc.

The actual events or parameters to monitor, acceptable form-factor for the sensors, and user interfaces to the health application will be established in close cooperation with care givers and other users during the project. Important scientific challenges addressed in the project are to select the optimal, least invasive sensors, provide an auto-configuring and self-healing network while enforcing security and privacy of sensitive data, and derive high-level client-related context using sensor fusion and inference.

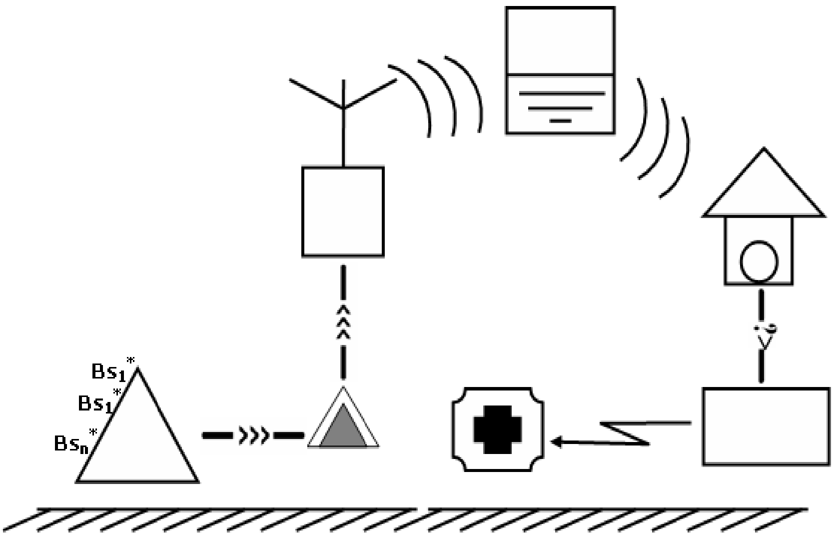

Figure 11: Hierarchical Level Abstraction of Smart Surroundings' Settings

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7.5.3 System Requirements

Communication capability: Capacity to use the underlying infrastructure—wired and wireless—an create ad-hoc networks when needed.

Sensing capability: Sensing plays a very important role in Smart Surroundings. A wide variety of sensors will be used to determine phyisiological parameters, environmental data, activity levels, etc.

Wireless sensor networks: WSN will be used both indoors and outdoors for sensing and location functions. Simple sensed data is combined in different ways to obtain more complex information, as explained in the stress management and the Home Care SenseNet settings.

Body area networks: To monitor physiological data and provide feedback.

Sense-making: How can systems make sense of user activity to provide ambient intelligence, and how can users make sense environments that are characterized by dynamic and spontaneous composition of services?

Security and privacy: Smart Surroundings have to be designed to empower and support people in their activities, but in ways that would avoid the control or manipulation of non-authorized others.

Context Awareness: Context plays a very important role in the settings. The most important type of context information that have been identified are location, topology, neighboring, movement and activity, social networks, agenda, behavioural patterns and historical data, facilities and resources, mood and stress level, external sources of information, and special events.

Personalization: The environment and devices should adapt to the preferences of the users. Also the way of controlling the devices and getting feedback should be easily personalized. The user should be able to manually set his preferences. Additionally, the system could try to learn from early behavior the preferences of the user.

Service Discovery: Both in the office setting and well-being setting we do need to control the environment and access services and resources available in the surroundings. Service Discovery (and usage) is, thus, a must. The information provided by other Mini-Me and the environment systems (e.g. office system) are also viewed as services.

Adaptability: The system, services, interfaces and feedback have to adapt depending on the environment and available resources (e.g. energy, communication capabilities, storage, displays).

Resource Management: Smart Surroundings envisons hundreds or thousands of users competing for the use of resources. Therefore, managing the resources efficiently is of crucial importance.

Energy Efficiency: With devices embedded in the infrastructure and sensors everywhere in the environment, it is virtually impossible to be changing batteries constantly. Thus, energy efficiency has to be addressed in the system architecture.

