SIXTH FRAMEWORK PROGRAMME
PRIORITY 2
INFORMATION SOCIETY TECHNOLOGIES

GoodFood
Food Safety and Quality Monitoring with Microsystems



Deliverable D11- WP7
"Users' Needs Report"

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Deliverable D11

"Users' Needs Report"

1 Executive Summary

This deliverable (D11-WP7D1: Users' needs report) is a result of Task 7.1: Analysis of user's needs and system requirements, where all WP7 partners (MIDRA, SYNAPSIS, HTA, NMRC, EADS, SSSA) are involved. It is structured in nine chapters (including this introductory executive summary as Chapter 1).

Chapter 2 (FROM PRECISION AGRICULTURE TO AMBIENT INTELLIGENCE IN AGRICULTURE) starts off with a survey of the currently most advanced application of ICTs in agriculture, in the so-called precision agriculture, continues with some key figures and fact about the wine market at global level, and finishes off with some early comments from a sample of interviewed wine producers (and consumers).

Chapter 3 (THE AMBIENT INTELLIGENCE PARADIGM) provides an introductory state-of-the-art of the AmI paradigm in two parts, the first dedicated to its general vision and the second to the verification of the proposed approach.

Chapter 4 (USER'S NEEDS AND REQUIREMENTS FOR THE GOODFOOD AMI SYSTEM) tackles the core of the deliverable's subject, and its starts off with a "visionary" tale, or a "scenario", that is to say, an imaginary tale of a day of an oenologist using the fully-fledged GOODFOOD system to take care of its vineyard, in an indefinite future time. It continues with more traditional sections on the methodology, on the requirements for the wine chain, on the test protocol, on the phases to be monitored, on the description of the chosen pilot site for the demonstrator, and finishes off with the definition of a general methodology for the description of user's need and requirement of food chains (other than wine).

The following chapters (5 to 9) are a detailed survey of the state-of-the-art of the Wireless Sensor Network and its components, that is to say, the architecture proposed for the implementation of the GOODFOOD AmI infrastructure.

Chapter 5 (WIRELESS COMMUNICATION INFRASTRUCTURE AND RELATED ISSUES) gives a general overview of the Wireless Sensor Network, of the RF module, concludes with HW/SW implementation issues.

Chapter 6 (WIRELESS SENSOR NETWORKS STATE OF THE ART) is a brief review of major current Wireless Sensor Network implementations.

Chapter 7 (COMMUNICATION PROTOCOLS) addresses security considerations and describes the node-to-sensor interface and the network mobile node.

Chapter 8 (SENSORWEB CONCEPTS) provides an overview to the concept and a description of its common features.

Chapter 9 (SOFTWARE PLATFORMS) focuses on a state-of-the-art analysis of some tools that will be used to implement the AmI framework.

To sum up, in this deliverable a list of desiderata sensed parameters for the wine production step has been expressed by the users; consequently, in the deliverable D12 (System Requirements and Design), a subset of these parameters has been proposed, taking into account sensors commercial / research availability and the activities carried out by other WPs.

2 From Precision Agriculture to Ambient Intelligence in Agriculture

2.1 State of art and related topics of the precision agriculture

Precision agriculture is a precision system that promotes variable management practices within a field, according to environmental site conditions. This system is based on tools and sources of information provided by modern technologies. These include the global positioning system (GPS), geographic information system (GIS), yield monitoring devices, soil, plant and pest sensors, remote sensing, and variable-rate technologies for applicators of inputs. The use of these different methods of sensing is related to the desired spatial resolution. GPS and GIS are optimally suited for wide surfaces avoiding any micro characterization of the site. On the contrary the use of soil and/or plant sensors allow a specific management in a very little surface.

Precision agriculture research started in the US, Canada, Australia and Western Europe in mid-to-late 1980s. Although a considerable research effort has been expended, it is still only a portion of farmers who have practiced any type of PA technologies.

In Australia, monitoring and mapping the spatial variability in small-grain crop yields have received much publicity. Crop-yield monitor are available for potato, peanut, and forage harvesters and, still under development, for cotton harvesters to monitor both quantitative and qualitative parameters. In Japan, the Ministry of Agriculture has started to invest in Precision agriculture research projects, focusing on sensing and controls related to agricultural mechanization.

Reports on PA experiments in China, Korea, Indonesia, Bangladesh, Sri Lanka, Turkey, Saudi Arabia, Australia, Brazil, Argentina, Chile, Russia, Italy.

The Netherlands, Germany, France, UK, United States and Canada have been found in recent literatures

GIS and Production Agriculture

At a grassroots level, GIS offers farmers various opportunities to increase production, reduce input costs, and manage the land in their care more efficiently. From handheld computer mapping in the field to the scientific analysis of production data at the farm manager's office, geography plays a part. These examples of applications of GIS at the farm level are meant to provide users, both experienced and inexperienced, with some ideas for implementation

Data Collection in the Field

Farmers and others involved in agricultural production at the field level, through firsthand knowledge, often have great insight into how best to manage a farm's natural resources. While never being able to replace such expert knowledge, technology is certainly able to assist in the planning and implementation of important decisions related to land management. In order to make the right decision, farmers need to have the best information at hand, often in the field. Geographic data has for many years been created, used, and delivered only in the office. Now, new technology in computing allows the farmer to take the power of

GIS into the field. Specific software can be used on handheld computers in the field for the creation, visualization, and querying of data.

Handheld GIS solutions provide farmers with the ability to look at images of their fields while they are actually standing in them. Editing capabilities provide the farmer with the ability to map various crop growing stresses found within a field such as pest infestations, nutrient deficiencies, and water shortages. These stresses are highlighted on the map. By collecting such data in the field, solutions can be devised and preventative measures outlined.

A farmer can connect to the Internet via a handheld telephone or Wide Area Network (WAN) for additional data input like weather updates. The data collected then can be analyzed and better decisions made by using the many different solutions

Agricultural Risk Assessment with GIS

Every season that a farmer plants a crop in the field, or raises animals for meat production, there is an inherent risk to their substantial economic investment. To guard against losses, policies from insurance companies willing to underwrite these risks for a premium are an option that can be bought. How this premium is calculated by the insurance company relies heavily on tables calculated by professional actuaries. Many of the potential reasons for filing a claim against an insurance policy are geographical in nature, for example, climatic events such as hail, frost, and drought. For this reason, spatial analysis has proven useful in the calculation of the risk assessment tables and hence the fixing of insurance costs.

It would, however, be incorrect to suggest that all risk to farming investments stem from physical parameters. Other elements need to be assessed including the claim history on a specific parcel of land or field, and the current management of the farm to assess whether best practices are being used, thereby reducing risks. Although not traditionally seen as geographic in nature, these factors do have a location aspect and can be incorporated into the final assessment. Finally, more ubiquitous elements, those not really controlled substantially by location, for example, federal interest rates and global commodity prices, are incorporated.

Precision Agriculture and GIS

Modern farming is about optimizing agricultural production. In this aspect, nothing has changed for thousands of years. Farmers have always been aware of striking a balance when applying inputs that increase crop yields but incur costs and reduce the eventual value of their harvests. So what has changed?

Ever increasing acceptance of information technology in everyday life has had an impact on farming, and this will only grow with increased accessibility. Perhaps the most influential development to expedite technology transfer to agriculture has been the development of GPS. By incorporating GPS into standard farming practices, farmers, researchers, and consultants have been able to improve the precision of existing agronomic management activities by implementing them at a subfield scale. Precision farming and associated variable rate technologies have been the result. Potentially, factors that influence crop productivity can be identified, mapped, and used to provide an implemented solution.

Added field level precision opens the way to better manage natural in-field variations where previously, in terms of treatments, a field was normally assumed to be homogenous. Of course, the farmer working on the field would have had

"inside" knowledge of the field, but this information is not always transferable, and those without experience would have had to rely on imprecise management practices. This heightened awareness and ability to map more precisely has enabled the agricultural sector to implement important spatial tools in a GIS.

Precision farming (PF) and variable rate technologies (VRT) use spatial databases within field environmental and management variables with the aim of evening the application of field inputs while maximizing production across a field. Data is collected in a variety of ways, from handheld computers connected to a GPS unit to mobile georeferenced sampling hardware such as tractors and combine harvesters. Once mapped, this data, which can include soil characteristics, pest locations, drainage systems, and previous harvest yields, can be used to formulate a location-based prescription for the field management in the coming year. These extensions provide the farm manager the tools to interpolate data surfaces from point information, calculate the probability of certain agronomic events such as unfavourable climatic events, and incorporate satellite data concerning land use or live weather reports.

Precision farming relies heavily on the spatial analysis embedded in GIS. As the costs of modern agricultural practices continue to grow as a result of natural resource price increases, more agricultural legislation, greater environmental awareness, and the need to feed burgeoning human populations, so will the need to optimize agricultural management through the utilization of GIS.

Agribusiness Inputs and GIS

Farmers need many inputs to successfully produce agricultural products for sale. A network of local farm supply outlets form the backbone of this supply chain. These farm inputs vary from seed, fertilizer, and agrochemicals to machinery parts; services are also often sold from the same location such as crop insurance and farm credits. How are the crop input manufacturers and service providers to benefit from GIS? Below is a selection of applications where GIS is being used to successfully increase operational efficiency while guaranteeing the best possible service for customers.

GIS-Based Distribution Network Management for Agricultural Businesses

Crop input manufacturers use market demand models based on existing sales information and factors of influence to routinely predict future production requirements. Such companies provide primary inputs, such as fertilizer, seed, pesticides, and equipment, but can also offer services, for example, agronomic consulting, human resources for specific seasons (i.e., harvest times), and others. An underlying principle of successful business is acquiring knowledge related to the whereabouts of assets and demands, analyzing this information, and using it to provide an optimized strategy to deliver where existing and future business opportunities are located.

The term "supply chain" describes the final outcome of the above outlined steps. If a business were to implement a GIS, benefits would include maximizing replenishment efficiencies. What this means is that by calculating current and future demand for a product that requires delivery to a specific location, losses incurred by material being stored for too long at the wrong location could be minimized. A more efficient distribution network would also affect the life cycle of products, reducing them, and thus releasing asset investments and returning

profits faster, improving resource accountability, and introducing an enhanced ability to match assets to specific delivery requirements on a time and location basis.

Depending on the size of the agricultural business involved, a scaled enterprise GIS solution can deliver an improved distribution network.

Post Harvest Processors and GIS

Companies and institutions in the industry that process raw food materials into more recognizable food products often manage huge volumes of commodities and assets across large distances and through many locations. Additionally, as agriculture becomes more regulated and responsive to public demands for greater awareness of food processing standards, improved communication within the company will not simply be advantageous but essential. Rapid data management and exchange between locations requires many integrated software solutions built around a robust data server, and the following stories describe how such systems can be implemented.

Raw Material Procurement and Delivery for the Food Processing Industry

The food processing industry relies on an accurate supply of spatial information related to markets, transportation, distribution networks, status of processing facilities, and raw material supplies to manage widely dispersed assets and maintain maximum profitability. Shortfalls or breakdowns in any part of the production chain such as redundancy at a processing facility can result in substantial losses, so ensuring timely product deliveries is essential.

Understanding the processes and movements along the transportation network from the point of production in the field to the processing facility is where GIS can assist greatly. Large food processing companies manage their operations in fine detail, contracting farmers prior to planting for delivery of specific quantities on specific dates. This management aims to reduce, as much as possible, a situation where either the processing capabilities of an asset (e.g., a mill) are underutilized or market demand outstrips production capacity. The management chain could be extended to include the delivery of the processed goods to either a retail distributor or even as far as the consumer shelf in a shop, but whether extended or not, the underlying principles remain the same.

Business models that are built and inherently contain natural phenomenon without consideration of variations outside of the control of normal land management practices are significantly weakened. The food industry is no exception and frequently suffers as a result of natural variations in such agricultural parameters as precipitation and temperature. Understanding the potential risks to agricultural production and food processing capacity relies on statistical analysis of historical information in a spatial or location-specific context. Geostatistical Analyst offered as an extension of ArcGIS software provides the tools to calculate these risks and, therefore, better prepare for them when they occur.

Locating transportation assets in real time is an essential element that only becomes intensified as the perishability of the food products increases. Time constraints between harvesting a crop and delivery only increase the value and therefore the margin of profit. Managing the movement of such commodities cannot afford delays.. GPS receivers and transmitters located on vehicles allow transport

managers to better coordinate supplies to processing facilities and, consequently, enhance profitability.

Identity Preserve of Agricultural Crops

Identity Preserve is one of the fastest growing segments in agriculture and is being driven by new discoveries in biotechnology. Genetic engineering is creating crops with favourable new traits by artificially modifying plant genes. These genetically modified organisms (GMOs) impact the entire food industry. Food processors and consumers need to know whether GMO food products are being processed or consumed. In answer to these concerns Identity Preserve (IP) describes the action of tracking the agricultural products from the farm field to the grocery store shelf and indicates what these food products contain in relation to GMOs.

Geoaccounting applications of Identity Preserve have demonstrated a significant benefit to agribusiness. Geoaccounting is a method to record crop input operations spatially and warehouse in a database for future reference. This type of GIS implementation is able to maintain every transaction on each parcel, warehousing metadata, and other critical data needs required for future certification of GMO compliance regulations. An example would be a 40-hectare tract of corn. Assume it is a new corn variety, that has been genetically modified. The farm operator has chosen a GMO corn variety because his/her yields will increase by 25 percent, and the corn will be used to feed pigs. This crop input field data is archived in the GIS spatially using a polygon that begins the geoaccounting traceability functionality.

Precision Agriculture in wine chain

In the last decades, strong and deep changes occurred in the wine producers' approach towards wine-chain, as a consequence of the rising number of new technologies, that led to product and process innovations. It should be clear that tradition and modernity are both basic concepts in order to obtain a quality wine-production. Unfortunately, just a small amount of wine producers have realized that innovation and research can easily work together with winery traditions. A better choice of grapes, leading to better wines, is the first step that wine-producers should consider. Only the adoption of an integrated quality oriented system among all the different wine-chain sub-processes can supply the right guidelines for a general grape growing system.

Also the European Union instructions underline the importance of obtaining grapes with high quality standards without just considering the vineyards yield. Grape quality means wine quality. This close relationship between tradition and technology in order to reach quality in viticulture brings to the so-called "zonation". Zonation is the keyword for quality viticulture; it is been developed by producers as a fulfilment of their needs to operate on a known area with defined pedological and climatic characteristics. Such a kind of zonation is called agro-ecological, since it determines areas with specific soil and climate peculiarities. The agroecological zonation can be used as a starting point for a methodology of land inventory and monitoring, as it shows uniform portions of earth's surface. Zonation leads therefore to the creation of a detailed map marking bent areas. In viticulture, there is another term strictly related to zonation: "terroir" (Morlat, 1998; Salette et al., 1998; Deloire et al., 2002).

Terroir is a French word representing the geographical and human coordinates of physical space: it describes a uniform and unique area for its climate, solar

exposure, soil characteristics, and its own historical identity. Terroir reproduces the interaction and relationship among climate, soil and landscape in wine chains.

Another keyword for quality viticulture is traceability. UNI (Italian Association for Norm Unification) describes traceability as "the capacity to rebuild the history and to follow the use of a product by the identification of the fluxes of materials and chain operators". It is a wide concept through which traceability can be considered as a multitask instrument for the evaluation of food health and quality management. Traceability can be used for the following aims: control of health risks, of origin warranty, of management, supervision of quality process, product's value improvement (Masoero et al., 2003).

How can we obtain zonation in a vineyard area and a traceability in a wine chain? Scientific researches have improved the wine factory competitiveness by enhancing system efficiency with the development of new technologies for each single step in the wine chain, from grape growth to the wine bottle. The main targets of quality viticulture can be contained into the term "denominazione di origine" (Carbone, 1997), giving importance to many variables and parameters such as the protection of genetic identity of Vitis vinifera cultivars, the marketing of final products, consumer's health, etc... The above mentioned concept meets into the term traceability.

The whole wine chain can be therefore considered as a physical process that has to be continuously monitored by a series of status variables. Monitoring process is based on the use of sensors. These sensors encode a multitude of physical and chemical parameters of the plant (leaf temperature, growth, xylem sap flux, photosynthesis, transpiration), the climate, the soil, the wine-making process, the wine itself. The data can be easily processed in order to obtain a complete monitoring of the vineyard. The grapes production capacity is connected to the environment, having grapes' similar genetic peculiarities. Environmental aspects that can affect plant growth and production are soil exposure and slope, vineyard microclimate (temperature, relative humidity, wind, solar radiation, rainfall) and soil physical and chemical characteristics. The latter are fundamental for a correct plant growth (macro- and micronutrients, pH, salinity, chloride, soil water potential). These environmental parameters will interact with plant physiology (photosynthesis, xylem flux, leaf temperature, sugar content, colour) determining the quality of the final product. All data measured by sensors can be employed to classify the vineyard, that is to say creating its zonation. Zonation can be then considered as the first step for product traceability. Until a few years ago, zonation was quite an empirical process, excluding weather stations operating on a large surface. A precise zonation was almost impossible to reach without having a solid scientific matrix.

With the use of new technologies, however, a vineyard can be easily and deeply mapped and defined in every important parameter. The zonation process loses in this way its empirical evaluation system and becomes a scientific process. Zonations operated in the same farm can lead to different results, when spatial variability is so accentuated: the microzonations. The emergence of precision agriculture technologies and an increasing demand for higher quality grape products have led to a growing interest in the practice of precision viticulture. Grape growers and winemakers have known that vineyards are variable for as long as they have been growing grapes and making wine, but in the absence of tools or methods to accurately observe and measure the variation, variability has been

accepted as a fact of life and the majority of vineyards have been managed on the assumption that they are homogeneous.

Since 1999, when the first winegrape yield monitor became commercially available, a major program of research has focussed on understanding the nature, extent and key drivers of variability in the winegrape production process, and on the opportunities to apply a precision agriculture approach to both viticultural management and winemaking. To date, the research has demonstrated that whilst grape yields from the same vineyard can vary from year to year, the patterns of variation within the block are stable. This has lead to a very recent ability to identify characteristically different microzones within vineyard blocks, and the development of the concept of zonal vineyard management. Thus, grapegrowers and winemakers may be able to differentially target their management of inputs during the season and/or selectively harvest at vintage. Information gathered by sensor networks could guide irrigation, fertilization, using of machinery, harvesting or just about any aspect of vineyard management. American, Australian and New Zealand winegrowers are experimenting with, or have already adopted, various Precision Agriculture techniques.

A number of tools already exist or are being developed to enable growers to understand variation on their land. These include yield monitors, various forms of remote sensing, the GPS, soil and tissue testing and electromagnetic radiation sensors. Using a combination of these can assist in the interpretation of precision viticulture data and can maximise its value to right and specific management planning of the microzones of the vineyard. The adoption and implementation of a Precision Viticulture approach to vineyard management is a continual cyclical process that begins with observation of vineyard attributes, followed by interpretation and evaluation of the collected data, leading to implementation of targeted management.

Potentially, one of the most powerful tools in precision viticulture is the use of remote sensing, which has the ability to rapidly provide a description of grapevine shape, size and vigour over entire vineyards. Its potential for improving viticultural practice will rely on being able to define useful relationships between these canopy descriptors and grape quality and yield. The quality of information available for management of a vineyard will be an important factor determining the quality of decisions made and, therefore, the quality of results of the grape produced, environmental effects and, of course, profitability. While agronomists are playing the leading role in precision agriculture, engineers have worked and are working to provide technologies needed to implement precision viticulture practices. Engineering innovations for precision viticulture involve development of sensors, controls and remote sensing technologies.

Pervasive computing technologies, such as sensor network systems, give us new capabilities for sensing and gathering data about an environment and new ways to manage this data digitally.

Robust, low-cost, and real-time sensing systems are needed for implementing various precision agriculture technologies. Commercial products have become available for some sensor types, while others are currently under development and grapegrowers and researchers have to work together to bring these sensors and wireless technology into the vineyard, giving winemakers access to a breadth of date they've never had before.

2.2 The world market of wine: some figures and facts.

World Wide Wine

The wine world market amounts to around 150 Billion USD, corresponding to roughly 27 millions of tons. EU production accounts for around 60% of it. Almost 10% of production comes from Easter Europe producers (mostly Hungary and Romania). Of the remaining 40 %, the most important shares are those of US (mostly California), Argentina, Chile, Australia, New Zealand and South Africa. These last three states, although still holding modest absolute shares, are attentively followed by all wine experts and market analysts as they are demonstrating an extraordinary growth capacity.

The EU is not only the biggest producer, but also the biggest consumer of wine, absorbing around 58% of the world production. Market consumption reflects faithfully production, with two main exceptions: South America and Oceania, where production is considerably exceeding consumption. No wonder that the fiercest competition comes from producers in these regions.

Consumption of wine per capita has followed extremely diversified trends in the last decade. In traditional consumption areas like Europe, it has on average diminished, while in other areas (eg Asia) it has registered spectacular increases (more than 50%). One general trend is anyway clear: consumers tend to spend more as the consumption is increasingly oriented towards quality wine. Quality and safety of wine has therefore become the "mantra" of wine marketing all over the world. There is no way to compete in an increasingly global market without investing in means to ensure quality and safety of wine. This is a statement unanimously accepted by all wine experts world-wide.

The European situation

In the EU Italy, France and Spain together produce almost 85% of the production. Germany is the most important non-Mediterranean producer. Not surprisingly, these four countries are also the first ones in terms of consumption. A strongly consolidated trend in terms both of production and consumption is the shift towards quality wines, accounting for around 42% and 48%, respectively. In Germany almost the totality of production (99%) is dedicated to quality wine, while in Italy, although growing, the share is still at around 25%. The consumption of quality wine has increased of 21% in the last decade.

International wine trade

Although if Italy, France and Spain together, in 2002, represented around 65% of the value of the wine internationally traded, there is no place for complacency, as trends are not favourable to EU. In the last decade, Italy has increased export of 56% and France of 12%, while for instance Australia, South Africa and Chile have more than quadrupled their export. This trend has just accelerated in the last years.

Strengths and weaknesses of EU producers vis-a-vis of "New World" competitors

Just a couple of "extreme" facts: in Italy there are more officially registered wine producers (around 810,000) then hectares of vineyards (around 790,000), giving an average of less than one hectare per producer. In Chile around 120,000

hectares are owned by a total of less than 100 producers. The average Chilean wine grower is therefore three orders of magnitude bigger than an average Italian one. In France the situation is closer to the Italian one, where the average producer owns just 7 hectares. It does not come as a surprise the fact that only 1,200 Italian wine producers export their bottles. In ten years, Australia has doubled the number of hectares of vineyards. It exports 60% of its products, 70% of which is made up by just four wine-growers.

While it is clear that centuries of tradition and know-how cannot be recovered in a few years it is also clear that there is no place for self-indulgence. To sum up in one concept the strength of the New World competitors, this is "economies of scale". This translates in huge budgets, among other, for innovation. Universities and research centres, especially in Australia, New Zealand and South Africa, are spearheading R&D in Precision Viticulture, whose results are immediately taken up by innovation-eager wine growers. While innovation for wine quality is important in all phases of the wine production chain (vineyard, cellar, bottling, distribution, storage) it is widely acknowledged that the most critical phase is the first one: wine excellence comes from the vineyard and the other phases are basically there to preserve it.

Factors influencing the European competitiveness

As said, the European Union occupies a leading position on the world market of wine, accounting for 55% of growing areas, 60% of production and 70% of exports in global terms. As a result of increasing globalisation, this European market is facing growing and stiff competition of imports from Third Countries all over the world. Producers from Australia, New Zealand, South Africa, Chile, Argentina and other emerging " oenological powers" are very aggressively offering wine at low price, adopting advanced technologies in the vineyards and in the cellars and using highly effective marketing techniques. In this highly competitive market, fair trade and fair prices are essential to maintain a level playing field for quality producers and to maintain consumer confidence.