Innovative interfaces: A key motivation for this research is to find new ways for people to interact with computer-based services while giving primacy to the real world. A main thrust of this work will

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be aimed at innovative and embedded interfaces, with particular emphasis on supporting ad hoc composition and configuration of tangible interface components.

7.6 Sustainable Bridges

7.6.1 Introduction

[28], [9] are the main resources of the scenario. This scenario examines the high-speed train railway bridges which are expected to meet the needs of the next decades. These needs are basically expected to be an increase on the capacities, heavier loads to be carried or increments in the speeds of the trains concerning the increased traffic on the railways. All types of bridges are to be considered in this scenario. The network of the railways in Europe will be inspected primarily.

These improvements can basically be realized by assessing of the bridge structure, determining the true behaviour of the structure, strengthening of certain portions of the bridge or by monitoring of critical properties.

The existing structures and designs of those bridges can detect the irregularities during their constructions or at any time while they are in service. But, it is very obscure that if they could carry much greater loads or handle much faster trains. That is why a new monitoring and alerting mechanism should be used. The overall goal is to enable the delivery of improved capacity without compromising the safety end economy of the working railway.

Most recent technique to determine the irregularities in the bridges is the installation of wired monitoring systems to analyze the structural behavior. However, such monitoring systems use standard sensors and several other devices which are time consuming to install and very expensive to spread around. Also kilometers of wires are needed for their communications, which means a waste of money and a high risk of communication failure in case of an irregularity in the medium.

An alternative way to monitor such railways and bridges is equipping them with a wireless monitoring system, using micro-electromechanical systems. Hence, the set up cost of a communication system will disappear (getting rid of wires), and using of small and intelligent sensor carrying devices will dramatically reduce the production and maintenance costs.

7.6.2 Application Characteristics

The basic principles of Structural Mechanics and Materials Science will be used and integrated with the new techniques in monitoring, measurement and modelling techniques in order to achieve the predetermined goal of this project. The idea is to analyze bridge types and their details where they are critical for load carry capacity, safest maximum speed level and remaining life time.

Current traditional monitoring of civil structures has been performed either by visual inspection or by installation of collections of sensors that communicate with each other using a cable technology. In the first case, the interpretation and assessment of the structure is based on the experience of the expert, whereas

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the second method requires the expensive installation of kilometers of cables to cover the object to observe.

The main goal of this project is to develop a cost effective solution for detection of structural defects and to better predict the remaining life time of the bridges by providing the necessary infrastructure and algorithms. Depending on the fact that this project aims to use the wireless sensor network technology in order to reduce the costs of installation and maintenance of the traditional systems, a carefully evaluated infrastructure has to be formed.

The sensor network will be composed of several types of sensor nodes; temperature, humidity, vibration and material stress sensors, which will be located at specific points within and outside the bridge. There will be formed a static network topology, where several types of nodes will cooperate with each other.

Each individual sensor is planned to be affixed to the structure, communicates with its neighbors and acts as a part of a cluster of nodes, which coordinates the decision process to evaluate weather a structural defect has occurred or an obvious change in the structural behavior has happened. The user (say an engineer), will have a global view of the network and will be able to specify which node to join a cluster or which will be the sink. In other words, the engineer will assign or modify the roles of each component in the system.

One requirement here is the need of determining the roles of the components exactly. The roles of sensor nodes are clear, they can be vibration sensing, temperature sensing or relative humidity sensing sensors. It is also possible that one sensor node can have more than one role at the same time. Other than sensing, the sensor nodes can be assigned to some other roles like; a *cluster head* or a *cluster member*, or a *data aggregator*. However, these are only the predicted role types. There can be more or less than stated here. The Figure 12 shows the hierarchical and the Figure 13 shows the picturized view of the system.