The Common Market Organisation (CMO) established in 1999 that each EU Member State having more than 500 hectares of vineyard should have reliable information about vineyard areas and ensure its good management. This responsibility is delegated to the Member States, where a number of stakeholders (national and regional organisations, wine producers consortia, local trade chambers, Controlled Origin Denomination Co-operatives) have to manage vineyards according to criteria of economic development, environment protection and human welfare maintenance. Projects are ongoing to develop appropriate tools for such a management.

What does exactly mean to be competitive in a globalised wine market for European wine producers (especially the small and medium ones, representing the overwhelming majority)? A slogan has been coined for them: *Innovating tradition*. It's indeed a catchy phrase, able to condense in two words a complex strategy. It means essentially that there is no possibility for them to take on the New World big companies competing with traditional marketing strategies. It can be put this way: if wine were soft drinks, they would have no chance. It is not a case that industry consolidation in wine is so spectacularly different from the one of soft drinks: world wide, the first three companies in the wine sector produce 6% of the offer, while

the first three in the soft drinks sector produce around 80% of them. Wine is an extremely diversified and complex product.

Increasingly sophisticated consumers are willing to pay a premium price for niche products. In Europe there are several hundreds of variety of vines, producing thousands and thousands of different wines in different terroirs, while in most of the New World territories only the most diffused "international" vines are planted and used for making few hundreds of wines. Competing successfully therefore means being able to preserve the immense value of the ancient traditions, while making use of the most advanced solutions for preserving the quality, the healthiness and the uniqueness of the vineyards.

2.3 Initial assessment of Ambient Intelligent approach by some wine producers

The survey

The Department of Agricultural Economics and Land Resource of the University of Florence has conducted an initial study to assess the availability of wine producers concerning the application of AmI-based technologies in their production sites. This study has been conducted through a series of interviews with some key players in the Toscana region. Different categories in the wine chain has been involved:

a) Farmers
b) Oenologists
c) Traders
d) Agents of distribution
e) Brand producers
f) Wine shops
g) Consumers

The main subject of this early survey on the potential application of AmI technologies in the wine chain was the assessment of its impact on the different phases: full field, wine cellar, bottling, storing. In such sense a survey of the analyses currently feasible on: soil, air, plant, pathogenic, wine cellar and bottle, has been carried out. In particular the survey has been focused on aims and technologies currently used, on their cost in relation to the sales and on the willingness to pay for the use of new technologies.

Samples

Isole e Olena, Barberino val d'Elsa (Fi).
(Interview with owner Paolo De Marchi 19.2.2004)

Agricultural area used:	270 Ha
Vine area used:	50 Ha
Grape production:	2500 Ql.

Wine production:	1600 Hl.
Bottled production:	100%
Sales:	4 ml. €

San Michele a Torri, San Michele, Scandicci (Fi)

(Interview with director Leonardo Francalanci 27.2.2004)

(With biological certification)

Agricultural area used:	157 Ha
Vine area used:	53 Ha
Grape production:	1800 Ql.
Wine production:	1260 Hl.
Bottled production:	85%
Sales:	1 ml. €

Tenuta dell'Ornellaia, Ornellaia, Bolgheri (Li)

(Interview with director Leonardo Raspini 1.3.2004)

Agricultural area used:	140 Ha
Vine area used:	91 Ha
Grape production:	4500 Ql.
Wine production:	2300 Hl.
Bottled production:	100%
Sales:	6 ml. €

Moris Farms, Cura Nuova, Massa Marittima (Gr)

(Interview with director Adolfo Parentini 3.3.2004)

Agricultural area used:	470 Ha
Vine area used:	70 Ha
Grape production:	4000 Ql.
Wine production:	4000 Hl.
Bottled production:	65%
Sales:	2,5 ml. €

Avignonesi, Montepulciano (Si)

(Interview with oenologist Paolo Trappolini 3.3.2004)

Agricultural area used:	175 Ha
Vine area used:	100 Ha
Grape production:	5000 Ql.
Wine production:	3500 Hl.
Bottled production:	100%
Sales:	7 ml. €

Podere La Cappella, S. Donato in Poggio (Fi)
(Interview with owner Natascia Rossini 21.3.2004)

Agricultural area used:	30 Ha
Vine area used:	8 Ha
Grape production:	300 Ql.
Wine production:	200 Hl.
Bottled production:	100%
Sales:	300.000 €

Querceto di Castellina, Castellina in Chianti (Si)
(Interview with director Jacopo Di Battista 21.3.2004)

Agricultural area used:	50 Ha
Vine area used:	11 Ha
Grape production:	200 Ql.
Wine production:	140 Hl.
Bottled production:	100%
Sales:	500.000 €

Tenuta Vecchie Terre di Montefili, Greve in Chianti (Fi)
(Interview with oenologist Tommaso Paglione 21.3.2004)

Agricultural area used:	35 Ha
Vine area used:	13 Ha
Grape production:	500 Ql.
Wine production:	350 Hl.
Bottled production:	100%
Sales:	600.000 €

Montevertine, Radda in Chianti (Si)
(Interview with owner Martino Manetti 21.3.2004)

Agricultural area used:	30 Ha
Vine area used:	11 Ha
Grape production:	450 Ql.
Wine production:	320 Hl.
Bottled production:	100%
Sales:	650.000 €

Fattoria Torre del Castellano, Reggello (Fi)
(Interview with director Lavinia Giovannini 21.3.2004)

Agricultural area used:	170 Ha
Vine area used:	15 Ha
Grape production:	900 Ql.
Wine production:	550 Hl.
Bottled production:	25%
Sales:	600.000 €

Fattoria La Torre, Montecarlo (Lu)
(Interview with owner Mauro Celli 21.3.2004)

Agricultural area used:	13 Ha
Vine area used:	6 Ha
Grape production:	400 Ql.
Wine production:	300 Hl.
Bottled production:	100%
Sales:	300.000 €

Tenuta Valdipiatta, Montepulciano (Si).
(Interview with owner Miriam Caporali 8.3.2004)

Agricultural area used:	40 Ha
Vine area used:	30 Ha
Grape production:	1600 Ql.
Bottled production:	100%

Querciabella, Greve in Chianti (Fi).
(Interview with director Paola Banchi 5.3.2004)

Agricultural area used:	190 Ha
Vine area used:	66 Ha
Grape production:	1800 Ql.
Wine production:	1260 Hl.
Bottled production:	100%

Villa S.Andrea, San Casciano Val di Pesa (Fi).
(Interview with director Stopponi 3.3.2004)

Agricultural area used:	328 Ha
Vine area used:	93 Ha
Grape production:	3200 Ql.
Wine production:	2380 Hl.
Bottled production:	50%

Casa Vinicola Carpineto, Greve in Chianti (Fi).
(Interview with oenologist Giovanni Sacchet 3.3.2004)

Agricultural area used:	180 Ha
Vine area use:	90 Ha
Grape production:	3000 Ql.
Wine production:	6900 Hl.
Bottled production:	100%

Wine shop Carlo Lavuri, Agliana (Pt)
(Interview with owner Carlo Lavuri 27.2.2004)

Sales:	1,3 ml. €

Survey results

Soil

All the interviewed producers carry out the analyses of the soil only before proceeding to a new plant of vineyard. It is also possible to have irregular samplings in case of nutritional problem for vines. San Michele Farm, with biological

production, carries out analysis periodically in order to find traces of heavy metals. Only Isole e Olena analyse with continuity the soil after the plant of a new vineyard. It is a pioneer farm: ten years ago, with an investment of 1.000 euro, realised an experimental permanent system of survey of temperature and humidity of soil, nowadays no more used for problems related to data reliability and elaboration.

Therefore, costs today supported from farms oscillate from 300 euro/ha for new plant, up to 2.000 euro/year (Ornallaia) for analysis of soil in which it is possible to find vines with nutritional problems.

The propensity to adopt AmI technologies is unanimous, moderate and conditioned to an effective facility of data interpretation. A wide shared requirement is represented by the possibility to capture data relative to micro and macro elements.

Air

Three farms are currently equipped with station for weather survey supplied from ARSIA (Regional agency) and able to record temperature, humidity, rain, atmospheric pressure and wind direction and speed. Moris Farms has a weather station no more in function, while San Michele a Torri is planning to buy one (5.500 euro) in partnership with other farms.

Other farms carry out surveys on temperature, humidity and rain using traditional instruments as thermometers, hygrometers and pluviometers. More innovative farms use external cooperatives that offer services for measurement and transmission of data via internet.

Also in this sector the propensity to innovation is high and unanimous, and even higher if surveys are distributed along all the farm area with costs equal or inferior compared with the actual one's. A lower interest is direct to the measurement of indices as light intensity, atmospheric pressure and wind direction and speed.

Plants and Pathogens

No farms carry out analysis on plant and pathogens, preferring to use direct survey or combination calendar/temperature. In this case interest for new technologies is low, while it would be well accepted if able to investigate the underground part of the vine or to map pathogenic agents in a such precise way to allow specific treatments with consequent saving of time and products.

Wine cellar

Wine cellar is the place in which farmers show the highest propensity to the introduction of the AmI technologies, above all if analytic variations are collected in continuous and with systems of automatic activation of protection procedures in case of need.

Today, above all in phase of alcoholic and malolactic fermentation, analyses are carried out mostly trough laboratories, internal or external to the farm, with the following costs (per year):

- Torre del Castellano	€ 1.500
- La Torre	€ 2.000
- Podere La Cappella	€ 2.000
- Querceto di Castellina	€ 2.000
- Vecchie Terre di Montefili	€ 2.000
- Montevertine	€ 2.500
- San Michele a Torri	€ 5.000
- Ornellaia	€ 7.000
- Moris Farms	€ 7.500
- Avignonesi	€ 23.000
- Isole e Olena	€ 30.000

The willingness to pay for technological innovations is at least equal to current costs and it might increase if such technologies are able to guarantee an effective reduction of risk.

Barriques

The wide use of barriques for wine refining, produce a great interest for AmI technologies. In the refining period, in fact, both farms with a lot of barriques and those with few ones are not able to carry out complete analysis for each barrique because of prohibitive costs. From an economic point of view, just consider that half of interviewed farms manage at least 400 barriques. And so, assuming to realise in a year a complete series of analysis for each barrique (at 30 euro each), the total sum would reach about 12.000 euro.

For this reason farms use sample analysis or analysis on a mixture of different barriques, with the risk to obtain less precise or even wrong results. It's rather frequent in fact that each barrique evolves in a different way without any possibility, for the farmer, to obtain specific data useful to manage it in the best way. In such sense the AmI technologies could be very useful, especially if able to supply data about sulphurous and volatile with a deep reduction of risk, linked with refining, and costs of labour for the management of barriques. Finally is important to consider that the collected data could be used to improve the management of barriques and to study wine/wood integration linked to barrique typology, level of toasting and degree of use.

Bottles

Among farmers, the possibility to apply to the bottle a technology able to realise a monitoring of its state of preservation is perceived more as a potential trouble rather than an advantage. In fact the first reported worry regards the subject to which debiting eventual responsibility for defect due to a bad conservation of the bottle. Only if technological innovations concur to obtain a clear

competitive advantage and/or an economic one, the attention would be greater. Similar considerations apply to any new system able to find eventual alterations of the wine due to the cork.

From the interview with Carlo Lavuri, owner of a wine shop, it rather emerges a strong interest for a technology, that applied to the bottle, is able to "tell" his story, offering an additional element in the proposal of purchase of wine. But this technology could also guarantee to the consumer the certainty of a corrected conservation of the acquired product.

To the contrary, a technology used to facilitate the logistic and the handling of the good, is perceived with less interest because of the relatively small volume of good exchanged.

The interest for an application of AmI technologies to the bottle has been verified also for Retailers trough an interview with the chief of purchase sector of Unicoop Tuscany (supermarket chain).

There is a potential interest to a substitution of their logistic system, based on the bar code, with one based on new AmI technologies. Concerning the potentiality of sale of bottles with interactive labels, the most important concern is related to the risk that an increase of price can compromise the purchase of the product. And the risk is greater in a phase of economical crisis like the current one.

The analysis of consumer propensity has been realised through specific questionnaires to wine shops consumers. The sample was made up of mainly men between 30 and 60 years old, with a high level of education. Concerning consumer behaviour, the purchase normally take place weekly in wine shops or in supermarkets. As purchase motivation, fundamental roles are played by label, price, producer and origin denomination. These consumers are in general not particularly expert but with an increasing interest in the wine sector and with a deep attention to food safety and quality. As far as the innovation propensity is concerned, it is possible to point out a strong interests for a technological implementation on the bottle finalised to obtain information about traceability of productive process and characteristics and state of preservation of products. It is more difficult, instead, to obtain a willingness to pay for this innovation. The first problem is the negative economic trend that force consumers against any kind of price increase, secondarily the difficulty to imagine potentialities of new sensors and to value a kind of technology never seen and tested personally.

First conclusions

The comprehensive framework is a general good propensity for new technologies based on AmI. At the same time there is a natural lack of confidence due to an unknown system, both at functional and operating level. All the interviewed people have immediately understood the big advantages that could be found in the applications in wine cellar, in which today is concentrate the greater risk and costs. In particular, has been perceived the importance to create a single database so as to create an historical archive useful in order to determine seasonal trends and to preview future scenes to farm and inter-farm level.

3 The Ambient Intelligence paradigm

3.1 The vision of Ambient intelligence (AmI)

Ambient intelligence involves the convergence of several technology areas. Namely, the ubiquitous or pervasive communications, computing and intelligence interfaces, the latter being combined with intelligent equipment and providing intelligence interaction with their surroundings and with other equipment.

Its major contribution is the development of various ad hoc networking capabilities that exploit highly portable or else numerous, very-low-cost computing devices. The second key area is intelligent systems research, which provides learning algorithms and pattern matchers, speech recognition and language translators, and gesture classification and situation assessment. A third element is context awareness; research on this problem lets us track and position objects of all types and represent objects' interactions with their environments. Finally, an appreciation of the interactions of objects in environments is essential.

There are many scenarios that attempt to give substance to what this research might produce. They span from the application of travel and tourism, the in-home or office automation application up to the futuristic scenario of a smart space for crisis management envisioned by the NIST. They are well covered by literature, (e.g. Manes, 2002, NIST: www.nist.gov/smartspace).

The main efforts and the closer to commercial products for Ambient Intelligence Technology are currently being studied and developed for in-home applications. First prototypes of Ambient Intelligence for home systems have been developed, but the realization of true Ambient Intelligence calls for much additional research of multidisciplinary teams consisting of technologists, designers, and human behaviour scientists, notably by the group leaded by Emile Aarts at Philips Media Lab (Aarts, 2000). The smart space environment is often congestioned by several heterogeneous services, mobile services are predominant, real-time and user-profile tailored services are needed and hand-free operation is required. Consequently, issues like user-interface, navigation/localisation, and intelligent software agents assume even greater relevance.

Ambient Intelligence technologies offer services provided by embedded devices, that are accessed and interconnected with portable devices carried or worn into the 'Ambient'. Then the combination of imported and native devices can support the information needs of the current users.

Mobile and stationary scenarios have to accommodate the following requirements:

Embedded: that means that many invisible distributed devices are displaced throughout the environment in a preordained or random distribution. The composing equipments have the capability to communicate in the background supporting distributed and local collaboration, facilitating interaction with information rich sources.

Personalized: the approach is user-centric allowing the 'ambient' be tailored towards the specific needs with identifying and perceiving capabilities

Adaptive: the 'ambient' can change in response to the user perspective and the surrounding environment without a specific and intentioned action providing extensive presentation capabilities

Anticipatory: the 'ambient' is structured and implemented to anticipate the needs and goals without conscious mediation, during task performance, and provide improved records and summaries for later use.

The scenarios of the future will be enabled by innovations in four major areas:

Perceptual Interfaces: These technologies will allow people to work in an evolving world of integrated, almost imperceptible devices, interfaces, and services. This will enable real-time cooperative work in using numerous devices that become invisible to their users, as do pencils and paper clips today.

Mobility and Networking: In the future numerous pervasive devices will move freely between work spaces with individuals. This will require unprecedented mobility and networking services. Devices will have to be rapidly discovered, and offered access to appropriate information and resources. There will also be many new security challenges posed by this mobility.

Pervasive Devices: These numerous special purpose computers will be carried and worn by workers. They will be equipped with low power wireless networking and facilitate many day to day work tasks.

Information Access: Information will be accessed in a natural way, there will be no more immobile interfaces keeping people prisoners of their computers.

Some examples of these innovations component enabling technologies include:

Perceptual Interfaces: Dialog processing, Pen input, Large screen displays, Geometry sensitive devices, Gaze tracking, Gesture recognition, Speaker identification, Microphone array processing, Voice detection, Acoustic imaging, Camera array processing, Speech recognition, Sensor fusion.

Mobility and Networking: Mobility layers (NAT, etc.), Directory services, Security management, Wireless link, protocols, Service discovery, Mobile session management, remote sensors, Voice over IP, Video over IP.

Pervasive Devices: Smart notebooks, Portable sensors, Electronic books, Palm top computers, Smart badges/tags.

Information Access: Visual document indexing, Spoken document indexing, Distributed multi media data bases, Spoken document retrieval, Text retrieval.

3.2 The AmI framework – verification

3.2.1 Overview

The data produced by a Sensor Network is streamed into the AmI layer according to the schema shown in figure 1.

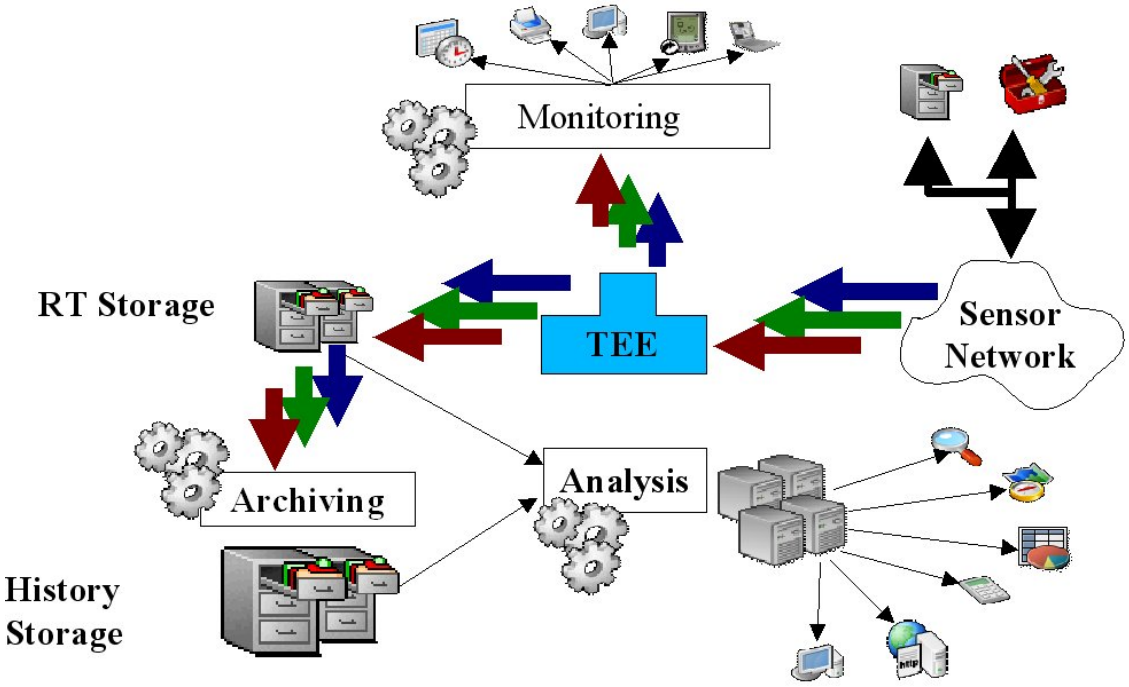


Figure 1 AmI framework data flow.

Note that with the term Sensor we refer to a whole class of similar sensor units. The realtime data flow is sent to a *Real Time (RT) Monitoring* process that is able to visualize the data coming from a sensor or simple combinations of that data that are produced by operations who aggregate the data in both ways intra sensor or inter sensors. The data is the streamed into a **Realtime Storage** that makes it persistent. However since the data produced by a Sensor Network might grow indefinitely, it useful to provide a historical storage system where the data can be flushed periodically for long term storage. This operation is called ***Archiving***. Archiving is a complex operation that might involve the functional transformation of the data along with a timing policy that drives the operation. ***Analysis*** involves both the storage systems (realtime and historical) and is intended to model the study of the acquired data to obtain cross comparisons among long time periods, decision and planning support, find new patterns in natural phenomenon, economically exploit the results and quality assurance. Finally all this information can be published.

3.2.2 Monitoring Facilities

The data monitoring phase focus on the following major aspects:

Data validation: the monitored data is compared with real sample data measured by the domain experts with specific instrumentation. This enables the test agent to establish correctness assessments that validate the data and exclude errors that could be introduced by the lower levels of the AmI stack, by the transport protocol that moves the information from the sensors to the applications and finally by the displaying agents that provide for data visualization.

User Interface (UI) validation: the interfaces designed for data visualization are designed according to explicit user requirements. The requirements can relate to visualization or interaction depending on the user needs.

Performance validation: in this step it is important that monitoring facilities are able to face the throughput enforced by the data stream. This means that it is necessary to intercept and report all the data items in any of the format chosen for visualization. Moreover, because monitoring is essentially a real-time activity, it is necessary that response time of the graphical user interfaces be very low.

Testing of data validity is done in a unit test phase where each monitoring facility or display is tested to verify that the data displayed is correct. Simulation techniques can be used to produce a data stream that can be monitored. The simulation technique combined with iterative development and extreme programming can be used to produce correct and stable visualization agents.

To verify that no error is introduced by the transport protocol that moves the data between the AmI framework and the lower layers, a cross comparisons of measures is necessary. This techniques applies at system test and system deploy phase and involves also domain experts that produce real measures using dedicated instrumentations.

Validation of the user interfaces occurs during the design of the application and consists in drawing the interfaces and establishing interaction on the widgets. These interfaces are then presented to the users who produce feedback and update requirements. This process is iterative and could be implemented in a unit test phase.

Finally, performance tests should prove that the system will be able to face the nearly real-time requirements of a typical monitoring facility. These tests can be performed with a simulation techniques that produces data at the maximum rates allowed by the overall system timings. Tests can be considered positive if the monitoring system is able to display all measured data without any loss due to flooding.

3.2.3 Storage Facilities

The storage facilities involves the following aspects:

Data Integrity and completeness: it is necessary to verify that data is stored in the databases correctly. This means that possible functional or time aggregation function are applied in a correct way, that no data is lost, that ordering is respected. Another point is to verify that the backup system respects itself these guidelines.

Size and capacity verification: a crucial point is to validate the policies chosen for defining the sizes of the various level of storage and backup space.

Performance in Data Insertion and Retrieval: because the quantity of data to be stored or archived tends to grow indefinitely it is very important that the time necessary to access the data remains constant.

Data integrity in the storage system should be guaranteed by a clean design of the database architecture and by formal methods that can be used for demonstrating

the completeness and correctness of the design. This tests can be performed as a unit test where the unit is considered the storage system as a whole.

Size and capacity can be estimated in advance through some quantitative study during the system design step.

For evaluating performance in data access often some benchmarking systems typical for databases and storage hardware can be used for theoretical access times and to compute an estimation of the way these measures change with the growing of the data amount stored.

3.2.4 Analysis [i,ii]

It can be supposed that the verification of the results of the analysis phase follows the verifications described in the previous steps. Thus techniques for testing this step of the AmI framework can rely on data integrity and correctness. Moreover, data access performance is guaranteed by the testing procedures of the storage facilities. Thus, the most important aspects to be tested in this phase are:

Semantic validation of the algorithms for datamining, KDD and DSS: it has to be proved that the algorithms used for these tasks are effective. This means that the processes used for analysis have to find out new semantical patterns in the acquired data, validate, increase or update the system knowledge base or contribute in a predefined way to the optimization of some quantitative or qualitative aspects of the whole system.