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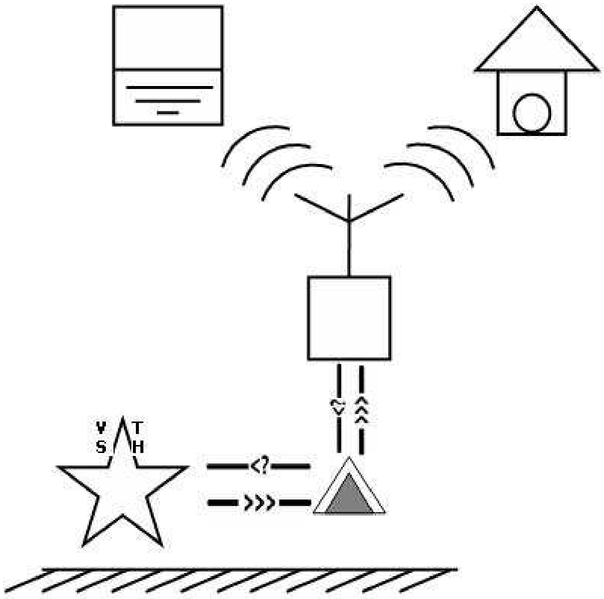

Figure 12: Hierarchical Level Abstraction of Sustainable Bridges

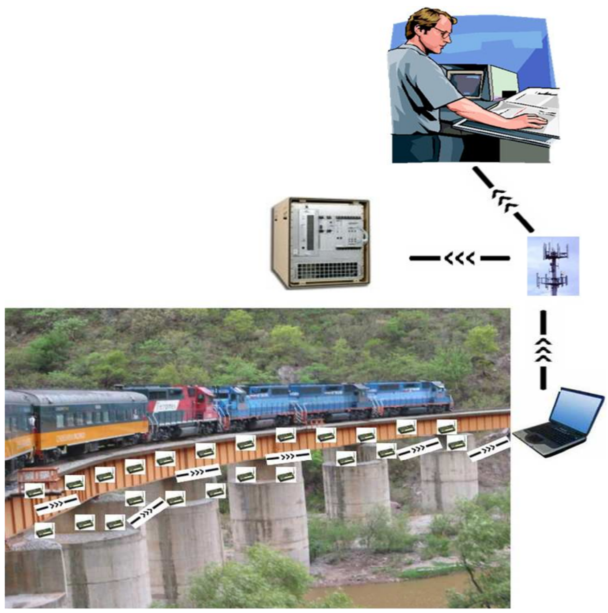

Figure 13: Picturized Abstraction of Sustainable Bridges

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7.6.3 System Requirements

Network Configuration: Network configuration issue should be detailed into two parts: assignment of the roles within the network and determining the optimal routes. The first part is thought to be solved by human interference. The user will have enough technical knowledge to determine what kind of roles should be assigned to each node. The second issue requires the optimization of the network route in the most power efficient way so that, the monitoring system must be able to function several years without changing the batteries.

Cluster Management: The whole sensor network must be divided into clusters because of the necessity to decide if the sensed event is related to a structural defect. In order to reduce the number of false positives, all members of a cluster that might have detected some changes as an event, will decide that it should be reported to the engineer, or not. Since the topology is static in this scenario, user has best to determine which node to act as the sink. This will be much efficient and much easier.

Event Localization: Most sensor data is associated with the physical phenomenon that is sensed. The event localization is the determination of the position of the specific events. The use of signal strength techniques for event localization is not a problem here, because these techniques only determine the position of the sensor itself, not the origin of the event. The use of the measured transient acoustic event and its onset time with the combination of the knowledge about the specific positions and the sensing rangers of all nodes in the network will make the precise locating of events possible. This will also reduce the number of packets to be transmitted.

Time Synchronization: Nodes within a cluster will compare their readings about the events. Hence, each should be able to compare its readings in order to discard data that does not need to be forwarded. Thus, the overall data to be transmitted in the network will be reduced. In this scenario, a time synchronization technique at a precision level of 60 us is needed. Hence, new algorithms should be developed in order to achieve this level. This synchronization level is also important to localize the event more precisely. If this value can be achieved, the location of the event can be defined within a few meters of precision. Otherwise, the evaluated area of the event will be too big.