Verification of the statistical algorithms: statistical results are quite useful for providing an evidence of the overall quality or improvement of the system. The significance of the results have to be tested in cooperation with domain experts to increase their usability.

Performance of the algorithms: performance in analysis could appear less important as it could be in monitoring operations because the real-time constraint can be relaxed and computation can be executed off-line. Actually, the amount of data on which analysis algorithm have to compute on is several order of magnitude bigger than that of real time operations and the computation itself could be very complex and heavy. Thus techniques for predicting, controlling and tuning performance of these algorithms are required.

Testing of the semantics of the algorithms and the verification of the statistical algorithms can be performed only after a considerable amount of real data has been collected. Thus testing procedure needs necessarily to be iterative. A good technique is represented by developing prototype versions of the algorithms and analyze the results together with domain experts in order to tune the knowledge base or the algorithms themselves to produce always better results.

Performance of the analysis algorithms, that show a significant computational load and a growing data intensity, can be estimated by applying performance models that take into account quantitative aspects (FLOPs, memory usage, IO). An implementation that focuses on reducing the impact of the quantitatively heavier steps of the algorithm, possibly by applying parallelization techniques, can be iteratively tuned to closely match the applied performance model.

MONITORING & ARCHIVING

This section shows a set of tables that have to be compiled in order to describe the classes of sensor that are used and in particular how the information produced by these sensors is fed into the RealTime (RT) Monitoring and Archiving process.

In the first RT Monitoring section of the first table, the user should specify how the data, that is fed to the RT Monitoring process, has to be aggregated functionally (average, sum, factor) or chronologically (every hour, daily...). In particular, for RT monitoring, the alarm/alert values (that is, the critical threshold values for the monitored parameters) and the user interface that is indicated for displaying this data can be defined.

The same description applies to the Archiving section of the table where the operations of flushing the real time storage into the historical storage is described. Moreover in this section some timing information is added to show when the data has to be archived.

Finally, the last section, describes the operations that may be performed on the specific sensor class for managing it (updates of sensors, sensor addition or removal).

Single Sensor	
Sensor Name	
Location (air, soil...)	
Chain Step (vineyard, cellar...)	
Short Description	
Number of installed Sensors	
Geographic positions	
Note	
REAL TIME MONITORING	
Temporal Aggregation	
Functional Aggregation	
Alarm and alert values	
User Interface (diagram, chart ...)	
ARCHIVING	
Archiving period	
Temporal Aggregation	
Functional Aggregation	
MANAGING	
Failure Notification	
Upgrade/change Notifications	

In the following table the user should resume the relations among sensors that have to be monitored or archived. With the term ***relation*** we mean displaying (in RT monitoring) or storing (in the archiving process) of data combined from different sensors.

As in Single Sensor description, both temporal and functional aggregations could be reported.

Sensors Relation	
Relation Name	
Involved Sensors	
Short Description	
Note	
REAL TIME MONITORING	
Temporal Aggregation	
Function Aggregation	
Alarm and alert values	
User Interface (diagram, chart ...)	
ARCHIVING	
Archiving period	
Temporal Aggregation	
Functional Aggregation	

ANALYSIS & DECISION SUPPORT SYSTEMS

In the following table the ***Analysis*** operations on the two storage system can be resumed. By now, the aspects of an analysis activity that can be described are:

Name, Description, Note: general information on one analysis activity.

Involved entities: the entities (sensors, data, ...) involved in the analysis activity.

Statistical views: statistical aspects such as temporal relations, functional dependencies and quantitative visualizations.

With the term temporal specification we indicate how the analysis operation has to be carried out. In particular if the operation has to be executed online or offline, if it has to be executed automatically at a fixed time period or if the result of the operation has to be stored for caching purposes.

Analysis Result	
Analysis Name	
Involved Entities	
Short Description	
Note	
STATISTICAL VIEWS	
Temporal Relations	
Functional Correlations	
Quantitative Visualization	
TEMPORAL SPECIFICATIONS	
Interactivity (On line –batch...)	
Elaboration period	
Result Caching	

4 User's needs and requirements for the GoodFood AmI system

4.1 The AmI vision in the wine-chain, it's there on a monitoring: the vineyard is breathing

Late summer sunlight filters through few clouds as Duccio Falciani unlocks a shed on a Tuscany hill and enters a room stuffed with equipment.

The machinery have been monitoring the vital functions of a section of the Montepaldi vineyard in the centre of the Chianti area. Bright red numbers dance on a display, flickering up and down several times a minute. The reading reveals the nitride oxide just on the leaf, where flexible electronics sensors sniff the air. This year the numbers are running surprisingly low, the vintage is promising exceptional results. In the mean time some remote controlled cameras monitor the grape colour waiting for the maturity. A three-dimensional map of the vineyard reveals in real time figures of merit related to the grape quality and growth, the work of the plant physiologist is much more effective in this way.

During the last months the vineyard has been closely monitored recording square meter for square meter the healthiness state of the plants and Duccio has maps for that. Doing a selective vintage he will ensure an high quality wine and for that reason the stocks of his firm have increased sharply since the AmI platform has been completely running in his farm.

Was a long time ago when his wife Anna and their children produced a nice wine and bottled it in flasks, then Anna, which is a good painter, designed the label on a small irregular piece of parchment in the old style fashion. All their friends, relatives and the trader, recognized the quality. Now his product is sold on international market and a complete set of information must accompany the wine. On their

bottles is attached flexible electronic tag which contains all the key factors acquired during the entire production chain and many other will be stored since the bottle will get out from their farm to begin the trip toward the consumer. The storage temperature, the level of lighting, the production date and the coordinate of the responsible for all the phases of the wine-chain are stored.

Just after the grape harvest the level of pesticide has been measured by using a portable tool that is now contained in a suitcase. On the other hand, the critical conditions for the peronospera attack this year have not reached alarm levels, hence the preventive treatment has been avoided resulting in a very low contaminant degree. Also the level of ocratoxin is then measured and only few traces are found. These data are automatically sent to the AmI database and then directed to the agricultural consortium for quality certifications.

He received several e-mail from Australia, some bottles had bad corks flavour and the historical of these bottles revealed that the storage temperature reached the 30°C, it is time to change cork provider and ensure a quick and safe transport.

It is now approaching the time for vintage. On the bases of the knowledge extracted from the database, the distributed network of sensors drives him in the field through the plants. It is obtained by a radio-localization system that utilizes the transceiver on the plants as fixed node of a network and the transceiver installed in his hand-held PC as mobile node. The transceivers implement the standard IEEE 802.15 which allows tracking and localization capability. He brings a portable unit with disposal cartridges for the measure of the sugar content in the grapes. It is a matter of few hours and Duccio is now able to select the unit areas that are closest to the optimum maturity. His hand held computer is wirelessly connected with the equipment and acquires and sends to the database the sugar level, along with the time and position of the samples. A neural network cross-correlates the data related to quality of the last year and tries to extrapolate a guess for this year quality, considering also the weather forecast for the next days. After few samples the system suggest the area that should be harvested.

An atlantics perturbation of strong intensity is expected for the end of the week with high risk of hail-storm. It is now to go sleep tomorrow will be a long day.

4.2 Good-Food AmI Scenario Methodology

The purpose of this section is to provide an instrument and a methodology for defining suitable scenarios and leading the design of the AmI infrastructure in the GoodFood context.

The defined methodology is the result of the interaction among M&NST and sensors design experts, food quality specialists, consumers' associations, users' clubs and more in general, all the involved actors of the selected food chains.

Considering the wine chain case study, the following three main steps have been implemented:

A detailed analysis of the entire wine food chain, including a definition of all the steps of the productive wine chain (ripening, harvesting in the vineyard; fermentation and ageing in the cellars; transport, storage and selling in bottles);

Definition of the wine scenario.

Filling of a sensor matrix, which contains information on the significant targets, sensors features and performances (Tables I-IV);

The analysis of the wine chain was carried out highlighting the critical aspects of each single step, with the support and collaboration of the agronomists and experts in this field. As follow up of this analysis, a number of state variables (a physical or chemical quantity) was individuated in order to monitor efficiently the wine chain and its critical points. In particular, suitable type of measurements, sensor features and AmI communication (i.e. measurement targets, measurement range, sensitivity, acquiring time, auto-localization requirement, commercial availability of sensors) have been identified by the experts on sensors and ambient intelligence domain.

The filling of the sensor matrix for the wine chain has two expected outputs.

The first is the extrapolation of a suitable scenario for the wine chain for the physical implementation of the pilot site. The scenario aims to describe in detail the suitable implementation of the sensor net and in particular how – when - where a certain sensor must be used.

It is understood that the definition of the wine scenario is a key step as it leads the physical implementation of the distributed network of sensors architecture for the AmI real case study.

The second output is the development of an instrument for the exploitation and scalability of the methodology to the other food chains. In order to simplify the procedure, this instrument has developed in the form of a questionnaire (see par. 4.7) to be filled by the responsible of the others food chains (WP1-WP6), in strong collaboration with experts of the field and technicians (sensor developer) analysing in details each step of considered chain. On the basis of these questionnaires, suitable scenarios should be provided. These scenarios will be the starting point for the definition of the general requirements for an "open" AmI structure applying to generic food chains.

Approach

The complete food-chain, and in particular the wine-chain, is considered as a physical process to be monitored through a convenient set of state variables. The idea is to review the phases of the chain and highlight for each of them the set of critical parameters, sensors, actuators and the 'information' the actors need to retrieve. The latter are introduced in order to furnish to so called users' needs.

In general terms the process may be sampled considering a reduced domain within which the process can be monitored maintaining a complete insight on the process dynamics.

The sub-domain setting is selected with respect to economical factors. Retrieval

A tentative value of min 15 and max 25 different sensors are guessed for the particular application with a number of 50 to 100 plants per hectare. The total extension of the vineyard is 1 hectare with a random distribution of the plants to be monitored

4.3 AmI requirements for the wine-chain

Firstly are considered the set of general sensors' features they must accomplish, the main are:

- Capability to operate in the selected environment; this results is a set of mechanical and physical requirements.
- relaxed requirements in terms of maintenance even if a periodical man-assisted operation may be considered.
- the distributed network of sensor must be fault tolerant, hence the node (the sensor unit) must indicate the lack or the reduced operation.
- sleep and wake-up operation mode with reduced time constant.
- transparent to the physical process.
- the communication mode must be wireless
- the output of the sensors, in particular the transducer output and the on-board intelligence is defined in Sec. B, the presence of an already available standard may be considered e.g. IEEE P1451.4 (electronics data sheet for sensors)

4.3.1 Layered sensors structure

The AmI concept applied to the selected scenario, foresees that data collected by sensors are locally pre-processed and analysed, then remotely stored in a database, using the network gateway unit. Local user, through web-based graphical interfaces, can then query the remote database, gathering either general information or single sensor parameters. The basic idea of the data-fusion and the data aggregation represents a network level of intelligence that allows a more effective fruition of the information and allows a first degree of knowledge discovery. User friendly tools for executing complex operations, such as comparing cross-related parameters and historical values, are also available. Moreover, the user interfaces are specifically arranged and presented according to the user skills and requirements, i.e. presenting raw data to the agronomist or biologist expert, or graphical interactive interface for the non-skilled end user. Data access could be made using a 2-D representation of the controlled area and sensors installed, providing direct information on the network state and monitored values, and highlighting anomalous detections.

Additional AmI-compliant devices, such as wireless cameras or portable analysis equipments, are also integrated in the same user interface, though they may not be on the sensor network local communication layer. User can also directly interact with the sensor network by using an handheld device (or similar), implementing local network specific communication protocols and networking interface; in this way he can easily access the monitored parameters while he is "on field", and directly query the requested information.

Two level of sensing are considered:

Level 1: all the micro-systems must be considered autonomous, not necessarily self-localizable but in any case aware about their own position and time reference.

Example 1: from the leaf narrowing the system understands that a stress condition is in force, the measurement of the water potential is then acquired and the decision about supplying water is possibly taken.

Because from a plant physiologist point of view, the vineyard shouldn't be irrigated, this example is to be considered as pathogenic attack. The event is monitored and stored in the historical record.

Level 2: Due to the exceptional complexity of a number of micro-systems, some of those with a practical interest are not completely autonomous.

In these cases the requirement consists in considering complex diagnosis on the basis of a simplified protocol that does not require the presence of specialized personnel. The information is acquired following the information provided by the network itself, which drives the operator in the specific point and time of the process requiring a detailed analysis. In the process flow, the information is then asynchronous rather then continuous and is again delivered to the database to be correlated with other information acquired in real time.

This envisages a different layered structure with an inner layer of sensor monitoring in real time, typically oriented to basic and standard parameters (i.e. pressure, temperature, humidity etc.) and a second that is considered only when the lower one exhibits a query.

Example 2:

in the case of the vineyard it is important to guess the condition for the attack of the peronospora (Plasmopara viticola), this may be obtained by monitoring the plant growth, the raining and the temperature. In the case of a selected set of these data the system responds with a critical message, driving the technician through the field to observe either visually or by using DNA based lab on chip the presence of the pathogenic factor. In such a way the decision to supply appropriate quantity of pesticide. The action is then selective preventing from a massive and anti-economic treatment, preserving the environment and increasing the product quality.

4.4 Test Protocol of the AmI Framework

4.4.1 Overview

Usability addresses the relationship between software applications and their users. In order for an application to be effective, it must allow intended users to accomplish their tasks in the best way possible. The same principle applies to computer programs, websites, and other application software. In order for these systems to work, their users must be able to employ them effectively.

Usability depends on a number of factors including how well the functionality fits user needs, how well the flow through the application fits user tasks, and how well the response of the application fits user expectations.

Usability (more often referred to as Quality of Use) is the quality of a system that makes it easy to learn, easy to use, easy to remember, error tolerant, and subjectively pleasing.

There are a number of usability evaluation methods available to ICT professionals to measure the usability (quality of use) of an application, and each of these methods has different characteristics. The choice of appropriate methods and deciding at what stage of the life-cycle they should be applied in order to achieve the highest quality system is one of the key aspect of *usability engineer*.

This section focuses on a specific aspect of the usability evaluation process, often referred to as "Technical Verification" of the application. In order to verify the behaviour of a software product, evaluation methods must be identified and executed. When dealing with technical verification, the application of tests is one of the most important means with which the technical quality of an application can be measured. In this case, the objective of the test is to identify, trace and fix defects of the product, thus enhancing the total quality of the application.

Acronyms:

CI Configuration Item

CSCI Computer Software Configuration Item

XP Extreme Programming

ASP Application Server Provider

BP Best Practices

Definitions:

Configuration Item or Computer Software Configuration Item: Item designated for configuration management.

CIs can be of different complexity, size and type. The whole system is the top-level CI. The system composition in terms of CIs shall be planned and agreed for each project.

General criteria for the selection of Configuration items are:

- Reusability (units that can be used on other projects or in multiple roles on the project shall be designated as CI)
- Developer (Items can be distinguished on the basis of the person/supplier/team who will develop the item – parallelization of development activities)
- A CI should be homogeneous in functionality, development language, etc.
- Critical performance, cost, etc.
- Maintenance
- Susceptibility to change
- Testability

Extreme Programming

Extreme Programming is a discipline of software development based on values of simplicity, communication, feedback, and courage. It works by bringing the whole team together in the presence of simple practices, with enough feedback to enable the team to see where they are and to tune the practices to their unique situation.

Extreme Programming focuses on delivering business value in every iteration. To accomplish this over the course of the whole project, the software must be well-designed. The alternative would be to slow down and ultimately get stuck. So XP uses a process of continuous design improvement called Refactoring.

Best Practices

Best practices are a set of commercially proved approaches to software development, which, when used in combination, strike at root causes of software development problems. These are so-called "best practices", actually not because we can precisely quantify their value, but rather because they are observed to be commonly used industry by successful organizations.

Best Practices are:

- Develop Iteratively
- Manage Requirements
- Use Component Architectures
- Model Visually (UML)
- Continuously Verify Quality Manage Change

Quality Dimensions

This section provides a brief description of the concept of quality dimensions. Existing tests can be grouped by:

- *Quality dimension*: that is the main factor on which the test is focused on;
- *Testing period*: that is in which period of the project life-cycle the test is carried out;
- *Test Type*: the objective of a single test, limited to a single dimension of the quality.

As far as the quality dimensions are concerned, the following aspects should be considered:

- *Reliability*: code integrity, structure and robustness.
- *Functions*: possibility to implement the requirements specified during the design phase of the application.
- *Application Performances*: profile of the execution time of the application.
- *System performances*: operational characteristics related to the production of the system, such as response time, the reliability of the system, the workload capacity.

For each quality dimension, one or more tests should be carried out, during one or more test phases.

4.4.2 Test phases

Software development Best Practices (BP) suggest and promote the testing phase as a comprehensive activity, to be carried out during different steps of the software development lifecycle, based on specific test objectives. The test phases follow one another in an incremental way, starting from the tests of single components, up to the tests of the overall system.

Unit test phase

The purpose of performing a unit test is to test the implemented components as individual units. The following types of unit testing are done on this phase:

specification testing – verifies the unit's external observable behaviour;

structure testing – verifies the unit's internal implementation (there may also be specific tests to perform for some units, such as tests of performance, memory usage, load, and capacity).

Integration test phase

The focus of this phase is to verify that the components interact properly with each other after they have been integrated into a build.

System test phase

In this phase the system functions are properly tested, as a whole.

Deployment test phase

The overall application is tested by the end-user (or by their representatives), to the aim of being deployed.

4.4.3 Test cases

Test cases specify the way a system will be tested, including what are the elements to be tested, with which input or expected result, and under which conditions the test will be performed. A test case can assess any system requirement or collection of requirements, following the set of use cases elicited during the analytical phase of the software development life-cycle.

A brief description of the major test cases is provided, each test being focused on a specific characteristic or factor of the software under evaluation.

Benchmark tests: It compares the (unknown) performances of a system with those of a second (already known) system.

Functional tests: Verify that the developed system realizes/implements the identified functional requirements.

Installation tests: Verify that the system can be installed on the customer platform(s), and that the system operates correctly when installed, in accordance to the constraints and requirements identified and agreed with the buyer.

Configuration tests: Verify that the system works correctly in different hardware and software configurations, such as different network configurations.

Negative tests: Try to cause the system failure, in order to identify its weaknesses.

Stress tests: Identify problems with the system when it is overloaded, it suffers from insufficient resources or when resources are competed for.

Integrity tests: Verify the reliability and the robustness of the system, as well as the technical compliance of the source code with the characteristic of the adopted development language, such as the syntax, the usage of resources, etc..

Overloading tests: Verify and assess the acceptability of the system's performance, when tuning and varying the workload of key resources.

Performance tests: Verify and assess the performances of the system, such as response time, with constant workload of the key resources.

Regression test

Regression test is not actually a class of tests, but a strategy following which a test, performed on a previous build, is carried out on a new (more recent) build of the system, in order to verify that anomalies are fixed, and that no additional bugs have been introduced in the new release, following the changes to the code or the implementation of new functions. In other terms, regression tests are primarily done to verify that "old functionality" in "old builds" still works when "new functionality" is added in a "new build". Regression testing is particularly important in an iterative, incremental life cycle, since each iteration produces a substantial addition to previous increment, as well as a fair amount of changes.

Performance Tests

This section provides a brief overview of basic test categories and terms for applications. A distinction is made between applications that show a significant human interactivity and applications that are mainly involved in computation tasks who do not require human interaction.

The principal metrics for evaluating performance issues in application that present an interactive behaviour are:

- **response time**: the amount of time it takes between initial request and complete download of response;
- **throughput**: the number of requests that can be processed in a given amount of time;
- **latency**: the difference in response time between a local and a remote operation invocation. Sources of latency include network speed, middleware overhead and communication overhead.

For application who have a particular heavy computation pattern but do not require an intense human interaction, the main metrics for performance evaluation are:

- **completion time**: the time it takes for a task to complete its computation and produce an output (possibly to a file system)

- **scalability:** the actual performance improvement measured when adding parrallelism to the application implementing a specific computation.

Proactive Performance Management is the term used to identify the techniques used to anticipate potential performance problems through a specific analysis of quantitative and qualitative aspects of an application. Performance issues are faced by the introduction of well known high performance solutions in an early state of application structure design.

Proactive Performance Management is in contrast with Reactive Performance Management where performance problems are faced when they just arise thus delaying appropriated handling of such issues in a late step of application implementation when often a restructuring of the application would be necessary.

Once the application underwent a performance oriented design, test that evaluate the adopted solutions have to be executed.

These tests should aim at matching theoretical performance models compiled during the design phase and targeted to specific runtime platforms (processor architecture, network infrastructure, operating system).

Once the performance related metrics have been measured for significant test runs of the application the following scenarios can be observed to adjust application policies for implementing the theoretical performance model:

the application performs well in terms of response/completion time, resource utilization, scalability. In this case the designers don't have to improve the system.

In a distributed, client server application, as the load grows, the latency of the system remains acceptable, but the response/completion time and the throughput grow a lot. In this case the designers have to improve the performance of the server side. The designers can decide to increase the power of the server, increase the CPU speed, the amount of RAM and/or the I/O service rate. However, one way to improve a distributed application to scale with heavier workload is to add processing power (provided that the CPU is a bottleneck and/or RAM is not enough). To improve the throughput of the distributed application the designers can pass from a single server to a server farm. To improve the single response time of the application, the designers have to add parallelism to the application.

As the workload grows, the local response/completion time and throughput have still good values, but the latency grows a lot. In this case the network bandwidth and/or the middleware is inadequate. The only way to address problems like these is to increase the capacity of the network link and/or improve the middleware.

4.5 Wine-chain phases, targets and monitoring systems

4.5.1 Vineyard

The sampling is around 20 plants in an 10.000sqm with a sampling time of about 1\2 hour.

The following subset of monitoring level are considered (the targets and the sensor topology are preceded by an ID number):

Soil

Targets to be monitored and sensors topologies:

ID1 – temperature at different deep level: microthermocouples

ID2 – absolute humidity: humidity sensor

ID3 – water tension: tensiometer (e.g. www.soilmoisture.com, www.sowacs.com/)

Air

Targets to be monitored and sensors topologies The monitoring of the following target is punctual.

ID4 – temperature

ID5 – relative humidity

ID6 – wind speed

ID7 – wind direction

ID8 – light intensity

ID9 – PAR (Photosynthetically Active Radiation) absorption of the light radiation in the 680nm;

ID10 - Raining

ID11 – atmospheric pressure

Many of the available commercial water stations are able to acquire all these data (e.g. Mod. MINIMET, Skye instruments, www.skyeinstruments.com)

Plants

Targets to be monitored and sensors topologies.

ID12 – leaf temperature: microthermocouples or infrared thermometric sensors (e.g. mod. EL21a Calex Electronics Ltd., www.calex.co.uk)

ID13 – leaf turgor potential: to develop – some sensors available (e.g. www.actahort.org/books/562/562_5.htm)

ID14 – leaf nitrix oxide (NO) production: to develop – electrochemical sensors available (e.g. WPI, www.wpi-europe.com/biosensing/NewISONO.html)

ID15 – leaf CO_2 production

ID16 – leaf O_2 production

ID17 – trunk oxygen concentration: fibre optic oxygen concentration (e.g. FOXY-AL300, Ocean Optics, www.oceanoptics.com/homepage.asp)

ID18 – xylem flux on root: sap flow sensors (e.g. Dynamax, www.dynamax.com/sap-flow.htm)

ID19 – xylem flux on cordon

ID20 – xylem flux on shoot

ID21 – diametric growth rate: LVDT (Linear Variable Differential Transformer) sensors (e.g. Solartron, available at www.rs-components.it)

ID22 – grape berry colour changes (veraison): videomonitoring

ID23 – videomonitoring of the vineyard

ID24 – pathogen fungi: to develop - biosensors- peronospora (Plasmopara viticola)- oidium (Uncinala necator, fc. Oidium tuckerii)- botrytis (Botrytis cinerea)

Harvest

Targets to be monitored and sensors topologies. Weekly sampling from veraison to harvest time of some berry for the must analysis in order to monitor the technologic and phenolic maturity.

ID25 – pH: fibre optic sensors (e.g. Ocean Optics, www.oceanoptics.com/homepage.asp) or solide state pH sensor

ID26 – sugar content: refractmeter

ID27 – color

ID28 – total plyphenols

ID29 – anthocyanins

ID30 – total acidity

ID31 – tartaric acid

ID32 – malic acid

4.5.2 Cellar

Punctual analysis of the following parameters on the must before the fermentation; the characteristics of the must (especially concerning the color, total polyphenols and anthocyanins) are a key to understand the future wine quality.

ID33 – color

ID34 – total polyphenols

ID35 – anthocyanins

ID36 – total sugar

ID37 – pH

ID38 – total acidity

ID39 – tartaric acid

ID40 – malic acid

ID41 – estimated plant-available N

ID42 – mycotoxin (e.g. ocratoxin A: it has been found to be dangerous for human health, nevertheless this is not yet recognized by legal threshold): to develop

ID43 – pesticides: HPLC analysis – it would be interesting to develop specific sensors

ID44 – copper: microelectrodes

Continuous analysis of the following parameters on the must and the cellar during fermentation; in this way it is possible to supervise yeasts activity during fermentation.

ID45 – ambient temperature
ID46 – must temperature: thermocouples
ID47 – must pH
ID48 – must CO_2: infrared sensor
ID49 – must O_2: fibre optic oxygen concentration (e.g. FOXY-AL300, Ocean Optics, www.oceanoptics.com/homepage.asp)
ID50 – must ethanol: to develop
ID51 – must total sugar: to develop
ID52 – must SO_2: to develop

Punctual analysis of the following parameters on the wine before the barrel-ageing and before bottling.

ID53 – color
ID54 – total polyphenols
ID55 – anthocyanins
ID56 – ethanol
ID57 – total sugar
ID58 – pH
ID59 – tartaric acid
ID60 – volatic acidità
ID61 – total SO2
ID62 – mycotoxin (ocratoxin A)
ID63 – pesticides
ID64 – copper

Continuous analysis of the following parameters on the ageing area.

ID65 – ambient temperature
ID66 – relative humidity
ID67 – light intensity

Table Ia: Sensor Matrix for Wine Chain: Vineyard

Food chain step		Measurement Target	Variable (t): time (x,y,z): spatial coordinates K: constant	ID	Acquiring time for continuous monitoring (f=f(t))	Measure range	Sensibility	Autonomous system		Fixed position		Auto localisation capabilities		Are available commercial sensors?		Are available commercial multisensors device?		Technical choice				Conventional methodology or device of detection
																		Sensor		Multisensors device		
								Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Use of commercial sensor	Development new sensor	Use of a commercial multisensor device	Integration into a multisensors device AmI compliant	
Vineyard	Soil	Soil Temperature	f=f(t,x,y,z)	1	30 min	-20 → +60°C	± 0.1°C	x		x			x	x				x			x	Conventional micro temocouppple
		Absolute humidity	f=f(t,x,y,z)	2	30 min	0 → 100%	± 3%	x		x			x	x				x			(Group A)	Conventional micro humidity sensor
		Water tension	f=f(t,x,y,z)	3	30 min	0 → -80 KPa	± 0.2 KPa	x		x			x	x				x			(see sheet 1 of 7)	Soilmoisture – www.soilmoisture.com,
	Air	Temperature	f=f(t,x,y,z)	4	30 min	-40 → +60°C	± 0.1°C	x		x			x	x		x		x			x	Conventional meteorologic unit (e.g. MINIMET model of "Skye instruments" www.skyeinstruments.com (not for PAR monitoring)
		Relative humidity	f=f(t,x,y,z)	5	30 min	0 → 100%	± 3%	x		x			x	x				x			(Group B)	
		Wind intensity	f=f(t,x,y,z)	6	30 min	0 → 50 $m \cdot s^{-1}$	± 0.5 $m \cdot s^{-1}$	x		x			x	x				x				
		Wind direction	f=f(t,x,y,z)	7	30 min	0 → 360°	± 3°						x	x				x			(see sheet 1 of 7)	
		Illumination intensity	f=f(t)	8	30 min	0 → 1800 $W \cdot m^{-2}$	± 10 $W \cdot m^{-2}$	x		x			x	x				x			x	
		PAR (Photosynthetically Active Radiation)	f=f(t)		30 min	0 → 2500 $\mu mol \cdot m^{-2} \cdot s^{-1}$	± 5%	x		x			x	x				x			(Group C)	
		Precipitation intensity	f=f(t)	10	30 min	0 → 150 $mm \cdot giorno^{-1}$	± 0.5 $mm \cdot giorno^{-1}$	x		x			x	x				x			(see sheet 1 of 7)	
		Atmospheric pressure	f=f(t)	11	30 min	750 → 1050 hP	± 5 hP	x		x			x	x				x				
	Plant	Temperature on leaf	f=f(t,x,y,z)	12	30 min	-10 → +60°C	± 0.1°C	x		x			x	x			x	x			x	Conventional micro temocouppple (IR sensor)
		Turgor potential of leaf	f=f(t,x,y,z)	13	30 min	0 → 2000 μm	± 1 μm	x		x			x		x			x	x		(Group D)	
		Leaf nitric oxide production	f=f(t,x,y,z)	14	30 min	0 → 10 $\mu mol \cdot cm^{-2} \cdot s^{-1}$ (*)	± 0.1 $\mu mol \cdot cm^{-2} \cdot s^{-1}$ (*)	x		x			x		x				x		(see sheet 1 of 7)	
		Leaf CO2 production	f=f(t,x,y,z)	15	30 min	0 → 2000 ppm	± 1 ppm	x		x			x	x				x				
		Leaf oxygen production	f=f(t,x,y,z)	16	30 min	0 → 100% *or* 0 → 20 $\mu mol \cdot cm^{-2} \cdot s^{-1}$	± 1% *or* ± 0.1 $\mu mol \cdot cm^{-2} \cdot s^{-1}$	x		x			x	x				x				
		Oxigen concentration in trunk	f=f(t,x,y,z)	17	30 min			x		x			x	x				x			x (Group E)	Optical fibre sensor www.oceanoptics.com/homepage.asp
		Xylem flux on root	f=f(t,x,y,z)	18	30 min	0 → +1000 μV	± 10 μV	x		x			x	x				x				Sap flow sensors (based on "granite" methodology, 1987)
		Xylem flux on cordon	f=f(t,x,y,z)	19	30 min	0 → +1000 μV	± 10 μV	x		x			x	x				x				
		Xylem flux on shoot	f=f(t,x,y,z)	20	30 min	0 → +1000 μV	± 10 μV	x		x			x	x				x			x (Group E)	
		Diametral growth of the shoot	f=f(t,x,y,z)	21	30 min	0 → 25 mm	± 0.1 mm	x		x			x	x				x	x		(see sheet 1 0f 7)	LVDT (Linear Variable Differential Transformer) sensor or Stem Microvariation Sensor, ...
		Grape colour variation	f=f(t,x,y,z)	22	Daily	Video monitoring of the cluster		x		x			x	x		x				x	x (Group F)	Digital image manipolation
		video monitoring	f=f(t,x,y,z)	23	30 min			x		x			x	x							(see sheet 1 of 7)	Videocamera
		Toxigenic Fungi (peronospora, oidio and botrite)																				

Table Ib: Sensor Matrix for Wine Chain: Vineyard; cont'd

In addition, during the ripening (**)	Grape	pH	f=f(t,x,y,z)		daily	1 → 5	0.01	x		x			x	x		x		x			(see sheet 2 of 7)	Optical fibre sensor www.oceanoptics.com/homepage.asp
		Total sugar	f=f(t,x,y,z)		daily	150 → 280 g·l^{-1}	± 2 g·l^{-1}		x	x			x		x			x				Babo densimeter, refractometric analisys, Fehling methodology (chemical
		Colour	f=f(t,x,y,z)		weekly	?	?		x	x			x		x			x				Lab test: Glories methodology
		Polyphenols	f=f(t,x,y,z)		weekly	?	?		x	x			x		x			x				Folin index (spectrophotometric detection)
		Anthocyanins	f=f(t,x,y,z)		weekly	?	?		x	x			x		x			x				spectrophotometric detection
		Total acidity	f=f(t,x,y,z)		weekly	1 → 5	0.01		x	x			x		x			x				Titration
		Tartaric Acid	f=f(t,x,y,z)		weekly	0 → 300 meq·l^{-1} *or* 0 → 30 g·l^{-1}	1 meq·l^{-1} *or* 0.1 g·l^{-1}		x	x			x		x			x				Spectrophotometric analisys/ HPLC
		Malic Acid	f=f(t,x,y,z)		weekly	0 → 600 meq·l^{-1} *or* 0 → 60 g·l^{-1}	1 meq·l^{-1} *or* 0.1 g·l^{-1}		x	x			x		x			x				Enzymatic methodology / HPLC

Table II: Sensor Matrix for Wine Chain: Cellar

ID	Food chain step		Target	Variable (t): time (x,y,z): spatial coordinates K: constant	Acquiring time for continuous monitoring (f=f(t))	Measure range	Sensibility	Autonomous system		Fixed position		Auto localisation capabilities		Are available commercial sensors?		Are available commercial multisensors device?		Technical choice				Convetional methodology or device of detection
																		Sensor		Multisensors device		
								Yes	No	Yes	No	yes	No	Yes	No	Yes	No	Use of commercial sensor	Development new sensor	Use of a commercial multisensor device	Integration into a multisensors device AmI compliant	
24	Cellar	Must	Colour	f=k	1 acquisition	?	?		x	x			x		x				x			Lab test, Glories methodology
25			Polyphenols	f=k	1 acquisition	?	?		x	x			x		x				x			Folin index (spectrophotometric detection)
26			Anthocyanins	f=k	1 acquisition	?	?		x	x			x		x				x			spectrophotometric detection
27			Total sugar	f=k	1 acquisition	150 → 280 $g \cdot l^{-1}$	± 2 $g \cdot l^{-1}$		x	x			x		x				x			"Babo" densimeter, refractometric analisys, Feeling methodology (chemical analisys)
28			pH	f=k	1 acquisition	1 → 5	0.01		x	x			x	x				x				Optical fibre sensor www.oceanoptics.com/homepage.asp
29			Total acidity	f=k	1 acquisition	1 → 5	0.01		x	x			x		x				x			Titration
30			Tartaric Acid	f=k	1 acquisition	0 → 300 $meq \cdot l^{-1}$ *or* 0 → 30 $g \cdot l^{-1}$	1 $meq \cdot l^{-1}$ *or* 0.1 $g \cdot l^{-1}$		x	x			x		x				x			x (Group G) (see sheet 3 of 7)	Spectrophotometric analisys/ HPLC
31			Malic Acid	f=k	1 acquisition	0 → 600 $meq \cdot l^{-1}$ *or* 0 → 60 $g \cdot l^{-1}$	1 $meq \cdot l^{-1}$ *or* 0.1 $g \cdot l^{-1}$		x	x			x		x				x				Enzymatic methodology / HPLC
32			APA (azoto prontamente assimilabile)	f=k	1 acquisition	0 → 1000 $mg \cdot l^{-1}$	1 $mg \cdot l^{-1}$		x	x			x		x				x				Sorensen Methodology
33			Mycotoxin (Ocratoxin A *or* OTA)	f=k	1 acquisition	0 →10 $\mu g \cdot Kg^{-1}$ *or* ppb	0.5 $\mu g \cdot Kg^{-1}$ *or* ppb		x	x			x		x				x				HPLC (fluorescent detector)
34			Pesticides (1)	f=k	1 acquisition	?	?		x	x			x		x				x				
35			Copper (Cu++)	f=k	1 acquisition	0 → 2 $mg \cdot l^{-1}$	0.1 $mg \cdot l^{-1}$		x	x			x		x				x				
36		Fermentation	Ambient Temperature	f=f(t)	30 min	-40 → +60°C	± 0.1°C	x		x			x	x				x					Conventional micro temocouppple
37			Must temperature	f=f(t)	30 min	-40 → +60°C	± 0.1°C	x		x			x	x				x					Conventional micro temocouppple
38			pH	f=f(t)	30 min	1 → 5	0.01	x		x			x	x				x					Optical fibre sensor www.oceanoptics.com/homepage.asp
39			CO2	f=f(t)	30 min	0 → 5000 ppm	± 100 ppm	x		x			x	x				x					IR sensor
40			O2	f=f(t)	30 min	0 → 100 %	± 0.2 %	x		x			x	x			x	x				x (Group H) (see sheet 4 of 7)	Optical fibre sensor (ie.g.FOXY-AL300, www.oceanoptics.com/homepage.asp)
41			Ethanol	f=f(t)	30 min	0 → 20 % vol	± 0.1 % vol	x		x			x		x				x				Lab test
42			Total Sugar	f=f(t)	30 min	150 → 280 $g \cdot l^{-1}$	± 2 $g \cdot l^{-1}$	x		x			x	x				x					spectrophotometric detection
43			SO2	f=f(t)	30 min			x		x			x	x				x					
44		Ante barrel	Colour	f=k	1 acquisition	?	?		x	x			x		x				x			Lab test, Glories methodology
45			polyphenols	f=k	1 acquisition	?	?		x	x			x		x				x			Folin index (spectrophotometric detection)
46			Anthocyanins	f=k	1 acquisition	?	?		x	x			x		x				x			spectrophotometric detection
47			Ethanol	f=k	1 acquisition	0 → 20 % vol	± 0.1 % vol		x	x			x		x				x			Lab test
48			Total sugar	f=k	1 acquisition	150 → 280 $g \cdot l^{-1}$	± 2 $g \cdot l^{-1}$		x	x			x	x					x			"Babo" densimeter, refractometric analisys, Feeling methodology (chemical analisys)
49			pH	f=k	1 acquisition	1 → 5	0.01		x	x			x	x			x	x				x (Group G) (see sheet 5 of 7)	Optical fibre sensor www.oceanoptics.com/homepage.asp
50			Tartaric Acid	f=k	1 acquisition	0 → 300 $meq \cdot l^{-1}$ *or* 0 → 30 $g \cdot l^{-1}$	1 $meq \cdot l^{-1}$ *or* 0.1 $g \cdot l^{-1}$		x	x			x		x				x				Spectrophotometric analisys/ HPLC
51			Volatic acidity	f=k	1 acquisition	0 → 2 $g \cdot l^{-1}$	0.05 $g \cdot l^{-1}$		x	x			x		x				x				titration
52			Total SO_2	f=k	1 acquisition	0 → 500 $mg \cdot l^{-1}$	10 $mg \cdot l^{-1}$		x	x			x	x				x					Lab analisys
52			Mycotoxin (Ocratoxin)	f=k	1 acquisition	0 →10 $\mu g \cdot Kg^{-1}$ *or* ppb	0.5 $\mu g \cdot Kg^{-1}$ *or* ppb		x	x			x		x				x				HPLC (fluorescent detector)
54			Pesticides (1)	f=k	1 acquisition	?	?		x	x			x		x				x				
55			Copper (Cu++)		1 acquisition	0 → 2 $mg \cdot l^{-1}$	0.1 $mg \cdot l^{-1}$		x	x			x		x				x				
56		Ageing	Temperature	f=f(t)	30 min	-40 → +60°C	± 0.1°C	x		x			x	x				x					Conventional micro humidity sensor
57			Relative humidity	f=f(t)	30 min	0 → 100%	± 3%	x		x			x	x				x				x (Group I) (see sheet 6 of 7)	Conventional micro temocouppple
58			Illumination intensity	f=f(t)	30 min	0 → 1800 $W \cdot m^{-2}$	± 10 $W \cdot m^{-2}$	x		x			x	x				x					Conventional micro diode

Table III:

Active substance	TYPOLOGY	LMR mg/Kg (=p.p.m.)
Bromuconazol	fungicide	0.2
Buprofezin	insecticide	0.5
Ciproconazolo	fungicide	0.02
Dietofencarb	fungicide	0.3
Etefon	phytoregolator	1
Fenazaquin	acaricide	0.01
Miclobutanil	fungicide	0.1
Procimidone	fungicide	0.5
Pyrimethanil	fungicide	2
Tebufenozide	insecticide	0.1
Tebufenpirad	acaricide	0.1

Table IV: Sensor Matrix for Wine Chain: Post wine bottling phase

Food chain step	ID	Measurement Target	Variable (t): time (x,y,z): spatial coordinate	Acquiring time for continuous monitoring (f=f(t))	Measure range	Sensibility	Autonomous system		Fixed position		Auto localisation capabilities		Are available commercial sensors?		Are available commercial multisensors device?		Technical choice				Convetional methodology or device of detection
																	Sensor		Multisensors device		
							Yes	No	Yes	No	yes	No	Yes	No	Yes	No	Use of commercial sensor	Development new sensor	Use of a commercial multisensor device	Integration into a multisensors device AmI compliant	
Post wine bottling phase (cellar, transportation, shelf)	59	Temperature	f=f(t)	30 min	-40 → +60°C	± 0.1°C	x		x			x	x				x			x Group (I) (see sheet 7 of 7)	Conventional micro humidity sensor
	60	Relative humidity	f=f(t)	30 min	0 → 100%	± 3%	x		x			x	x				x				Conventional micro temocoupple
	61	Illumination intensity	f=f(t)	30 min	0 → 1800 $W \cdot m^{-2}$	± 10 $W \cdot m^{-2}$	x		x			x	x				x				Conventional micro diode


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4.6 Pilot site

The Montepaldi farm is an exclusive property of the University of Florence and it is in use by Agriculture Faculty for educational, trial and research activities ,as a consequence it has been chosen as location for Good Food WP7 pilot site.

The farm

The farmland spreads over an area of 320 hectares, all within the area of Chianti, within the municipal area of San Casciano Val di Pesa (lat: 11°09'E - long: 43°40'N) and is about 20 kilometres south of Florence. Its altitude ranges between 300 and 450 metres above sea level. The main core of the property encircles the rinascimental villa, on a plateau that descends southwest towards the Pesa river.

Vineyards and the olive groves are the main types of cultivation on this farmland, the remaining property is mainly covered by woods.



Figure 2: Montepaldi Farm

The grapes

The vineyards that belong to Montepaldi spread over 41 hectares, most of which (32) have been designated as Chianti Classico DOCG. The remaining hectares belong to Igt Toscana. It is worth noting that the main part of the land planted with vineyards has Sangiovese vines. The prince of all Chianti vines, Sangiovese represents the focal point of Montepaldi, and it is not only at the heart of wine-making here. It is also the focus of any research work carried out at Montepaldi.

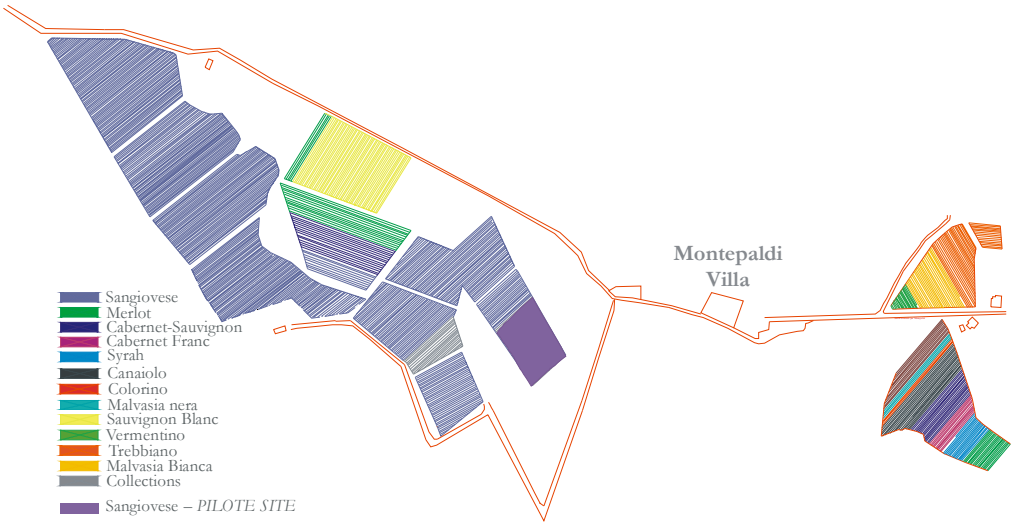


Figure 3: The grapes

The pilot site

The area chosen for the AmI infrastructure concerning the Good-Food project embodies suitable characteristics for the project aims. The vineyard, 1 hectare wide, has been established in 1997 with Sangiovese grafted on 420A (Vitis berlandieri x Vitis riparia), south west exposed. Vines are trained on 0.7 m high vertical trellis system, cane pruned, 2.8 x 0.9 m spaced (3970 vines/hectare).



Figure 4: One of Montepaldi vineyards

Mesoscale site selection, the soil:

The soil, one of the fundamental considerations in the choice of the pilot site, is a typical sedimentary origin terrain. In general these kinds of soil are substantially clay made up of limestone and marl, resulting from the disintegration of limestone and some kind of shale made of clay typical to Tuscany, and they rest on sandstone.

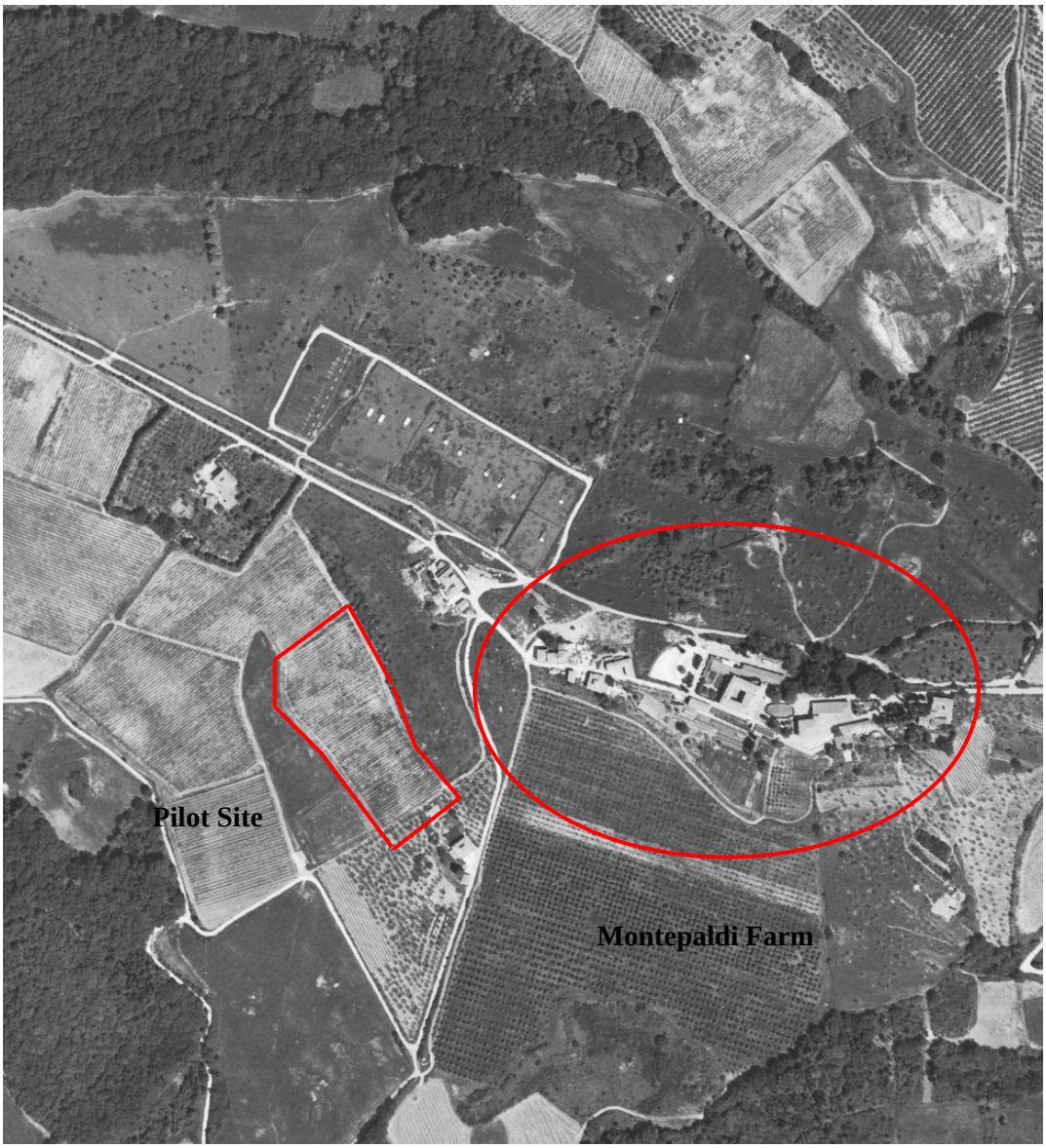


Figure 4: Montepaldi area and Pilot Site

From a physical point of view, this sedimentary terrain (whose origin probably belongs to the superior Pliocene, 2 million years ago) consists of a mixture of average density, rich in "skeletal" material (the coarse stone component).