But; this level of precision is very difficult to achieve, and it seems to be nearly impossible to achieve by using the current technology. This fact comes up with another issue: the need of developing better algorithms to handle lower synchronization level while the precision level is high enough.

Data Aggregation: To support energy saving, the number of packets are tried to be reduced as much as possible. So, data aggregation should be used to add some more efficiency to the whole system. Although there can be found existing aggregation algorithms for such purposes, the scenario specific properties, like static topology information and role specification, can be used as an advantage to develop more efficient algorithms.

7.6.4 Functional Specification

A wireless monitoring system with microelectromechanical system sensors can reduce costs in compare to the use of the traditional systems, as explained before. The referred system is described below:

Each mote, which itself is a complete small measurement system, has to be power and cost optimized, so it can provide data only at small distances of maximum 100 meters or less. For that reason, there is the demand to install a central processing unit on site in addition to the installation of the sensor motes. This central unit has to collect, to store the data in a database and further to analyse the data from the sensor motes until this data is requested by the user or until a sudden event is detected which results in an alarm message. The central unit also should allow a calibration and a wireless reprogramming of the sensor nodes to keep the whole system flexible. A conventional computer equipped with a constant power supply and specific hardware and software is expected to fit all those purposes.
The sensor network will continuously collect sensed data from the bridges and the sinks will forward the whole data to a data center in a higher level in the architecture. The database will continuously be analyzed at the end point, and if a critical change occurs, the immediate interference will be supplied. Or if the continuity of the information shows that maintenance became mandatory or just necessary, the required action will be planned for the future demands and the stability of the structure.

7.6.5 Object Decomposition

Sensor Motes: There are several tasks of the motes that have to be performed. These are collecting and processing data from various sensors, storing those data, acting as a pre-processor to analyse the data, sending and receiving selective and relevant data among other motes and working for a long time without an externally wired power supply. Therefore, those motes should consist of a CPU or DSP, memory, a low power radio, an aligned ADC, a power supply and one or more diverse sensors.

a. *Acceleration Sensors* For the bridge like structures, a bandwidth of 0.1 to 20 Hz is important in order the related algorithms work best. Acceleration, velocity and sensitivity depend on these frequencies. Separate sensors to detect each of those changes are necessary to gain appropriate results.

b. *Humidity and Temperature Sensors:* The temperature and the moisture of the air and of the structure are general values, which are relevant for almost all monitoring tasks.

c. *Stress, Strain and Displacement Sensors:* A high amount of strain gauges are in practical use to measure strain and also stress under static or dynamic loads.

Sink nodes: The sensor network is connected to one or more sinks, which may even be desktop computers located close enough to the observed structure, and which will have a purpose of collecting data and interfacing of the sensor network with the user.

Base station: Eventually, the base station will forward the meaningful data to the data center and to the user, which do not have to be located nearby the structure.

Data Center: The forwarded data will be continuously collected in a data base system to evaluate them in the long term. Hence, statistical information will lead us to develop better structures and even better monitoring systems in the future.

Facility: In case of a sudden emergency event and hence, in case of the need for an immediate interference, the user will independently be informed about the event which is continuously stored in the data center. The engineer then will decide what to do next.

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8 Conclusions

State-of-the-art projects clearly indicate that a wide spectrum of applications can benefit from CO paradigm. Diversity of the characteristics and requirements make the field a challenging research domain. As a result, various enabling technologies such as energy efficient schemes for networking, time synchronization, localization and tracking are being invented and studied in the last decade. Table 19 summarizes the common and scenario dependent requirements and challenging research issues for each CO application domain. Whereas $\surd$ stands for common characteristic of that category, X means that it is not relevant for that category. Application dependant issues are represented by 'AD'.