In particular, the pilote site soil texture shows transversal irregularities, mainly concerning the percentage and size of "skeleton", determining two main different root zone conditions, since skeleton makes for a good water rationing system and abundant airing of the terrain, both conditions necessary for the proliferation of micro-organisms, whose activity in the soil is fundamental for correct and healthy plant growth.

Mesoscale site selection, Elevation and topography:

The vineyard is located in the higher farm slope, whose considerable degree implies different elevations. Elevation has a profound influence on the minimum and maximum temperatures in a vineyard, particularly in hilly and mountainous terrain. Because frosts and freezing temperatures can so dramatically reduce vineyard profitability, elevation is one of the most - perhaps the most - important feature of vineyard site suitability.

The physics of topographic effects on air temperature are well documented and its horticultural significance generally well appreciated. Under radiational cooling conditions, with calm winds and clear skies, the earth loses heat to space and cools the adjacent layer of air. If the vineyard is on a slope, the cold, relatively dense air moves downhill.

The sinking, cold air displaces warmer air to higher elevations producing thermal inversions and thermal belts. Above these relatively warm belts, air temperature again decreases of 16°C/300 meters of increase in elevation.

The sinking, cold air collects in low-lying areas and can create frost pockets. Generally, the steeper the slope, the faster cold air will drain downhill, assuming there are no barriers to air movement. Land slope also is important for surface and, to some extent, internal soil water drainage. As discussed later, surface and internal soil drainage are extremely important, and a slope is conducive to these movements

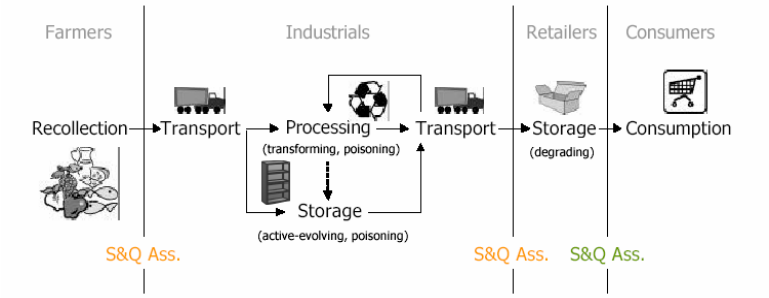
4.7 Definition of user's need and requirement for other food-chain

The exploitation and scalability of the above described methodology to the other food chains, require the definition of suitable scenarios, user's needs and requirements. In order to simplify the procedure, an instrument has developed in the form of a survey document, a questioner to be filled by the responsible of the others food chains (WP1-WP6), in strong collaboration with experts of the field and technicians (sensor developer).

It consists in the starting point for the definition of the general requirements for an "open" AmI structure applying to generic food chains

Section 1:Food chain description

Specify the food chain target (e.g. fruit, fish, milk and dairy products, wine)



List the steps of the food chain (please refer to the above figure)
Farmers

_____
_____
_____
_____

Industrial

_____
_____
_____
_____

Retailers

_____
_____
_____
_____

Consumers

_____
_____
_____
_____

Section 2: Food chain step information
[This section must be compiled for each food chain step]

Specify the food chain step

_____
_____

Insert the name or give a brief description of the food at this step

_____
_____
_____
_____

Specify the food phase

❒ solid ❒ liquid

Specify the target to be addressed

Physical parameters

_____

_____

_____

Antibiotics detection

_____

_____

_____

Pesticides detection

_____

_____

_____

Mycotoxins and toxigenic fungae detection

_____

_____

_____

Pathogens detection

_____

_____

_____

Chemicals

_____

_____

_____
__
Foodstuff emissions monitoring

_____
__
_____
__
_____
__
Ambient monitoring

_____
__
_____
__
_____
__

Specify the sensor density (sensor number for area/volume unit)

_____
__
_____
__
_____
__

Identify the involved actors

_____
__
_____
__
_____
__

Section 3: Sensors/targets
[This section must be compiled for each sensor/target]

General information

Specify the measure place/environment

_____

Has the sensor a fixed position?

❒ YES ❒ NO

If significant, the sensor spatial coordinates/position and the reference

_____
__

Is a weapon environment?

❒ YES ❒ NO

If YES please specify the type of wear

❒ mechanical

❒ physical

❒ chemical

_____
__

Specify the sensor packaging required to operate in the selected environment

_____
_____
____

Specify other requirements related to the sensor capability to operate in the selected environment (mechanical/physical/chemical strength)

_____
_____
_____
_____

Describe the conventional methodology or device use for the detection (state of the art)

_____
_____
_____
_____
_____

Are available commercial sensors/devices?

❒ YES ❒ NO

If not available, will the sensor/device be developed within the project?

❒ YES ❒ NO

If YES, the sensor will be developed:

❒ within the consortium (Specify the partner name_____)

❒ by external (Specify the external name _____)

Specify the sensor dimensional feature (*)

Size _____

Volume _____

Weight _____

Shape _____

The system is autonomous (an autonomous system does not require the operator activity)? (*)

❒ YES ❒ NO

Performance

Specify the sensor measure range (**)

_____

Specify the sensor sensibility (**)

_____

Specify the type of monitoring (**)

❒ continuous ❒ punctual

In the case of continuous monitoring specify the acquiring time_____

AmI requirements

Specify the type of interface (*)

❒ Analogical

❒ conditioned output (specify type and range _____)

❒ non conditioned output (specify type and range _____)

❒ Digital

❒ parallel output (specify type _____)

❒ serial output (specify type _____)

❒ Other

_____

_____
_____
_____
_____
_____
_____

Specify the power need source (*)

❒ On board ❒ From the node of the network

Specify the power need from the node of the network

Tension _____

Current _____

Are man-assisted operations for sensor maintenance necessary?

❒ YES ❒ NO

If YES please specify the frequency _____

Does the sensor work in the sleep and wake-up operation mode? (*)

❒ YES ❒ NO

Will the sensor/device be physically connected to the network node? (*)

❒ YES ❒ NO

Does the sensor/device have some kind of on-board intelligence (microprocessor,...)? (*)

❒ YES ❒ NO

Comments_____
_____
_____

Does the measure require auto localisation capabilities?

❒ YES ❒ NO

Comments_____
_____
_____
_____
_____

(*) For commercial sensors refer to factory specifications, for developed sensors refer to planned specifications.

(**) For commercial sensors refer to factory specification, for developed sensors refer to planned specifications, otherwise specify the food chain step need/requirement.

Appendix

Wireless Sensor Network State of the Art

5 Wireless communication infrastructure and related issues

5.1 Wireless Sensor Network overview

Many typical monitoring applications are implemented through ad-hoc deployments of wired, high-precision sensors. The high cost of the hardware and the complexity of the wiring process set a practical limitation to the number of sensors that can be used, resulting in systems with a low fault tolerance and a reduced flexibility. Lately, the availability of low cost sensors and chips for wireless communication allow to consider a new approach in the design of monitoring applications.

A Wireless Sensor Network is a monitoring infrastructure with distributed sensing and processing capability; it can be usefully implemented for environmental monitoring, home automation, military and industrial applications. Its characterization is closely related to specific application requirement, due to the restrictions on two basic resources, energy and communication bandwidth: this often forces a trade-off on system performances and features. However, these technological limits could be significantly reduced by optimising communication protocols and networking strategies, and calibrating their parameters to single application requirements – i.e. number of nodes, topological and topographic configuration, real-time and ambient constrains.

Furthermore, node density is a crucial parameter: higher node density could cause redundant data, interference on radio communication, or increase network latency; on the other hand, lowering the node density could require to increase the radio communication range, and could cause energy waste.

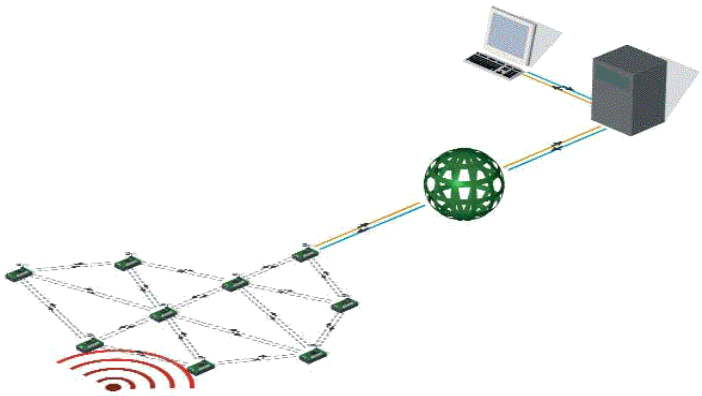


Figure 5: A network of wireless nodes interfaced to the external world through a gateway

Wireless Sensor Networks are composed of nodes (also called Pods or Motes) that communicate and exchange data using radio links. Each node is a battery-powered system consisting of a board with a microcontroller, a memory unit for data storage and a transceiver for communications. In addition to the basic hardware, a variable number of sensors can be connected in order to provide the node with the necessary monitoring functionalities. Data read from the sensors is internally routed through the nodes of the network to a gateway for post processing. The unwired nature of this approach makes it particularly suitable

every time flexibility and scalability are key requirements for the problem to solve. In fact, nodes can be easily repositioned, added or removed from network, depending on the needs of the application.

The typical purpose of a Wireless Sensor Network is to sense an environment and report collected data to the users, minimizing deployment and maintenance costs and offering highest operational flexibility. Moreover, significant improvements in the software procedures implemented in the nodes, make possible to realize more complex systems, offering many of the following features:

- expanded area coverage and node density, with multi-hop routing protocols: data is transmitted across the network and each node has routing capabilities, thanks to increasing computational and storage performances offered by embedded microcontrollers; this results in extending the total area coverage while reducing transmitting power.

- distributed data processing, cooperative event responsiveness and resource sharing: complex software procedures could be implemented and customized, to improve overall system performances and offer refined user interaction methods; the common approach is to enforce data pre-processing, adopting distributed computing procedures, where it allows lower power resources consumption. Furthermore, combining and aggregating the different "views", obtained from each node, allows more accurate analysis of the monitored environment. [iii, iv]

- easy deployment, fault tolerance and system robustness, implementing self-organizing network nodes: advanced network layer procedures and routing protocols help to minimize user operations either during node deployment and responding to partial system failure; moreover, application specific mobile or semi-mobile features could be generally integrated. [v]

- data-driven operations: to reduce power consumption, nodes and sensors are normally in a sleep or in idle state; this is, they should resume and transmit sensed data only when particular conditions are met (i.e. values exceed a threshold), and their sampling interval could be dependent on neighbours' reported measures and operating conditions. [vi]

Collected data is usually transmitted, through dedicated gateways, to remote servers, where it is stored, processed and presented to the users; therefore, user interaction is mainly provided by remote server interface (i.e. web interface), even if specific applications could request direct user interaction with local nodes/units: in this case, improved ad-hoc networking protocols should be considered to satisfy on-the-field user mobility requirements.

5.2 RF module technical overview

Wireless data transmission among network nodes is usually managed by a transceiver radio chip that operates on non-licensed ISM frequencies (i.e. 433 or 868 MHz in Europe, 916 MHz in the US). The transceiver is responsible for the management of the communication protocol physical layer; it dictates the modulation used for bits transmission, the output power and the receiving sensitivity. RF module should support different data rate and could able to dynamically select best data rate depending on packet error rate. RF module could be able to operate between 4800 bits/sec and 152kbits/sec. The RF module should also support different out power levels up to 15dbm and automatically decide on best output power for reliable communication and to extend the life of battery. RF module should have at least -110dbm sensitivity at 4800 bits/sec with a BER (bit error rate) 0.1%. RF module should operate either with 3xAA size battery or 1 single Lithium battery. The service life of battery is normally 1 year.

Anyway, where application consists of a large number of close nodes that exchange small data packets, the output power and the bit rate of the chip are kept low in order to minimize power consumption. The RF modulation is generally wide band FSK for constant envelope RF signal, which makes possible to design efficient RF power amplifiers to extend the battery life. This scheme makes it possible to use of single chip solutions for low cost compact size designs and use of future all in one IC solutions, which also includes RF integrated circuits with sensor.

Radio systems and are ruled by the national governmental regulations. For industrial, scientific, and medical (ISM) applications, frequency bands are allocated. Keeping the limits concerning bandwidth and the effective isotropically radiated power (EIRP), the rules for short range devices (SRD) and low power devices (LPD) with reduced licensing requirements can be applied. In Europe, the limits of operation of radio sensors can be found in the ETSI CEPT/ERC 70-03 regulations EN300330 (9 kHz to 25 MHz), EN300220 (25 MHz to 1 GHz), and EN300440 (1 to 25 GHz).

According to ETSI CEPT/ERC Recommendation 70-03, which describes the use of short range devices in Europe, the ISM frequency band should either lie in 433 MHz, 868 MHz or 2.4 GHz. The 433 MHz band operation requires bigger antenna size than 868 MHz band, which avoids compact designs. The RF module should also satisfy the ETSI EN 300-220, Electromagnetic compatibility and Radio spectrum Matters (ERM) for Short Range Devices (SRD). Moreover, the ERC Recommendation 70-03 limits the output power and duty cycle of the transmission and the output power. The radiated power is measured in ERP (effective radiated power) which includes antenna gain. Therefore maximum radiated power from the antenna is limited to 25mW or 14dbm.

This limitation forces to use fixed antenna (not user replaceable) since during conformance tests antenna gain is part of the measurement. In RF module design, to improve and maintain the communication range, mechanically orientation adjustable quarter wave antenna could be also used.

Usually, proprietary wireless systems were developed for applications that do not require high data rates, but do require low cost and very low current drain. These proprietary systems commonly use lower ISM frequency bands (433 MHz

or 868 MHz), and were designed because there were no standards that met their requirements.

Obviously, these legacy systems are creating significant interoperability problems with each other and with newer technologies.

In the ISM 2.4 GHz band, there are instead a multitude of standards that address mid to high data rates for voice, PC LANs, video, etc. However, up to now, there has not been a wireless network standard that meets the unique needs of sensors and control devices. Sensors and controls do not need high bandwidth but they do need low latency and very low energy consumption for long battery lives and for large device arrays.

A comparison of the properties of these standards is presented below. The standard IEEE 802.15.4 (also known as ZigBee) appears in the first column and will be described in the next section, as one of the most suited choice for high data rate Wireless Sensor Network applications.

	802.15.4	802.15.1	802.11b	802.11g	802.11a	802.15.3	802.15.3a
Standard Version/status	IEEE approved	V1.1 (Low-rate)	IEEE approved	IEEE approved	IEEE approved	Draft	Draft IEEE 802.15.3a
Max. data rate	250 kbps 40 kbps 20 kbps	1 Mbps	11 Mbps	54 Mbps	24 Mbps mandatory; 54 Mbps optional	11 Mbps (QPSK) 55 Mbps	110 Mbps (10m) 200 Mbps (4m)
Avg. distance	10-30 m	10 m	100 m	100 m	50 m	10 m	10 m
Frequency allocation	868-868.6 MHz; 902-928 MHz; 2400-2483.5 MHz	2.4 GHz (ISM)	2.4 GHz (ISM)	2.4 GHz (ISM)	5 GHz UNII (5.15-5.35 + 5.725 – 5.825) GHz	2.4 GHz (ISM) 2.4 – 2.4835 GHz	3.1 – 10.6 GHz
Channel bandwidth	0.3 MHz; 0.6 MHz (2 MHz spacing); 2 MHz	1 MHz	25 MHz	25 MHz	20 MHz	15 MHz	Min. 500 MHz Max. 7.5 GHz
Number of RF channels	1; 10; 16	79	3	3	12 US. 8 EU 4 Japan	5	1 – 15
Modulation type	BPSK; OQPSK	GFSK	11 Mbaud QPSK	OFDM (64+CCK (legacy)	COFDM PSK QPSK, 16 QAM	DQPSK 16/32/64 QAM	BPSK, QPSK
Spreading	DS-SS	DS-FH	CCK	OFDM	OFDM		Multiband
Maximum allowed RF power	US: 1W+6dB antenna gain (FCC 15.247); EU: (868 MHz) ERC70-03E: 25mW if duty cycle < 1% in 1 hour.	0 dBm 20 dBm	US: 30 dBm EU: 20 dBm Japan: 10 dBm	US: 30 dBm EU: 20 dBm Japan: 10 dBm	50 mW; 250 mW; 1-watt (depending on the used channels within the band)	US: 50 mV/m EU: 100 mW² EIRP (ETS 300-328) Japan: 10 mW (ARIB STD-T66)	-41.3dBm/MHz (Max average EIRP over entire band = 0.562 mW) (FCC First Report and Order: Part 15 ET Docket 98-153)
Required receiver sensitivity	-85 dBm PER < 1%	-70 dBm BER < 10^{-3}	–76 dBm	From –76 dBm to –74 dBm	From –82 dBm (6 Mbps) to – 65 dBm (54 Mbps)	From –82 dBm (DQPSK) to – 68 dBm (64 QAM)	
Approx. power consumption	< BT	BT (–40 – 100mW)	–4BT	–4BT	–6BT		(–2-3BT)
Approximate cost	– 0.5 BT	BT (– $5)	– 4BT	–4BT	–5BT		–1 to 2 BT

Table 4 : Comparison of different IEEE 802 standards.

The ZigBee physical layer was designed to accommodate the need for a low cost yet allowing for high levels of integration. The use of direct sequence allows the analogue circuitry to be very simple and very tolerant towards inexpensive implementations. The media access control (MAC) layer was designed to allow multiple topologies without complexity. The power management operation doesn't require multiple modes of operation. The MAC allows a reduced functionality device (RFD) that need not have flash nor large amounts of ROM or

RAM. The MAC was designed to handle large numbers of devices without requiring them to be "parked". The network layer has been designed to allow the network to spatially grow without requiring high power transmitters. The network layer also can handle large amounts of nodes with relatively low latencies.

ZigBee is poised to become the global control/sensor network standard. Wireless sensors are expected to be the main driver of this technology. Among the various applications we may find.

- SCADA (supervisory control an data acquisition): manufacturing, shipping, warehouse,
- Precision agriculture: irrigation, wineries
- Healthcare: home health monitoring, in-hospital monitoring
- In-building: HVAC, lighting, security
- Homeland Security: shipping, transportation

It has been designed to provide the following features:

Low power consumption: Users expect batteries to last many months to years! Consider that a typical single family house has about 6 smoke/CO detectors. If the batteries for each one only lasted six months, the home owner would be replacing batteries every month. Bluetooth has many different modes and states depending upon your latency and power requirements such as sniff, park, hold, active, etc.; ZigBee/IEEE 802.15.4 has active (transmit/receive) or sleep. Application software needs to focus on the application, not on which power mode is optimum for each aspect of operation. Even mains powered equipment needs to be conscious of energy. Consider a future home with 100 wireless control/sensor devices,

Case 1: 802.11 Rx power is 667 mW (always on)@ 100 devices/home & 50,000 homes/city = 3.33 megawatts

Case 2: 802.15.4 Rx power is 30 mW (always on)@ 100 devices/home & 50,000 homes/city = 150 kilowatts

Case 3: 802.15.4 power cycled at .1% (typical duty cycle) = 150 watts.

Low cost (device, installation, maintenance): Low cost to the users means low device cost, low installation cost and low maintenance. ZigBee devices allow batteries to last up to years using primary cells (low cost) without any chargers (low cost and easy installation). ZigBee's simplicity allows for inherent configuration and redundancy of network devices provides low maintenance.

High density of nodes per network: ZigBee's use of the IEEE 802.15.4 PHY and MAC allows networks to handle any number of devices. This attribute is critical for massive sensor arrays and control networks.

Simple protocol, global implementation: ZigBee's protocol code stack is estimated to be about 1/4th of Bluetooth's or 802.11's. Simplicity is essential to cost, interoperability, and maintenance. The IEEE 802.15.4 PHY adopted by ZigBee has been designed for the 868 MHz band in Europe, the 915 MHz band in North America, Australia, etc; and the 2.4 GHz band is now recognized to be a global band accepted in almost all countries.

One of the most important factors for a high data rate sensor based network is the battery operation of the node. According to the mode of operation of the sensor system, the ZigBee offers several advantages in terms of power consumption. The Bluetooth standard is primarily designed to maximize ad-hoc functionalities whereas ZigBee is designed to optimize slave power requirements. The IEEE 802.15.4 (ZigBee) standard uses a CSMA-CA protocol which means that the end nodes wake up only when they have data to send. The benefits are:

- No waiting for polling (however they must wait for a clear channel which shouldn't be a problem in low duty cycle networks such as with sensor and control devices).
- Current drain is substantially reduced over a polling protocol that must poll to maintain latencies even though the majority of the time the device needed be polled.

ZigBee devices can be quickly attached to the network for the exchange information. Once detached they can be put in a 'deep sleep' mode of operation in order to achieve a very long battery life (about 2 years or more for 'normal' batteries). Bluetooth devices require about 100 times more energy for this operation. The power model is based on a regular charging like mobile phones.

5.3 Hardware implementation and Operative Systems

Each network node includes all the hardware and software resources to interact with the sensors, elaborate the data and transmit the results through the radio link.

All these functionalities must be accomplished with minimum power consumption, so the adoption of extremely low power architectures is mandatory. Data elaboration and communication protocol management are often carried out using one or more microcontrollers, a class of programmable devices widely used in control and automation applications. Although a microcontroller (MCU) offers reduced data elaboration and memory resources, especially if compared to those of CPUs used in desktop PC, the use of microcontrollers is particularly suitable for the design of deeply embedded systems.

Packaged inside a small footprint chip, a microcontroller consist of a CPU for instructions execution, a non-volatile memory (e.g. EEPROM or FLASH) for program storage and limited amount of RAM for data processing. In addition to this, a MCU also posses additional modules such as hardware timers and counters for fine time management, communication modules (e.g. UART, I2C, SPI), ADC input for analog values conversion and a number of general purpose I/O lines to interact with other digital components. The use of microcontrollers in the design of nodes permits to build compact embedded systems with a reduced number of external components, as requested by the size and power consumption constraints of sensor networks applications. Battery life can be further extended by putting the MCU in idle mode when data elaboration is not required. Power requirements of MCU can be reduced up to some hundred folds when the idle mode is enabled. Generally, an efficient use of the microcontroller

should embrace the philosophy of getting the work done as quickly as possible and going to sleep.

Since a microcontroller has a limited amount of internal memory, often an external memory module is used for data storage, for example to save sensors readings or to maintain routing tables used for multi-hop protocols. External memory can also serve for dynamical reprogramming of nodes: byte codes instructions can be sent to the node over the wireless link and stored in the external module. When the transmission of the new firmware is completed, the content of the MCU code memory can be replaced with the content of auxiliary memory (i.e. the new program).

The number and the type of sensors connected to each node are strictly related to the monitoring functionalities needed by the application. Analog sensors can be interfaced using the built-in ADC lines of the microcontrollers made available through a dedicated connector. Data acquisition from digital sensor can be instead performed using specific protocols like I2C, SPI or asynchronous serial communications.

In addition to sensors, network nodes can be connected to additional hardware components, such as GPS receivers for absolute positioning, sounder/microphone modules for distance measurements and various kinds of actuators.

6 Wireless Sensor Networks state of the art

In this section a brief review of major WSN implementations is reported; in particular, the commercially available MICA platform, proposed as the Trial Site hardware architecture, is also described.

The Smart Dust research project

One of the most relevant research activities on autonomous systems worldwide is the "Smart Dust" project at the University of Berkeley [vii]. In this project, the goal is to develop a system of wireless sensor modules where each unit is the size of a mote of dust. The work includes miniaturisation using die bonding, flip-chip, and wire bonding assembly sequences, integrated micro sensors, and computation, as well as line of sight wireless communication in a 5mm cube.

The next generation of 'Smart Dust' is currently undergoing laboratory prototype tests but does include an RF transmitter. The high level details are that it measures approx 2mm × 2.5mm, has an AVR-like RISC core on it, 3K of memory, 8 bit On-chip ADC, FSK radio transmitter, paged memory system, communication protocol accelerators, register windows, 32 KHz oscillator, SPI programming interface, RS232 compatible UART, 4-bit input port, 4-bit output port, encrypted communication hardware support [viii].

It runs the TinyOS operating system, which was also initiated as a research project at Berkeley, and has evolved into almost an industrial standard. It is an event based operating environment designed for use with embedded networked sensors. More specifically, it is designed to support the concurrency intensive operations required by networked sensors with minimal hardware requirements. There are hundreds of TinyOS projects throughout the world. The programming

language of TinyOS is stylized C that uses a custom compiler 'NesC'. SPINS is also implemented using TinyOS and NesC.

The "Disappearing Computer" initiative

Notable development work for distributed collaborative systems is taking place in the research area of robotics, and in the "Disappearing Computer" Initiative (EU IST Future and Emerging Technology Programme)[ix].

In the "Disappearing Computer" initiative, scaling and power aware computation techniques are being applied to development of solutions for distributed artefacts, which are everyday objects with embedded electronics. The nature of the individual artefacts is based upon the mobile computational units, such are the mobile phone, PDA, etc, and thus intelligent use of power and bandwidth are major issues. Again, the process of scaling is a major issue, in particular where dynamic and mobile services and functions are required of the distributed system of artefacts.

The use of component software forms, applied to units with both a tangible physical and digital presence, is one method under development to address this challenge.

In this project sensor networks were integrated into everyday objects such as tables, chairs using FPGA technology to interface the signals to PDAs with WLAN cards. The PDAs were running a Java based operating system called GAS-OS (Gadget Architecture Style) that allowed artefacts to be dynamically interconnected over the WLAN so that users could configure their own automated environment. For example in a study scenario if the chair is occupied, near the table and the table detects that a book is open upon it then the light could be synapsed to turn on.

"Secure and Intrusion Tolerant Wireless Sensor Networks", Colorado University

This project [x] is exploring a variety of security issues in Wireless Sensor Networks, including secure routing, secure in-network processing, and anonymity.

Security is essential to protect the routing infrastructure and packet data from threats such as eavesdropping, tampering, denial-of-service (DOS) attacks, and the physical compromise of sensor nodes deployed into enemy territory. The research challenge is to secure the routing infrastructure against such threats given the severe resource constraints imposed by Wireless Sensor Networks. While it has been demonstrated that symmetric key cryptography can be implemented on today's wireless sensor platforms, initial results indicate that public key cryptography remains out of reach for today's sensor networks due the compute-intensive nature of public key methods.

They have designed, implemented, and experimented with a protocol called INSENS (INtrusion-tolerant routing protocol for wireless SEnsor NetworkS). INSENS provides support for discovering the topology of a Wireless Sensor Network and building secure routing mechanisms in the presence of passive and active security attacks and compromised sensor nodes. This work has been extended to defend wireless sensor network base stations against denial-of-service attacks, as well as search and destroy attacks. In particular, a novel technique has been proposed to distribute trust in building a hierarchical wireless

sensor network, and provided support for secure, in-network data processing, a novel technique to address a replay-style, denial-of-service attack in secure and reliable end-to-end communication in wireless sensor networks.

This technique is based on one-way hash chains, and can potentially be used in the design of the next-generation, secure network protocols and algorithms. Confusion of address and identification fields in packet headers via hashing functions is explored as a technique to help disguise the location of the base station from eavesdroppers and relocation of the base station in the network topology is studied as a means of enhancing resiliency and mitigating the scope of damage.

MIT "Pushpin" Project

The Pushpin Computing project [xi] was started in 2000 and is currently headed by the Responsive Environments Group at the MIT Media Lab.

It is an attempt at realizing a scalable system that is able to incorporate processing and data sharing at the level of the sensors and actuators themselves, as biological systems usually do. In order to pursue this end several system-specific heuristics have been considered at first but eventually forming a more general theory. It was inspired in large part by Bill Butera's Paintable Computing simulation work and the programming model presented therein.

This project consists in a hardware and software platform primarily used for experimenting with distributed sensor networks. The platform currently consists of approximately 100 Pushpins inhabiting a 1.25m x 1.25m substrate.

Moreover, the hardware platform consists of many individual Pushpins. Each Pushpin is made up a power module, a communication module, a processing module, and an expansion module.

On the other hand, the software platform is equipped with the Pushpin Operating System (Bertha Release 4.0) and integrated with the Pushpin IDE and Debugging Tools. Furtherly, several testing codes, utilities, libraries, and examples are provided.

The MAI-AES team

The MAI-AES team was formed in May 2001, with the vision of creating hardware solutions for Europe's new vision in Ambient Intelligence (AmI). The team currently consists of twelve members, including three PhD level researchers, and three PhD postgraduates.

The goal of the MAI - Ambient Electronics Systems (AES) Team is to build the Intelligent Seed (I-Seed); the I-Seed is NMRC Institute's specification for future autonomous transducer nodes in the ubiquitous computational networks that will drive the vision of Ambient Intelligence (AmI).

In specific terms, the objectives are to:

- Create Innovative Interconnect Solutions for Highly Miniaturised I-Seed platforms, targeting effective functionality in modules between $5mm^3$ and $1mm^3$ in size.

- Create Innovative Assembly Solutions for Highly Miniaturised I-Seed platforms that incorporate sensing, actuation, computation, power, and communications for effective autonomous systems performance in ad-hoc network nodes.
- Develop novel versions of the I-Seed platform that permit the investigation of fundamental issues in the development of authentic and effective AmI hardware infrastructure.

To achieve this, a Workprogramme has been created with four parallel activities, focussed upon creating intelligent and collaborative autonomous sensors modules of decreasing sizes (25mm^3, 10mm^3, 5mm^3, and 1mm^3 nodes). The larger modules are the focus of collaborative study to investigate appropriate architectures (i.e. optimised sensing, actuation, computation, power, and communications subsystems), while the smaller modules are the focus of development for novel interconnect and assembly processes.

The 25mm cube module

To provide a novel 3-D programmable modular system that could be used as a toolkit for ambient systems research (such as robotics, autonomous agents and neural networks, telemetry, transducer networks, etc).

The target objectives for the 25mm cube module are to develop:

- A low volume prototyping and experimentation platform,
- A platform for sensing and actuating through physical and chemical parameters,
- A scalable, reconfigurable distributed autonomous sensing platform, and
- Intelligent, reconfigurable algorithms for scalable AmI Systems.

The first and second objectives incorporate the creation of a platform that is robust, available as a low volume prototype, and contains the ability to interface to a broad range of physical and chemical transducers. This will provide a foundation for the third deliverable, provision of functional low volume prototypes for implementation and evaluation in case study application areas. The fourth deliverable is a reconfigurable development tool for distributed autonomous transducer networks that are then to be investigated as a building block technology for ambient intelligence.

The 10mm cube module

The goal of this Workprogramme is to provide a novel and exploitable miniaturised 3-D programmable wireless system for use in transducer networks and related resource (including power and computing) constrained systems research.

The target objectives for the 10mm cube module are to develop:

- A functional wireless micro-transducer network,
- A platform for sensing and actuating through chemical parameters,
- A Test Platform for Performance Evaluation of 10mm Module Designs,
- Prototyping capability for modular 10mm systems.

The first two objectives incorporate the creation of a platform that is robust, available as an autonomous functional module, and contains the ability to interface to a number of physical transducers and one family of chemical transducer devices. The third objective provides a test platform for performance evaluation of the fabrication methodology in the context of future case study application requirements. The fourth deliverable will provide functional low volume prototypes for implementation and evaluation in case study application areas.

5mm cube module

This Workprogramme aims to create innovative integration and assembly solutions (including novel flex and silicon interconnect, research on novel connectors, etc) that demonstrate proof-of-concept of the viability of highly miniaturised 3-D programmable systems.

The target objectives for the 5mm cube module are to develop:

- A 5mm Cube 3-D Evaluation Test Vehicle Platform,
- Define and demonstrate an assembly procedure for manufacturing 5mm modules,
- A fully functional, modular wired micro-transducer demonstration platform,
- A research technology roadmap for constructing units and systems of 5mm modules

The first and second deliverables incorporate the creation of a platform for evaluation and assembly that is robust, and provides low volumes of test vehicle modules for performance evaluation. The third target will provide functional low volume prototypes, based upon a wired system for signal and power transfer, for implementation and evaluation in a case study application area. The final target will determine a roadmap for prototyping units, developing a core group of target metrics, including "system-functional-power-to-volume ratio".

1mm cube module

The ultimate aim within the NMRC Ambient Electronic Systems group is to create very highly miniaturised transducer systems and subsystems through the implementation of novel assembly and integration techniques (including 3-D silicon stacking and interconnect, novel silicon substrates, etc)

The target objectives for the 1mm cube module are to develop:

- A 1mm cube 3-D evaluation test vehicle platform,
- Define and demonstrate an assembly procedure for manufacturing 1mm modules,
- A functional module with size as close to 1mm as possible,
- Research technology roadmap for constructing units and systems of 1mm modules

The first and second targets incorporate the creation of a platform for evaluation and assembly that is robust, and provides low volumes of test vehicle modules for performance evaluation. The third deliverable will provide key functional elements for innovation, in particular acting as an investigative tool for deployment, and a benchmark for analysis of future systems. The novelty, and in particular the potential real impact of the innovation, will need to be measurable in a manner that clearly defines the added value, using metrics such as "system power to volume ratio".

Comparisons can be made with the MICA and Intel Motes when evaluating the NMRC 25mm module system.

Table 5: Comparison between 25mm Modules, Mica2 Mote and Intel® Mote

	NMRC 25mm (Preliminary)	MICA2 Mote	Intel® mote
PCB Area (mm^2)	25 x 25	58 x 32	30 x 30
Clock Speed (MHz)	4	7.3827	12
FPGA	Spartan IIE 300E	No	No
Microcontroller	ATMega128L(MLF)	ATMega128L(TQFP)	ZEEVO (ARM Core)
ADC channels	8	8	Planned for future motes
ADC resolution (bits)	10	10	
Power supply	Coin Cell 3V	2 x AA	Coin or AA
Hardware UART	2 (Microcontroller) + Multiple (FPGA)	2	1
USB	Planned	no	Slave
Expansion Connector Size (pins)	80 + 40 + 20 (Microcontroller)	51	21 + 9
Flash (kB)	128 + 524 (FPGA Config.)	128	512
SRAM (kB)	4 (Microcontroller) + 20 (FPGA) + Expansion Module planned	4	64

EEPROM (kB)	4	4	4
Processor current (mA)	5.5 (Microcontroller) + 20-30 (FPGA)	5.5	?
RF	Nordic nRF2401 (GFSK)	CC1000 (FSK)	Bluetooth
RF Data Rate (bps)	1 M	38.4 k	723.2 k
Radio Freq. (Hz)	2.4G	916M/433M	2.4G
RF Tx. current (mA)	10.5	25	?
RF Rx. current (mA)	18	8	?
RF Sleep current (mA)	1	1	?
Radio range (m)	10 (Low power mode)	300	30

UCLA – ASCWS Project [xii]

The Centre for Embedded Networked (CENS) Sensing is currently on four experimental application drivers:

- habitat monitoring for bio-complexity studies;
- spatially-dense seismic sensing and structure response;
- monitoring and modelling contaminant flows;
- detection and identification of marine micro-organisms.

To support this scope, CENS must combine the expertise of faculty from diverse engineering disciplines with the expertise of biological, environmental and earth scientists. During the lifetime of the Centre, it is expected to pursue additional opportunities for applying these technologies to other natural and engineered systems. However, the progress in the current application research areas is related to:

- Habitat Sensing Array;
- Seismic Monitoring and Structural Response;
- Contaminant Transport Monitoring;
- Marine Microorganisms.

Besides, CENS is involved in some projects concerning the sensor network management, that is the providing of an infrastructure able to detect the node failures, resource depletion, and other abnormality. Such information can provide early warning of system failure, and guidance for incremental deployment. It can also serve to self-test for known external stimuli, or discover unknown stimuli.

The project proposes an infrastructure to monitor and manage Wireless Sensor Networks with different level of details while we alleviate the overhead of monitoring activities. Three different types of monitoring tools, that are complementary to each other, are monitorized. The first component consists of tools such as dump: upon user's request, dump collects detailed node states or logs over the network for diagnosis. Because the amount of data per node may be large, such tools should only be invoked for small fraction of the network. The

global views of node states are collected by another set of tools similar to escan taking advantage of in-network aggregation. Finally, an early warning system by continuously computing aggregate network properties on the background has been proposed. Each aggregate property consists of only a few bytes of data.

EYES Project

The EYES project (IST-2001-34734) [xiii] was a three years European research project on self-organizing and collaborative energy-efficient sensor networks. The goal of the project was to develop the architecture and the technology which enables the creation of a new generation of sensors that can effectively network together so as to provide a flexible platform for the support of a large variety of mobile sensor network applications.

Two distinct key system layers of abstraction are defined:

the sensor and networking layer: contains the sensor nodes and the network protocols;

the distributed services layer: contains distributed services for supporting mobile sensor applications Distributed services co-ordinate with each other to perform decentralized services.

On top of this architecture applications can be built using the sensor network and distributed services. Communication in sensor networks is data-centric since the identity of the numerous sensors is not as important as the data they contain.

When new sensor nodes are added to the sensor network, they should learn about the capabilities and functions of other sensor nodes and work together as a community system to perform co-operative tasks and networking functionalities.

The approach to exchange this information has the following phases:

Discovery phase: nodes explore their environment and establish contact with neighbors using ad-hoc networking techniques.

Synchronization phase: in this phase nodes try to synchronize with neighboring nodes in order to have some common notion of time.

Positioning phase: In this phase nodes try to find out their relative and possibly geographic positions.

Registration phase: In this phase, the nodes are capable to communicate, and there exists some common knowledge on time and position/topology.

Configuration phase. In this phase the lookup service configures the sensor node.

Sensor nodes may be dynamically composed into cooperative clusters that work together to provide abstract services for the sensor network and they may adapt to changes in sensor node capabilities, events and real-time information. Two types of clusters are defined :

Networking clusters: consist of a set of neighbouring sensor nodes collaborating to establish a connected global topology. The technique is based on the election of the set of nodes that are needed to provide the required network connectivity and capacity.

Information clusters provide distributed information services by coordinating the tasks among the sensors, such as aggregating information and executing collaborative algorithms.

Both types of clusters allow distribution of tasks and hierarchical operation, leading to improved energy efficiency.

Crossbow's MICA platform

Established in 1995, Crossbow Technology Inc., is a Silicon Valley company specialized in the manufacturing and marketing of a broad range of MEMS-based inertial sensors.

During the past few years, Crossbow has been collaborating with U.C. Berkeley for the commercialization of boards based on the MICA [xiv] mote design. It has also been supported by Intel for the development of wireless network solutions based on Intel Technology.

Crossbow has been the first company to deploy wireless sensors based on MICA motes and TinyOS for large-scale commercial use. Nowadays it is currently providing it's products and services to several companies and academic institutions. The product line commercialized by Crossbow includes:

Mica motes. Crossbow ships three mote processor/radio module families – MICA, MICA2 and MICA2-DOT. These modules are designed for both end-user and OEM applications. All modules provide a processor that runs TinyOS based code, two-way ISM band radio transceiver, and a logger memory capable of storing up to 100,000 measurements. The MICA2 and MICA2-DOT modules are Crossbow's latest generation of products, and they are recommended for new designs. These newer units feature a frequency-tunable, FM radio capable of improved range. In addition, these boards offer enhanced processor capabilities, including a boot loader that allows for over-air reprogramming of the Mote code.

Sensor and data acquisition boards. A variety of sensor boards for the MICA, MICA2, and MICA2DOT motes are available. These include boards with temperature, light and various environmental monitoring sensors. Boards with inertial sensors, magnetometers, sounders, microphones and optional GPS modules are available for positioning applications.

Gateways. Crossbow offers the MIB family of basic mote programming and interface boards for the MICA, MICA2, and MICA2DOT. These boards offer RS-232 based serial programming and serial interface to the MICA family of Motes. The MIB600 Ethernet Interface board delivers a LAN data interface and Mote programming. Crossbow also offers the Stargate family of products for interfacing its Sensor Networks to the Internet and WWW. The Stargate is a powerful Linux based single board computer with Compact Flash, PCMCIA, Ethernet, USB Host, and additional interface

Software and tools. A wide range of data collection and network management software is available for mote-based wireless sensor networks. Crossbow supports both open-source software packages available thru the TinyOS distribution, as well as 3rd party turn-key systems. Software application and tools that exist within the TinyOS distribution include the Surge Network Viewer and the TASK and TinyDB Multi-Hop Sensor Data Logging Software. Crossbow's

hardware also supports a complete environmental monitoring software solution from Sensicast.

Crossbow offers training classes that cover the use and programming of the motes with the TinyOS and support for the configuration and deployment of sensor networks.

7 Communication protocols

In this section will be described the communication stack for the sensor networks. For each communication layer will be described the most important functionalities, focusing to the common problems in developing them for sensor networks. In particular each communication layer is analysed, taking into account its problem and the main literature references where a suitable solution to the problem is found.

Wireless Sensor Network communication protocols overview

Physical Layer

The physical layer is responsible for frequency selection, carrier frequency generation, signal detection, modulation, and data encryption. In particular the interest will be mainly focused on modulation and synchronization schemes for their crucial role in wireless sensor networks.

Modulation Schemes

Simple and low-power modulation schemes need to be considered for sensor networks [xv]. The modulation scheme can be either base band, as in UWB, or pass band. One way to increase the energy efficiency of communication is to reduce the transmit on time of the radio. This can be accomplished by sending multiple bits per symbol, that is, by using M-ary modulation. Using M-ary modulation, however, will increase the circuit complexity and power consumption of the radio. In addition, when M-ary modulation is used, the efficiency of the power amplifier is also reduced. This implies that more power will be needed to obtain reasonable levels of transmit output power.

Synchronization Scheme

Time synchronization is a critical piece of infrastructure for any distributed system [xvi]. Distributed, wireless sensor networks make particularly extensive use of synchronized timelines: for example, to integrate a time-series of proximity detections into a velocity estimate, to measure the time-of-flight of sound for localizing its source, to distribute a beam-forming array or to suppress redundant messages by recognizing that they describe duplicate detections of the same event by different sensors. Sensor networks also have many of the same requirements as traditional distributed systems: accurate timestamps are often needed in cryptographic schemes, to coordinate events scheduled in the future, for ordering logged events during system debugging, and so forth.

The broad nature of sensor network applications leads to timing requirements whose scope, lifetime, and precision differ from traditional systems. In addition, many nodes in the emerging sensor systems will be untethered and therefore have small energy reserves. All communication - even passive listening - will have a significant effect on those reserves. Time synchronization methods for

sensor networks must therefore also be mindful of the time and energy that they consume.

Two main synchronization methods exist in the literature: post-facto synchronization and reference-broadcast synchronization. In the post facto synchronization, nodes' clocks are normally unsynchronised. When a stimulus arrives, each node records the time of the stimulus with respect to its own local clock. Immediately afterwards, a third party node - acting as a beacon - broadcasts a synchronization pulse to all nodes in the area using its radio. Nodes that receive this pulse use it as an instantaneous time reference and can normalize their stimulus timestamps with respect to that reference. This kind of synchronization is not applicable in all situations, of course: it is limited in scope to the transmit range of the beacon and creates only an "instant" of synchronized time. This makes it inappropriate for an application that needs to communicate a timestamp over long distances or times. However, it does provide exactly the service necessary for beam-forming applications, localization systems, and other situations in which we need to compare the relative arrival times of a signal at a set of spatially local detectors.

In Reference-Broadcast Synchronization (RBS), each node sends reference beacons to its neighbours using physical-layer broadcasts. A reference broadcast does not contain an explicit timestamp; instead, receivers use its arrival time as a point of reference for comparing their clocks.

Data Link Layer

The data link layer is responsible for the multiplexing of data streams, data frame detection, medium access and error control. It ensures reliable point-to-point and point-to-multipoint connections in a communication network. In the following two subsections, some of the medium access control (MAC) and logical link control (LLC) strategies for sensor networks will be introduced.

MAC Layer

The MAC layer in a wireless multi-hop self-organizing sensor network must achieve two goals. The first is the creation of the network infrastructure. Since thousands of sensor nodes are densely scattered in a sensor field, the MAC scheme must establish communication links for data transfer. This forms the basic infrastructure needed for wireless communication hop by hop, and gives the network self-organizing capability. The second objective is to fairly and efficiently share communication resources between sensor nodes. In order to achieve the peculiarity of a wireless sensor networks three different approaches are feasible in MAC layer design: SMACS and EAR [xvii], Hybrid TDMA/FDMA [xviii] and CSMA-based [xix]. Their functionalities will be described more in-depth in the following.

SMACS is an infrastructure-building protocol that forms a flat topology (as opposed to a cluster hierarchy) for sensor networks. Moreover, it is a distributed protocol which enables a collection of nodes to discover their neighbours and establish transmission/reception schedules for communicating with them without the need for any local or global master nodes.

In order to achieve this ease of formation, the neighbour discovery and channel assignment phases have been combined in the SMACS protocol. Unlike other methods in which a first pass is performed on the entire network to discover

neighbours and then another pass done to assign channels, or TDMA slots, to links between neighbouring nodes, in SMACS a channel is assigned to a link immediately after the link's existence is discovered. This way links begin to form concurrently throughout the network. By the time all nodes hear all their neighbours, they will have formed a connected network. In a connected network, there exists at least one multihop path between any two distinct nodes. Since only partial information about radio connectivity in the vicinity of a node is used to assign time intervals to links, there is a potential for time collisions with slots assigned to adjacent links whose existence is not known at the time of channel assignment. To reduce the likelihood of collisions, we require each link to operate on a different frequency. This frequency band is chosen at random from a large pool of possible choices when the links are formed. It cannot be assumed that each mobile node is aware of the global network state and/or node positions. Also, a mobile node may not be able to complete its task (data collection, network instruction, information extraction) while remaining motionless. Thus, the EAR protocol attempts to offer continuous service to these mobile nodes under both mobile and stationary constraints.