	CA	HO	L	TA	EM	H	SS	T	ET
Network Topology	AD	Single	AD	Multi	Multi	AD	Multi	AD	AD
Indoor/Outdoor	AD	In	Both	Out	Out	Both	Out	Both	In
Scalability	AD	X	$\surd$	$\surd$	$\surd$	X	$\surd$	AD	AD
Packaging	AD	X	AD	AD	$\surd$	X	$\surd$	AD	AD
Fault Tolerance	$\surd$	AD	$\surd$	AD	$\surd$	AD	$\surd$	AD	AD
Localization	AD	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	AD	AD
Time Synch.	$\surd$	AD	AD	$\surd$	AD	AD	$\surd$	AD	AD
Security	AD	$\surd$	AD	AD	AD	AD	AD	X	AD
Infrastructure	AD	AD	AD	AdHoc	AD	AD	AdHoc	AD	AD
Prod-Maint.cost	$\surd$	$\surd$	$\surd$	X	$\surd$	X	AD	$\surd$	$\surd$
Mobility	AD	AD	$\surd$	$\surd$	AD	AD	AD	$\surd$	AD
Heterogeneity	$\surd$	AD	AD	$\surd$	AD	$\surd$	AD	X	AD
Automation	$\surd$	AD	X	AD	AD	AD	AD	AD	$\surd$
Power Awareness	AD	AD	$\surd$	AD	$\surd$	AD	$\surd$	AD	AD
Real Time	$\surd$	AD	AD	$\surd$	AD	$\surd$	$\surd$	AD	AD
Context-awareness	AD	$\surd$	X	X	X	$\surd$	X	$\surd$	X
Reliability	X	X	$\surd$	X	X	$\surd$	X	X	X

Table 19: Characteristics of CO application domains (AD: application scenario dependent)

Moreover as illustrated in Figure 14 almost all CO projects have emerged in the last five years and only few real sensor applications readily available today, if academic test-beds do not count. Most projects are at testbed stages yet, mainly, verifying node prototypes or identifying real requirements of the applications. Today, currently deployed applications share some common characteristics; raw sensor data transmission over wireless connection, mostly data processing at collection points, simple routing schemes, best-effort data transport delivery. However these characteristics do not reflect the real requirements of most application domains. Therefore common characteristics given in Section 3 are still challenging research issues especially in multihop, scalable and real-time environments.

The field is analogical to the situation of Internet back in 30 years ago. The major difference is that CO research is oriented towards application specific solutions. General-purpose systems, standards for open interconnections, services and interfaces are yet to come for wider use. Another fact to point out is that

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the requirements and constraints of various applications are not fully understood yet. As a result, most of the applications are not ready for real world.

As a conclusion, this new CO paradigm has a potential of improving the quality of our lives considerably. For measurable outcomes, research in the field of common features needs to be matured. With the progress on sensor fabrication techniques and multi-disciplinary research cooperation, we can expect that real-world cooperating object applications containing wireless sensor networks will come to life in the near future.