In a TDMA scheme, the full bandwidth of the channel is dedicated to a single sensor for communication purposes. Thus, the signal bandwidth per sensor is equal to the available bandwidth, and sensors can transmit at the highest data rate. Since the transmit on-time of the radio model is inversely proportional to the signal bandwidth, it is minimized in TDMA schemes. On the other hand, in an FDMA scheme, the signal bandwidth (total available bandwidth divided by number of sensors) is minimal. Thus, transmit on-time is at its maximum. A hybrid scheme involving both TDMA and FDMA (TDM-FDM) is also possible. In a TDM-FDM scheme, both time and frequency are divided into available transmission slots. If the receiver consumes less power, a TDMA scheme is favoured. On the other hand, if the receiver uses more power, FDMA is more appropriate.

Carrier Sense Multiple Access (CSMA) and the Collision Detection (CD) scheme found in Ethernet protocol are examples of listening mechanisms. Listening is very effective when all nodes can hear each other, (i.e., without hidden nodes). Unfortunately, collision detection is not possible in wireless network technology without additional circuitry. Though listening is simple, it does come with an energy cost, because the radio must be on to listen. To conserve energy, it is important to shorten the length of carrier sensing. Many protocols such as IEEE 802.11 require sensing the channel even during backoff. However, CSMA for sensor networks should take this opportunity to turn the radio off. Traditional CSMA schemes have two basic design parameters: the carrier sense (or listening) mechanism and the backoff mechanism. In sensor networks we optionally add a random delay prior to listening to avoid repeated collision due to synchronized behaviour. The half duplex nature of the networking stack makes CSMA vulnerable to the capturing effect. That is, during reception of neighbouring node's transmission, the network stack will not start any transmissions issued by the application. Instead, it will fail the transmission back to the application. If the two nodes remain synchronized with one starting its transmission before the other, the channel may remain captured even though traffic load is extremely low.

LLC

Another important function of the data link layer is the logical link control, whose main functionality is to perform the error control of transmission data [xx]. Common error control methods in communication networks are forward error correction (FEC) and automatic repeat request (ARQ). The usefulness of ARQ in multi-hop sensor network environments is limited by the additional retransmission energy cost and overhead. On the other hand, the decoding complexity is greater in FEC since error correction capabilities need to be built in. Considering this, simple error control codes with low-complexity encoding and decoding might present the best solutions for sensor networks. In the following, the basic design considerations for FEC in sensor networks are introduced.

Network Layer

Traditional ad-hoc routing algorithms focus on avoiding congestion or maintaining connectivity, whenever they are faced with mobility. However, they do not consider the limited energy supply of the network devices, thus lowering the overall performance and wasting the resources. As a consequence, a power aware routing strategy is to be develop to allow the sensor network to perform its functionality as long as possible.

Though the optimal traffic scheduling (energy optimal) scheme requires an exact knowledge of future traffic, however only a statistically optimal scheme can be managed with the aim of maximizing the network efficiency.

A routing scheme is energy efficient when it is statistically optimal and causal, i.e., it considers only past and present conditions. The most important parameter to be optimised is the node lifetime, that is the worst-case duration until a node breaks down. It is worth noticing that the minimum hop paths of different communication streams usually have a large number of nodes in common, thus these nodes are likely to exhaust their resources sooner and, therefore, to limit the network lifetime. A routing scheme is efficient when it minimizes the average energy utilized by each node together with minimizing its variance too.

In order to properly characterize a routing protocol, we analyse the main approach leading to an optimal solution according to a proper metric and, then, we introduce the routing protocol adopted in practice, providing an insight into current research on the networking layer.

Routing approaches

Energy-efficient routing approach might be based either on the available power (PA) at the nodes or on the energy required (α) for transmission over the links along the selected route.

Maximum PA Route

The route having the maximum total PA, that is the summation of the PAs of each node along the route, is selected. However, this approach may include not power-efficient extra nodes, so it is important to resort to the minimal route, avoiding unnecessary paths and not taking them into account in the considered metric.

Minimum Energy (ME) Route

The route that consumes the minimum energy to data delivering between the sink and the sensor node is the candidate ME route.

Minimum Hop (MH) Route

The route having the minimum number of hops to reach the sink is preferred. Note that the ME scheme selects the same route as the MH when the same amount of energy is used on every link, i.e., all α values are the same.

Maximum Minimum PA Node Route

The route along which the minimum PA is larger than the minimum PAs of other routes is preferred. This scheme avoids to use up a sensor node with low PA before the other nodes, as they belong to a route with high PAs for each nodes.

An important issue is that routing may be based on the data-centric approach, where an INTEREST dissemination is performed to assign the sensing tasks to the sensor nodes. Two approaches could be used for INTEREST dissemination: sinks broadcast the INTEREST [xxi], and sensor nodes broadcast an advertisement (ADV) for the available data [xxii] and wait for a request from the interested nodes.

Routing protocols overview

Small Minimum Energy Communication Network (S-MECN)

This protocol [xxiii, xxiv] computes an energy-efficient subnetwork (sub-graph), given a particular network graph. The sub-graph G of a graph G′ minimizes the energy usage satisfying the following conditions:

the number of edges in G is less than in G′, while containing all nodes in G′;

if two nodes, u and v, are connected in G′, they are also connected in G;

the energy required to transmit data from node u to all its neighbours in G is less than the energy required to transmit to all its neighbours in G′.

MECN search for the sub-network with the minimum-energy property, stating that there exists a minimum-energy path in sub-graph G between nodes u and v for every pair (u, v) of nodes that are connected in G′.

Flooding

Flooding is a reactive technique, that is whenever a node receives a data or a management packet it repeats it by broadcasting, unless a maximum number of hops for the packet is reached or the destination of the packet is the node itself. It does not require costly topology maintenance and complex route discovery algorithms. However, it has several drawbacks such as:

implosion: duplicated messages are sent to the same node;

overlap: if several nodes observe the same region they are likely to generate a redundant information amount;

resource blindness: the protocol does not take into account the available energy resources.

Gossiping (Epidemiological)

A derivation of the flooding principle is the gossiping [xxv], in which nodes do not broadcast but send the incoming packets to a randomly selected neighbours. Although this approach avoids the packet implosion sending only one copy of the message at any node, it takes a long time to propagate the message to all the sensor nodes. This have been built to implement not only reliable multicast [xxvi] but also failure detection [xxvii] and garbage collection [xxviii]. Nearly all gossip protocols have been developed assuming the failure model for the processor crashes and the message links failure that lead to message drop. They are characterized by the following features:

scalability: the performance does not rapidly degrade as the number of nodes grow;

adaptability: it is easy to remove or add a node in the net;

graceful degradation: many protocols use to not function correctly whenever the number of failures overcomes a threshold f. Hence, it is advantageous to have a protocol whose probability of functioning correctly does not rapidly decreases as the number of failures increases: the gossiping protocol permits to pursue this property, even if the number of failures is greater than f.

Since a node selects its partners randomly, there is some chance that a message may not reach the sink even if there are no failures. However, such probability is usually kept small [xxix].

Sensor Protocols for Information via Negotiation (SPIN)

A family of adaptive protocols called SPIN is designed to address the deficiencies of classic flooding by negotiation and resource adaptation. Nodes operate more efficiently and save energy by sending metadata describing the data characteristics instead of sending them. SPIN resorts to three types of messages, that is, ADV, REQ, and DATA. Before sending a DATA, the sensor node broadcasts an ADV message containing a descriptor (i.e. meta-data) of the DATA. If some neighbours are interested in the data, they send a REQ message and the sensor select the proper node sending the DATA to it. Then the process is repeated for all the nodes.

Low-Energy Adaptive Clustering Hierarchy (LEACH)

LEACH [xxx] is a self-organizing adaptive clustering protocol that uses randomisation to distribute the energy load evenly among the sensors in the network.

In LEACH, the nodes organize themselves into local clusters, with one node acting as the local base station or cluster-head. LEACH includes randomised rotation of the high-energy cluster-head position such that it rotates among the various sensors in order to not drain the battery of a single sensor. Sensors elect themselves to be local cluster-heads at any given time with a certain probability depending on cluster-head number, past sensor history and energy issue. These cluster-head nodes broadcast their status to the other sensors in the network. Each sensor node determines its cluster by choosing the cluster-head that requires the minimum communication energy; once all the nodes are organized into clusters, each cluster-head creates a schedule for the nodes next to it and

when it receives data from the nodes within its cluster it aggregates and transmits them compressed to the gateway.

Directed Diffusion

The directed diffusion data dissemination paradigm is a data centric approach, where the sink sends out INTEREST, which is a task description, to all sensors. The task descriptors are named by assigning attribute-value pairs that describe the task. Each sensor node then stores the interest entry with a timestamp field and several gradient fields in its cache. As the INTEREST is propagated throughout the sensor network, the gradients from the source back to the sink are set up with a reinforcement procedure. When the source has data for the INTEREST, it sends data along the interest's gradient path. The interest and data propagation and aggregation are locally determined.

*Transport Laye*r

The need for a Transport Layer has been pointed out in the literature [xxxi]. This is especially relevant when the system is planned to be accessed through the Internet or other external networks.

In particular, an approach such as TCP splitting may be needed to make sensor networks interact with other networks such as the Internet. Accordingly, the TCP connections are ended at sink nodes, and a special transport layer protocol can handle the communications between the sink node and sensor nodes. As a result, communication between the user and the sink node is either by UDP or TCP via the Internet.

Conversely, communication between the sink and sensor nodes may be purely by UDP-type protocols, because each sensor node has a limited memory.

Moreover, some troubles concerning this Layer usually arise in a sensor network, that is [xxxii]:

the goodput decreases drastically when network capacity is exceeded;

the congestion resolution has to be taken into account.

In order to face these problems, the wireless TCP variants are not suitable since in a sensor network there is a different notion of end-to-end reliability, the buffering requirements are too large if compared with available resources, and the N/ACK sending is energy draining. Moreover, the reliable multicast solutions are not viable, as the multiple sender/single receiver transport features are traditionally solved by means of a multiple unicast, while in this scenario it is required the notion of collective reliability.

Several relevant protocols proposed in the literature are outlined in the following.

Reliable Multisegment Transport (RMST)

This protocol [xxxiii] operates in conjunction with the Direct Diffusion routing algorithm and affords the guaranteed data delivery by using in-network caching, despite this approach brings significant overhead in terms of power and processing.

Pump Slowly Fetch Quickly (PSFQ)

According to this approach [xxxiv], it is performed a slow injection of packets into the network. In the case of packet losses PSFQ resorts to aggressive hop-by-hop recovery . The pump mechanism performs controlled flooding and requires each intermediate node to create and maintain a data cache to be used both for local loss recovery and in-sequence data delivery.

The main applications of PSFQ are to strict sensor-sensor guaranteed delivery and for control and management of the end-to-end reliability in the downlink, i.e., from sink to sensors. However, it does not address congestion control..

Application Layer

The most relevant applications of the sensor network paradigm are related to military and civilian fields such as environmental, disaster relief, health or to space exploration. To this aims several, sensor types and, moreover, sensor tasks are pointed out. However, to allow the system administrators to remotely interact with sensors, it is required a proper application protocol, since they use an attribute based naming and a location based addressing not originally supported by the sensor network being this system infrastructureless and without a global nodes identifications.

The main tasks this protocol is expected to afford are:

the management of the sensor nodes mobility within the network together with their turning on and off;

the exchanging of the data related to the location finding algorithms;

the support to the queries about the sensor network configuration and the status of the nodes, so enabling a quick re-configuration;

the security issues such the authentication, key distribution and security in data communications procedures;

the time-synchronization of the sensor nodes;

the provisioning of efficient and flexible rules for the remote interaction. These rules are related both to the data aggregation, to the attribute-based naming and to the high level clustering of the sensor nodes as well.

Sensor Management Protocol (SMP)

To develop this protocol it is needed a Sensor Query and Tasking Language (SQTL) [xxxv] definition. It is a procedural scripting language providing interfaces to access sensor hardware and change the sensor status. Besides, it is expected to manage the location awareness and the communication procedures.

By means of a set of commands, defined by SQTL keywords, the Administrator might create an event handling block for three types of events:

events generated when a message is received by a sensor node (receive);

events triggered periodically (every);

events caused by the expiration of a timer (expire).

Task Assignment and Data Advertisement Protocol (TADAP)

This protocol is based on both interest dissemination by the user and on advertisement of available data by the sensors.

Firstly, the users send their interest to a sensor node, a subset of the nodes or the entire network. This interest may be about a certain attribute of the sensor field or a triggering event.

On the other hand, the sensor nodes advertise the available data to the users and the users query the data which they are interested in.

Sensor Query and Data Dissemination Protocol (SQDDP)

This protocol provides user applications with interfaces to the most common interaction as queries, respond to queries and collect incoming replies.

These queries are not issued to particular nodes, and can be both attribute based naming queries or location based naming queries.

7.1 Security Considerations

Wireless networks, in general, are more vulnerable to security attacks than wired networks, due to the broadcast nature of transmission medium. Wireless sensor networks are even more vulnerable since the nodes are often placed in a hostile or dangerous environment where they are not physically protected.

A sensor network should not leak sensor readings. In many applications, nodes communicate highly sensitive data. Since node data contain some confidential information, the content of all messages in the network must be encrypted. The standard approach for keeping sensitive data secret is to encrypt the data with a secret key that only intended receivers possess, hence achieving confidentiality.

Authenticated broadcast requires an asymmetric mechanism; otherwise any compromised receiver could forge messages from the sender. Asymmetric mechanisms have high computation, communication, and storage overhead, which make their usage on resource-constrained devices impractical. This can be overcome by introducing asymmetry through a delayed disclosure of symmetric keys, resulting in an efficient broadcast authentication scheme.

A suite of security building blocks is optimized for resource-constrained environments and wireless communication. Security Protocol for Sensor Networks (SPINS) has two secure building blocks:

Secure Network Encryption Protocol (SNEP) provides data confidentiality, two-party data authentication, and data freshness.

µTESLA (the micro version of the Timed, Efficient, Streaming, and Loss-tolerant Authentication Protocol) provides authenticated broadcast for severely resource-constrained environment.

These protocols are practical even on minimal hardware, and can be used for building higher level protocols.

7.2 Node-to-sensor interface

The aim of this section is to show what kind of specifications have to be developed in order to allow the definition of "AmI Compliant Sensor".

In the AmI vision an "AmI Compliant Sensor" is a sensor that can be easily connected to whichever node of the network and that is able to work without changing any configuration parameters in the network (plug and play sensors).

To achieve this goal, a well defined interface has to be developed.

The interface requirement will be defined within the Subtask 7.3.2 of WP7. The definitive specification for the interface between Network Node and Sensors will be available at the end of May. The definition of the specification will be

performed on the basis of the possible scenario of utilisation taking into account the results of the user needs analysis, carried out within WP7.

The "AmI Compliant" Sensors will have to satisfy some basic interface requirements in terms of Packaging, Hardware and Software (Communication Protocol) aspects.

Packaging / Mechanical standard

All packaging and mechanical interface aspects will be defined. In particular the main topics to consider are:

- Geometric aspects: shape and maximum dimensions for sensors and plugs; maximum number of connections for each Node.
- Physical connectors: choice of plug; materials to use; number of pins.
- Special requirements: temperature requirement (maybe extended range can be required, it depends on the analysis of the scenario); humidity requirement; waterproof could be required; definition of other particular requirements.

Hardware / Electronic standard

Electronic aspects of the interface implementation will be defined. In particular the main topics to consider are:

- Pin out: definition of number and functionality of connector pins (power line, signal line, digital line); definition of analogical and digital output.
- Power specification: definition of power source voltages; maximum current sourcing specification...
- Communication interface (physical layer): digital serial interface choice (i.e. rs232, SPI, I2C or microwire)
- Positioning of sensors: definition of a system for sensor position identification: i.e. bus ID specification or selection via "chip select" pin.

Software / Communication Protocol standard

This subsection is focused on communication protocol; this is a very important topic because it allows the sensor plug an play features. In fact each plug an play sensor must contain (and transmit to the network node) all information about itself:

- Communication interface (software layer): serial interface basic software parameters definition.
- Data to exchange to achieve plug and play sensor: definition of higher level communication protocol; implementation of sensor "descriptors" concept.
- Descriptors: the "descriptors" must contain all sensor information required for automatic identification and installation on the node network; a realistic list of the field composing the "descriptors" is showed

- ID sensor (an unambiguous identification number)
- Physical or Chemical quantity measured (definition of sensor classes)
- Order of magnitude of quantity measured (sensor of the same class can be different measuring range)
- Data format
- Timing Information (a measurement can be instantaneous, with a fix or variable delay; a sensor can also contain historical data)

7.3 Network Mobile Node

The application Scenario involves the deployment of wireless sensors for environmental monitoring.

In addition to the nodes used to implement the Communication Infrastructure, a number of Mobile Nodes will be used to interact with networks with different aims. Those nodes will be implemented using Mobile Devices (e.g. PDA or custom microcontroller board) provided with tools for chemical, physical and biological analysis or different functionality. Such devices will be connected to a MICA Mote provided with a specific hardware and software interface.

The exploitation of this section will contain the complete definition of both the interfaces and the communication protocol between the MICA and the Mobile Devices. This approach will allow the data transmission from the Mobile Node to the main gateway using the wireless infrastructure. This could apply to some measurements made directly by the end-user in some specific circumstances.

Interfaces and communication protocols will have to guarantee wide compatibility with a large number of different devices without constraints in integrating commercially available tools or devices. In order to fulfil this requirement, some different interfaces (based on radio links or IR links or cable connections) will be identified and a plug and play protocol will be defined.

Off the shelf commercially available solutions will be preferred.

It will be also defined, according to the user needs, the method used to start the communication between a wireless sensor and the MICA Mote. Basically that could happen in two ways:

- with a command by the operator that can turn on the sensor network;
- waiting until the sensor network turns on and performs an automatic task in order to retrieve information from the relative sensor devices.

Mobile Devices to Mica interface

Suitable interfaces for Mobile Devices and MICA Mobile Nodes will be defined. These interfaces will be chosen among the commercially available ones.

Output of the section will be the following:

- Compatible interfaces will be identified (i.e. IrDA or Bluetooth).
- Electrical and mechanical, data rate, frequency and bandwidth (if necessary) standards will be provided for all the selected interfaces.

Mica to Mobile Device standard communication protocol

The protocol to be used between the Mobile Devices and the MICA will be described in this subsection. It will regard how a Mobile Device registers itself to the MICA mobile node and specifies its parameters. This protocol will be compliant with the one used to exchange data between MICA motes and their connected sensors.

Output of the section will be the following:

- A proprietary communication protocol will be defined.
- Frame structure will be provided.

Extension of "AmI Compliant Sensor" concept

Not only plug and play sensors will be able to connect with AmI. Also more complex devices can be "AmI compliant":

Sensor array to Node Interface: an array of sensors will be probably equivalent to many sensors connected to the same connector. The sensor array will contain all information discussed at point 2.3 for each sensor.

Handheld and mobile devices to Node Interface: this device will be connected to the Node or through industrial standard communication protocol like IR or Bluetooth, using the high level protocol discussed at point 2.3. In alternative a mobile device could be probably connected directly to the Node Network using a Node integrated on the system.

The IEEE 1451 family of standards

There is an increasing interest in smart sensors as a direct result of the need to communicate sensor information in distributed measurement systems. Unfortunately, numerous protocols have been defined for data communication: industry and consumer standards have been developed to satisfy different requirements. Interoperability should allow the implementation of various interfaces across different networks for network independent operation. True transducer "plug&play" capability is the vision.

Since 1993, IEEE and NIST have been developing different standards for smart sensors:

- IEEE 1451.1 "Network Capable Application Processor Information Model (NCAP)"
- IEEE 1451.2 "Transducer to Microprocessor Communication Protocol and Transducer Electronic Data Sheet (TEDS) Formats"

One of the key focuses of this family of standards is the interoperability of transducer sensors in different network protocols. An architecture for this interoperability is defined where the glue between the smart sensor and the

network is provided by the NCAP. The smart sensor (STIM in the terminology of the standard) provides an standarized connection to the NCAP.

This standard family is an ongoing effort and there are two more that have not been fully accepted yet and there are under the ballot procedure

IEEE 1451.3 "Digital Communication and Transducer Electronic Data Sheet (TEDS) Formats for Distributed Multidrop Systems"

IEEE 1451.4 "Mixed-Mode Communication Protocols and Transducer Electronic Data Sheet Formats"

There are even currently two more under development

IEEE 1451.5 "Wireless Communication Protocols and Transducer Electronic Data Sheets (TEDS) Formats"

IEEE 1451.0 "Family Interoperability"

A number of terms and acronyms have appeared as a consequence. The TEDS is a machine-readable specification of the characteristics of the sensor, with the intention to easy sensor installation and replacement. The STIM (Smart Transducer Interface Module) includes the TEDS and supporting electronics based usually in a microcontroller to interface the transducer to the NCAP (Network Capable Application Processor). The NCAP is a device that supports a network interface, application functionality, and capabilities to communicate with the STIM. A transducer independent interface (TII) is a 10-wire digital communication interface that allows the NCAP to obtain sensor readings as well as request of TEDS data.

The "AmI Compliant Gateway" concept

The gateway consists of an IP-based, typically wireless, wide-area network module and firmware procedures implemented, to provide standard operating interface for local operations. In this way, each AmI-compliant subsystem (i.e. sensor networks, stand-alone sensing unit, wireless camera) can expose the same communication interface and protocols to the PH, for wide-area data exchange.

Moreover, the gateway network modules should be considered technology independent, and their communication interface can be selected matching the specific application requirements (i.e. GPRS/UMTS modules for remote/outdoor applications, LAN/wLAN for laboratory equipments, XDSL access for indoor requirements).

Basic requirements are here exposed:

- wide-area communication interface on GW must support TCP/IP protocols;

- GW is responsible for keeping the TCP connection alive, and periodically testing the connection state;
- a custom protocol for data exchange between GW and PH will be properly specified in the subtask 7.3.2; to standardize and simplify the custom protocol implementation, a standard, platform-independent C language library could be released, to be implemented in all AmI-compliant GW modules. The custom protocol will rely on TCP/IP stack.

Other requirements will be exposed concerning timeliness constrains in order to set up efficient alarm signals, e.g. whenever the monitored parameters overcame a fixed threshold. In particular, an explicit assurance that data have been received correctly at the receiving end within a maximum latency will be requested.

As to the information exchange between sensor networks and other network entities via gateways, the Differentiated Services seems to be an effective management paradigm as it provides a resource allocation to a certain number of traffic classes. Usually they are assumed to be three classes, i.e., Assured Forward (AF), Expedited Forward (EF) and Best Effort (BE) that properly characterize our data traffic.

8 SensorWeb concepts

8.1 SensorWeb overview

The SensorWeb is a macro-instrument concept that allows for the spatio-temporal understanding of an environment by coordinating several and different types of sensing platforms, including both orbital and terrestrial and both fixed and mobile. Each of these platforms, or pods, communicates within their local neighbourhood, and thus distributes information to the instrument as a whole [xxxvi].

According to this approach, the SensorWeb is likely to develop a macro-intelligence as a result of its distributed information with the pods, reacting and adapting to their environment in a way that is much more than their individual sum. As a matter of fact, the sharing of data among individual pods will allow for a global perception and purpose of the instrument as a whole. In other words, the SensorWeb is to sensors what the Internet is to computers, with different platforms and operating systems communicating via a set of shared and robust protocols.

Typical sensor use involves placing a single transducer in an environment to monitor and record a particular aspect of it. Though the monitoring process may have a remarkable resolution, there is scarce information regarding the general nature of the dynamics associated with the phenomena, save their spatio-temporal localization. Moreover, there is no way for the sensor to anticipate its environment.