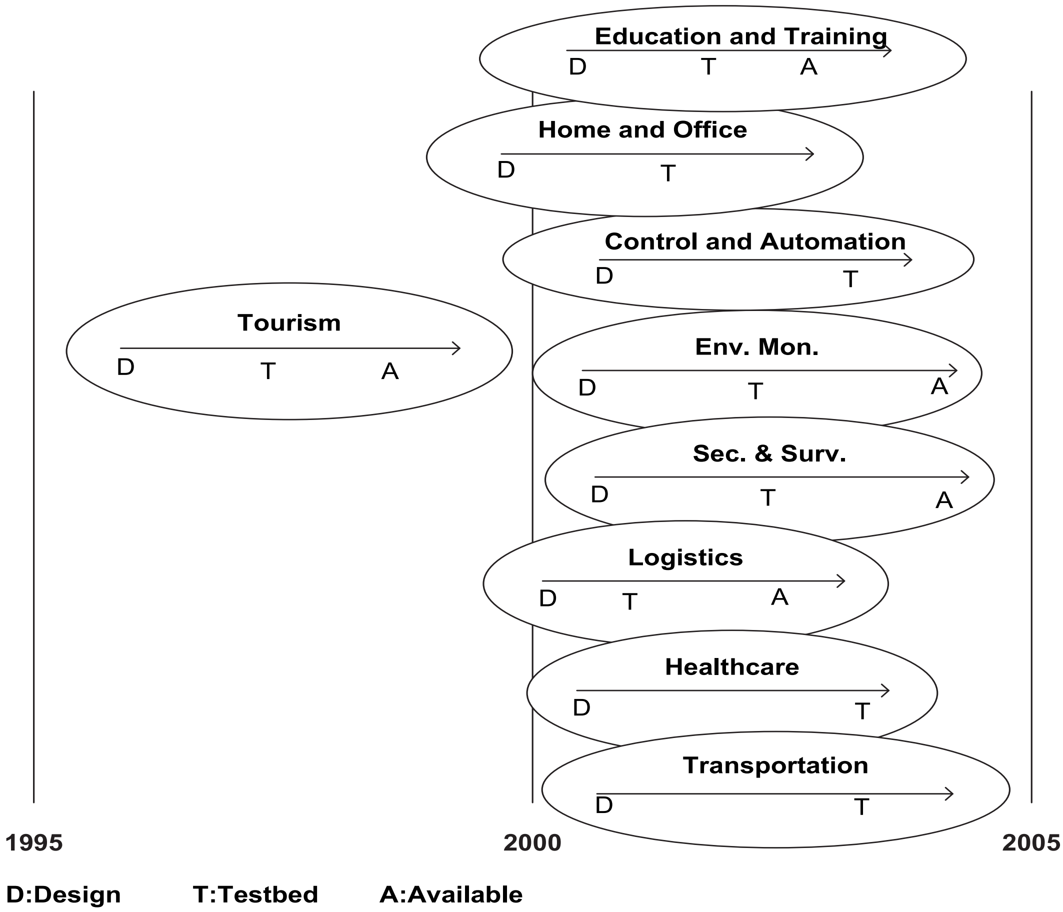

Figure 14: Timeline for CO application categories

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9 List Of Abbreviations

A	Acoustics Sensor
ADC	Analog-to-Digital Converter
AICIA	The Association of Research and Industrial Co-operation of Andalucia
AmI	Ambient Intelligence
AOA	Angle-of-arrival
APIT	Approximate Point-In-Test
B	Barometer Sensor
CBL	Calculator Based Labs
CD	Compact Disc
CO	Cooperating Objects
CoBIs	Collaborative Business Items
CORTEX	Co-operating Real-Time Sentient Objects
CPU	Central Processing Unit
CVD	Cardio-Vascular Diseases
DSP	Digital Signal Processing
DV	Distance Vector
DVD	Digital Versatile Disk
EPA	Environmental Protection Agency
EU	European Union
GPS	Global Positioning Systems
H	Humidity Sensor
I/O	Input/Output
IEEE	Institute of Electrical and Electronic Engineers
IST	Information Society Technologies
KU	Kopenhag University
M	Magnetometer Sensor
MBL	Microcomputer-Based Labs
MP3	MPEG Audio Layer 3
P	Photo Sensor
PCR	Polymerase Chain Reaction
PDA	Personnel Device Assistants
PIT	Point-In-Test
RFID	Radio Frequency Identification
RiscOFF	Rapid Intelligent Sensing and Control of Forest Fires
RSSI	Received Signal Strength Indication
SCOWR	Scalable Coordination of Wireless Robots
SNS	Sensor Network Server
T	Temperature Sensor
TDOA	Time difference of Arrival
TOA	Time-of-Arrival
UAV	Unmanned Aerial Vehicles

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UT	University Twente
UWB	Ultra Wide Band
VCR	Video Casette Recorder
WLAN	Wireless Local Area Networks
WSN	Wireless Sensor Network
X	Accelerometer Sensor
YTU	Yeditepe University

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