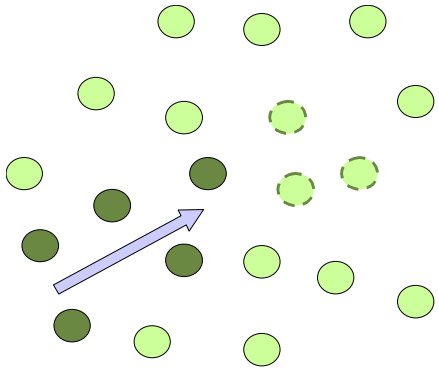


Figure 6: A SensorWeb can monitor spatio-temporal dynamic of phenomena.

According to an apposite approach, several cheaper and disposable sensors are used with a presumed reduction in measurement fidelity. Nevertheless, by correlating these measurements over space and time, it now becomes possible to extract spatio-temporal dynamics associated with a phenomenon. As a result, these cheaper sensors, correctly configured, can provide a different type of information altogether. This is the essence of a SensorWeb.

SensorWebs are made practical by the present revolutions in computation and telecommunication hardware, making the hardware so inexpensive as far as the electronics manufacturers and telephone companies too. The SensorWeb is,

therefore, a new kind of instrument that exploits the availability of this low-cost, but extremely advanced, hardware. Additionally, because of its ability to discern spatio-temporal phenomena, the SensorWeb provides a new way to think about environmental monitoring and creating a virtual presence. The SensorWeb is a new instrument concept, capable of being developed for a wide range of applications.

The very essence of a SensorWeb, with its multiply redundant pods, allows for an instrument to be "reseeded" against instrument degradation. In other words, as various pods drop out of the web because of hardware malfunction or exhausted batteries, it is possible to deploy new pods in the instrument area that will seamlessly mesh with the pre-existing web communication backbone. In this way, though the pods themselves are expendable, the SensorWeb instrument can continue to function indefinitely. Moreover, this reseeding allows the macro-instrument to evolve over time, as new pods can be more sophisticated and technologically advanced than older ones. Because the SensorWeb has no definitive boundaries (the mother pods may be located anywhere in the network), multiple deployments of webs in a given area will naturally mesh with one another. Consequently, a SensorWeb represents an instrument whose surveying area can be expanded via multiple deployments.

The information flow have no preferred direction on the SensorWeb, though the mother pods represent an immediate point of accessing into and out of the SensorWeb. This allows the SensorWeb instrument a complete flexibility: pods can be dropped in or out at random points in space and time and mother pods may be added to grow the extent of the web. Unlike a star-network, in which a mother pod must be centrally located, mother pods in a SensorWeb may be distributed wherever convenient. The assumed omni-directional wireless communication between pods further reduces rigid placement requirements in a SensorWeb.

In addition to omni-directional communication, the radio traffic is also bi-directional. That is, there is no preferred direction within the peer-to-peer network. At first this may seem obvious, yet when applied to the communications associated with the mother pod, powerful results occur. Because the end-user interacts with the SensorWeb via the mother pod, the bi-directional communication property allows the user not only to receive information from the SensorWeb, but also send instructions into it. As a result, the SensorWeb is a field-programmable instrument.

To formalize these notions, we define a "pod" as a physical piece of hardware containing the two modules of transducers and infrastructure as described above. In contrast, a "node" is a logical (or abstract) construct that simply is a vertex on a SensorWeb. A node can be either a pod or another SensorWeb. Thus a SensorWeb can be viewed recursively as a web of webs.

As defined in the NASA New Technology Report on SensorWebs [xxxvii], the SensorWeb consists of a system of intra-communicating, spatially distributed sensor pods that can be deployed to monitor and explore new environments.

Typically, the communications are wireless. Each pod consists of two modules. The first module comprises the transducers that physically interact with the environment and convert environmental parameters into electrical signals. The second module represents the infrastructure of the SensorWeb itself. Included in this module are telecommunication capabilities, power sources and energy harvesting devices, and computation devices to run the protocol schemes and provide for local data analysis. The penultimate goal of a SensorWeb is to extract knowledge from the data collected and to adapt and react accordingly.

Strictly speaking, the SensorWeb as defined is not limited to terrestrial platforms. In fact, any constellation of satellites or a group of autonomous vehicles may be viewed as a SensorWeb, so long as their activities are coordinated by their shared local knowledge of the environment. Although this system could be a type of SensorWeb, it is only a subset of the general concept. The connotation of the term "SensorWeb" has a much broader scope and extends from ultra-large-scale in situ instruments to correlated remote measurements, to the coordinated flying (swarming) of distributed spacecraft and everything in between. It is thus too restrictive to say that the SensorWeb concept is a design for a cluster of satellites or an in situ instrument, since it can be either one.

As a result, the SensorWeb concept is not a "one-size-fits-all" solution any more than one would expect all satellites to be the same. For example, pod-to-pod baud rates can vary from very low (sonar applications) to the very high (satellite applications). The SensorWeb concept simply allows for information synthesis over a large spatial area and tracking of dynamic phenomena over multiple length scales simultaneously. The unifying feature of all SensorWebs, therefore, is that the information gathered by the instrument is also used by the instrument, perhaps even modifying its own behavior. The ultimate SensorWeb has an environmental self-awareness and reacts accordingly.

SensorWebs are often confused with projects that fall under names such as "distributed sensors" or "sensor networks". The most characteristic feature of the SensorWeb is that information gathered by one pod is shared and used by other pods. Distributed sensors networks merely gather data and communicate it to an uplink point. Typically, in a distributed sensor system, the information is purposefully routed directly to the end-user. The information gathered by a particular pod on such a network typically does not influence the behavior of another pod, especially a pod that is not on the route between the data collection point and the end-user. In contrast, the purpose of broadcasting information on a SensorWeb is to share the information with other pods such that the delivering of the knowledge obtained by the instrument to the end-user is almost incidental to the operation of the instrument. For example, if one pod should cease functioning, its lost presence could cause neighbouring pods to increase their sampling rate to gain in time resolution what has been lost in spatial resolution. While the distributed sensors collect data, a true SensorWeb can digest the collected data and even modify its behaviour on the basis of this processed knowledge. There is a global, macroscopic "purpose" to data collection by SensorWeb pods that is not apparent in the distributed sensor network.

8.2 SensorWeb common features

Data processing

Although the computation hardware in a pod can be quite sophisticated, it is the sharing of information among the pods that gives the SensorWeb a macro-intelligence. Intelligence in the human brain is created because of a complex, inhomogeneous network of neurons, and not because of individual intelligence from each neuron. Similarly, the SensorWeb is an instrument where greater functionality is derived from a parallel-type architecture as sensor measurements (including pod location) are passed, and collectively interpreted, from pod to pod. This global sharing of information will lead to pod synergism (the whole of their activity being greater than the sum of their parts) by permitting intelligent resource (power, bandwidth, consumables) management by the web, and allowing for self-modifying behaviour based on environmental factors and internal web diagnostics.

Some of the major issues that must be addressed to implement a soundly pods synergism are:

- Time Synchronization. Accurate description of temporal dynamics requires every node to be synchronized on a common clock. Time synchronization should be achieved using algorithms that minimize the number of packet exchanged among the nodes.

- Localization. Localization techniques aim at deriving a fine-grained localization of randomly deployed nodes. As for time synchronization, localization is required to provide spatial information about the phenomena being monitored

- Sensor Calibration. In the assumptions that nodes cannot be accessed after deployment, it's important to adopt techniques that allow for validation of sensor readings. These algorithms should aim at identifying faulty sensors to avoid that erroneous information is reported to the user. If possible, data from similar sensor on neighbor nodes should be used to recalibrate the sensor.

- Network Management. Since sensor networks will operate in unpredictable environments, it is important to have an infrastructure to provide indication of node failures, resource depletion and other abnormalities. In general, the key challenge in monitoring sensor network is to collect network health indications form within the sensor network in a manner that scales well with network size, is robust to node failures and is energy efficient.

The wireless communication between sensor pods is presumed to be omni-directional and not routed like conventional networking schemes. Unlike star-

network configurations where data collected from all pods is passed directly to a central point, information within the SensorWeb is passed to an uplink point, denoted as a prime or mother pod, by hopping it from pod to pod. In other words, data from various pods are shared as well as communicated throughout the entire web. The overall protocol is quite simple. Information is obtained at each pod via three routes:

direct measurements taken by local sensors at that pod;

combining cross-related measurements, obtained also from sensors located on different pods;

information gathered by other pods and communicated throughout the local web.

The key concept is that there is no differentiation between the above types of information. The protocol then is to rebroadcast some combination of the data (actual measurements) or information (digested data) to any pod within communication range. Any information received at a mother pod is accessible to an outside user.

Power saving

Because the SensorWeb is not a one-size-fits-all solution, each instrument must be designed specifically for the needs of a particular task. Nevertheless, if the SensorWeb infrastructure is costlier, heavier, and more power-wasting than its component sensors, it will be useless in practice. As a result, a crucial role is played by the transmitted power optimization.

The requirement, of the micro-power minimization, is dealt with by hopping the data pod to pod since this not only allows for sharing locally collected data but also is power efficient [xxxviii]. From elementary electromagnetic theory, it follows that the total power P_{Tx} required to transmit a signal that ensures a received power P_{Rx} a distance D away is:

$$P_{Tx} = \left(\frac{D}{\lambda}\right)^{m} P_{Rx}$$

where λ is the wavelength of the transmitted signal and m is 2 in free space and can range to 4 or more in environments with multiple-path interferences or local noise. As a result, the total power required to transmit a given distance with N hops is reduced by a factor of $N^{(m-1)}$ compared to the total power required by direct transmission. The reason why hopping data is power efficient is that more of the power is directed along the path to the receiver. Since the free space case is the best-case scenario in terms of transmission efficiency, the value of hopping is only increased in more hostile environments.

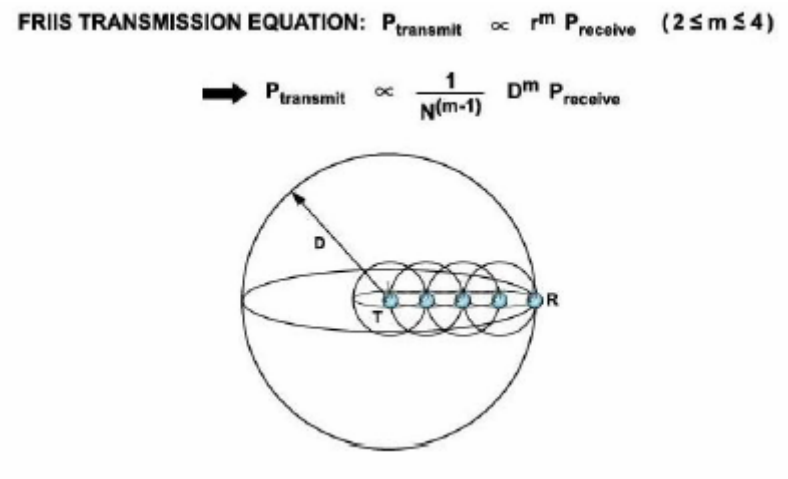


Figure 7: Power efficiency of multi-hop communication

Dynamical reprogramming

Embedded systems used in sensor networks contain a microcontroller that need to be programmed before deployment. The program code controls how the node performs data acquisition from sensors and how it communicates such information to its neighbors. At a lower level, the application program also contains instructions for advanced power management schemes and for network protocol handling. Since nodes need to be programmed in advance, it's important to have a clear understanding of the functionalities to implement in the application.

This programming scheme is well suited for simple applications where the requirements can be clearly fixed in advance, but it doesn't apply very well to the SensorWeb concept. In fact, the ultimate goal of SensorWeb is to extract knowledge from the environment and how this must be accomplished can be extremely hard to define in advance. Moreover, SensorWeb deployments need to operate unattended for years and even if the computational model is well defined a priori, it could change with time. It would be also desirable for a SensorWeb to serve the request of different transient users, so the algorithms to be used for data elaboration can't be predicted.

As solution to these issues, SensorWeb applications should implement systems that allow for dynamical reprogramming of deployed nodes. A first viable approach consists in compiling new executables images and use the wireless network infrastructure to transfer them to nodes. The program code is split in several small packets that are routed through the network like normal data packets. Code packets are stored in an external memory module until to the completion of transmission. When the new executable image has been entirely transferred to the node, a coprocessor is used to replace the content of microcontroller's flash with the new firmware. Starting from this point the network node executes a totally new application.

Other more sophisticated solutions rely on the use of virtual machines or command interpreters. These software modules run on the network nodes and are capable to dynamically run precompiled applications (like java classes) or command scripts. The advantage of this solution is that the node's firmware doesn't need to be totally replaced and smaller code packets are transferred within the network. By adopting this approach, it is possible to write small scripts that define the new task to perform and inject them into the network. These scripts can also contain information about how they should be propagating from node to node, so they are able to autonomously spread among network nodes in a way that recall how computer virus propagate themselves among different machines.

9 Software Platforms

This section focuses on a state of the art analysis of some tools that will be used to implement the AmI Framework . The tools that will be analysed are:

- Resource Management
- Component Interfaces
- KDD/ DSS
- Architectures and Data Models

Resource Management Systems (RMS) have a main role in handling a dynamically evolving set of distributed, interconnected and heterogeneous hardware devices. Below it is shown some common implementation patterns and some example RMS taken mainly from GRID computing [xxxix] where aspects such as security, fault tolerance, autonomy and heterogeneity have been faced intensively.

Component interfaces are not trivial aspects when designing a complex system like the AmI framework. In particular, when the systems are logically and physically distributed across different computing resources, a set of common features to be faced are communication, protocols, automation/interaction techniques, dynamic service discovery.

Knowledge Discovery in Databases (KDD) and Decision Support Systems (DSS) are general terms that wrap a set of tools, algorithms and techniques for the activity of analyzing big quantities of data, stored in a structured way in databases, to find interdependencies that could help to establish rules or to train intelligent software agents for optimising common activities or for helping human operators in automating tasks inside the AmI framework. Finally will follow a study of the state of the art in terms of tools for KDD and datamining.

9.1 Resource Management

Resource Management is a complex task involving security, fault tolerance, scheduling, flexibility, extensibility and naming of resources.

In the viewpoint of the AmI framework, the most important features of a possible implementation of a Resource Management System (RMS) are fault tolerance, flexibility, extensibility and naming of the resources.

Flexibility and extensibility are achieved by applying appropriate Resource Dissemination and Resource Discovery mechanisms.

An ad hoc Resource Dissemination Protocol can be used to advertise a resource in the framework an to report the status of a resource to an RMS. Protocols for Resource Dissemination can be:

- periodical: In periodical dissemination protocols status information of a resource is batched and reported periodically to the RMS. This information can be pulled (it is the RMS that collects the information from the resources) or pushed (the resources send status information to the RMS).
- on demand: Resource information is updated when a specific event or status change triggers the update.

Resource Discovery is tightly bound to Resource Dissemination and can be implemented through:

- Query based approaches where the system is queried by the RMS to find out availability of resources.
- Agent based approaches where discovery agents traverse the system to gather information about resource availability.

An RMS should be able to identify every sensor device used in the Sensor Network or sets of related devices. To do this a common and global name spacing mechanism will be required. Global name spaces can be organised in three different policies:

- flat: In this scheme every resource gets a name at creation time and this name carries no information on the structuring imposed by the system architecture. Flat name spaces are not very scalable and thus they are not quite suitable for the AmI framework.
- hierarchical: With this policy the layer structure of a system architecture is transported to the naming convention used for the resources. Resource names are constructed by traversing the hierarchical structure in a top-down visit.
- graph based: With this policy no hierarchical ordering is established thus resources are named by following the links from one object to the other in the graph structure.

9.2 Component Interfaces

Implementing clean interfaces to connect software components is a quite important task in a project that presents modularity, scalability, extensibility and generality as its main features. Moreover, in many cases the project encompasses distributed computing resources, be it software like processes and data or hardware resources like embedded micro or nanodevices, gateways, servers or storage devices. In these scenarios the design complexity for component interfaces grows rapidly involving mechanism for interprocess communication, design of information exchange protocols, remote service requests and remote service discovery, synchronization, handling of heterogeneity.

There are a great number of possible comparison arguments for studying component interfacing software. Possible choices are:

- Data Representation: What kind of data is moved and how it is wrapped to preserve typing information among possibly heterogeneous components.
- Transport Protocol: How data is moved across the connection that bind the (possibly distributed) components.
- Service Description and Service Location: How services available on servers are described and if such a description exist for a specific implementation. What kind of formalism can be used for discovery of service availability.
- Language Binding and Language Paradigm: In which programming language the formalism can be embedded and what kind of paradigm does it conform to (object oriented, functional, streaming).
- Remote Reference: What is the representation of a reference to a remote service supplier component.
- Synchronization: Whether the communication underlying the component interaction is implemented in a synchronous or asynchronous way.

A very important note is that there exist many bridge middleware tools that enable component using different architectures for their interfaces to transparently interconnect them.

As a final remark it should be noted that often the only way to interconnect components that are distributed on an open network such as the Internet, is to encapsulate all information into HTTP packets. This technique is called tunneling and it is useful to bypass security firewalls who often enable only HTTP to access the target server machine.

9.3 Knowledge Discovery in Databases

Knowledge Discovery in Databases (KDD) deals with a set of theories and software tools that assist humans in extracting significant and useful information from rapidly growing databases [xl]. KDD is a complex iterative process involving different steps that are:

- Understanding of the domain and selection of data sets
- Cleaning, preprocessing, reduction and projection of data
- Matching goals of KDD application to a specific Data Mining method and applying it to data
- Interpretation of and acting on the discovered patterns

Although many of these steps are very important, the core of a KDD process is the data mining step. Data mining may be employed to verify already existing hypothesis or to discover new patterns in data semantic. It is based on tried and tested techniques of machine learning, pattern recognition and statistics.

The tasks a data mining process accomplishes are:

- Data Processing: select, filter, aggregate, sample, clean or transform data.
- Prediction: given a data item and a predictive model predict the value of an attribute of the item.
- Regression: given a set of data items, analyze the dependency of some attributes from others and automatically produce a model that can predict the values of these attributes

- Classification: given a set of classes determine to which class a data item belongs.
- Clustering: partition the data set into a set of classes each of which groups together similar data items.
- Link Analysis: identify relations among the attributes of a set of data items.
- Model Visualization.
- Exploratory Data Analysis: enable interactive exploration of a data set.

There are a big number of different techniques that can be used for implementing data mining algorithms:

- Statistical Methods: used for fitting models to data and verifying existing hypothesis.
- Case-Based Reasoning: examines a set of stored cases and finds similar ones.
- Neural Networks: a system that models the scheme of human brain with the application of learning algorithms to improve the knowledge of the network.
- Decision Trees
- Rule Induction: rules state statistical correlation among attributes or data items.
- Bayesian Belief Networks: graph-based representation of probability distributions.
- Genetic algorithms / Evolutionary programming: algorithmic optimization methods inspired by the principles observed in natural evolution.
- Fuzzy Sets: exploit of uncertainty to make system complexity manageable.
- Rough Sets: may be seen as Fuzzy Sets with a three-valued membership function (yes-no-perhaps).

Another issue related to KDD and in particular to the data mining process is related to the databases that are used during the process.

Many of the KDD tools currently available are generic tools from the AI or the statistic communities. Such tools generally operate abstracting from the data source and this leads to a significant effort in importing, exporting, pre and post processing of data. A classification of the tools used for data mining, in terms of database connectivity, may consider the following features:

- Ability to access distributed and scattered data resources.
- Online / Offline data access.
- Underlying data model used for representing data structure (record stores, relational, object oriented)
- Maximum number of tables, row or attributes and the global size of the databases that the tool can handle.
- Attribute types the tool can handle
- Query language used as the interface between the user of the KDD tool and data. There may be some query language like SQL or some graphical

user interface (GUI) but also some tools offer just the possibility to change the parameters of predefined operations.

9.4 Decision Support System

A Decision Support System (DSS) is a computer based system designed to assist humans in establishing a decision when a high number of variables should be taken into account, or when an intelligent analysis of pre-acquired knowledge is need to achieve a conclusion. DSS make generally use of either KDD methodologies or Expert Systems (ES) techniques.

DSS are computer based applications designed to aid users in making decisions in patient care. They can simplify access to data and visualization needed to make decisions, provide reminders and prompts at the time a particular event occurs, assist in establishing protocols or strategies and in entering appropriate orders into the system when new patterns in the data are recognized. DSS have been shown to be highly effective, sustainable tools for changing operators' behaviour. Designing and implementing such systems is a challenging task because of the computing infrastructure required, the need for data stored in a machine-processable form and the changes to existing work-flow that may result.

DSS are often based on specific vertical tasks such as the generation of alerts and reminders when a particular combination of events occurs.

DSS applicability covers a wide range of application scenarios.

In the clinical field DSS are used to assist clinicians in establishing therapies, detecting trigger conditions in computer monitored patients, discovering new patterns in new forms of diseases, finding anomalies in medical images [xli].

In earth observation DSS has a major task in finding regions of interest on the surface of the planet for real time discovery or prediction of geo-physical or meteorological phenomenons, disaster recovery in case of flood or fire [xlii].

Urban applications involve GPS, traffic monitoring, building analysis, elevation data extraction, underground deployment of pipelines [xliii].

In the military field, simulations can use decision support for establishing defensive or offensive strategies, determine whether a potential target has to be destroyed or not, recognise unidentified flying objects [xliv].

9.5 Model and Architectures for Sensor based applications

In the last years, a great attention, in commercial and academic environments, has been directed toward building of networks of sensors scattered throughout the world [10]. The big differences between sensor-based data sources and other (often well-engined) business-like data sources introduce some problems in adapting traditional database approaches sensor data. On the server side it is necessary to design architectures who can access and efficiently querying sensor data stream without wasting limited energy resources on the sensors. On the client-side, the software installed on the sensors can use their computing power to partially execute data-base operations like joins or aggregations within the

sensor network reducing the very time and energy consuming communication operations.

Near real-time processing because the it could be too expensive to store whole data streams to disc space and because sensor streams represent real world events (accidents, failures) which have to be faced in real-time.

Sensor are typically not reliable.

Sensor have an own computing power which can be used to partially compute queries as data flows through them.

9.6 Server-Side Issues

A first issue related to traditional database behaviour that has to be enhanced to face sensor networks requirements is the assumption of static data sources. This assumption does not apply to sensors who represent, instead, a streaming source of data. The major problem is that a query processor cannot wait indefinitely for data requested from sensor that can be temporarily down because of low power, disconnections due to particular weather or environment conditions or maintenance operations.

Possible solutions are shown in Volcano [xlv] and Fjords [xlvi] and focus on the introduction of queues which present different kind of asynchrony mechanism and pull/push strategies.

Another important issue is related to ensure maximum resource exploitation and optimization.

Reusing data produced and sent by sensors on the central query processor to answer sets of related (overlapping) queries has both the advantages of limiting storage space required in the database and reduce the number of times a sensor has to deliver the same data for different queries.

Adjusting the sample rate of the sensors can be very useful for reducing the overhead introduced by sensors who go on sampling at high frequencies when it is not required.

Directing the sensors to aggregate samples in predefined ways or to drop sensed values that exceed some threshold values can reduce the quantity of information that travels inside and outside of a sensor network.

Other issues have to be faced when the discussion moves from a data acquisition viewpoint to a viewpoint more related to querying the data once it has been received.

Continuous Queries (CQ) is a mechanism that allows a user to query data which is continuously updated over time [xlvii]. A common technique to approach CQ is to store, on the central query processor, the posted queries. When a tuple arrives from the sensors, the related queries are applied to it and the results are forwarded to the poster of the query.

Some experimentations have been made to extend the CQ concept to be adaptive and to apply also to streamed data [xlviii]. Adaptivity refers to changes in the query set, query status, sensors, sensor sample rate or operator order. Applicability to streams requires the query operators to be non-blocking and the

introduction of new operators for some common operation that do not match easily the stream concept (for example the sort operation) [xlix].

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