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Visions for Innovative Applications
and their Social, Legal and Ethical impact

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Abstract

Embedded Wisents devised a roadmap that will accelerate European research in the area of wireless sensor networks and cooperating objects. An important part of the roadmapping is to identify appropriate directions that fully recognise and address the social and ethical impact of cooperating object technologies and their future applications.

This whitepaper explores visions for application areas and their technical scenarios that could potentially be realised once a wide-ranging technology of cooperating objects becomes available. The focus here is on longer term visions that are clustered around a 10-year horizon. It furthers the discussion with an analysis of the social, legal and ethical impacts of such cooperating object's applications.

1. Introduction

This document is structured as follows. First, we examine emerging technological basis for future application scenarios, including ideas from ubiquitous computing, embedded sensor networking, and cooperating objects. This information is derived from relevant technical experts and presented in Section 2, and in much more detail in the WiSeNts Research Roadmap [9]. The technical vision is one in which heterogeneous, loosely coupled systems interact with each other and the environment.

Second, we explore the broad application areas for these emerging technologies. A systematic technical survey of ongoing research in this area was done in the WiSeNts studies D3.1.1, D3.1.2, D3.1.3 and D3.1.4. The process of envisaging future possibilities for applications based on these technologies was opened to a broader audience in two contests where participants submitted short essays describing future applications. A large number of submissions covering a broad range of topics from social interaction to environmental monitoring were received.

Section 3 presents a brief overview of these contests. The range of application areas seen in the submissions, along with highlights of some of the most interesting entries are discussed in Section 4.

Third, we examine the social implications of such applications. We shared the results of the work above with distinguished experts in this area and held an exciting and highly interactive workshop on social, legal and ethical implications of future cooperating objects applications. The workshop is briefly introduced in Section 3 and its results discussed in Section 5. The full report can be found in Appendix D

The workshop highlighted eight main areas in its study of legal social and ethical implications of cooperating object technology. Major issues included: privacy; responsibility for the behaviour of these systems, given the complexity and unpredictability of autonomous interactions between humans, system and environment; ease of use and the digital divide problem; environmental sustainability; and the role of government and industry.

The conclusion was that a variety of legal and technical approaches was required and that it was important to consider these issues early in the development of future systems.

Finally, in Section 6, we use these three sources of input - *technological, application oriented, and social implications* - to consider issues for future visions. We suggest key issues for future technical development and examine the technical and other implications of potential roadblocks raised in the social workshop in the context of cooperating object' applications.

2. Technology

The classical concept of embedded systems as a control system for some physical process (e.g. machinery, automotive industry) has been recently revisited. Two new technical developments emerged and support the notion that systems based on very small communicating computers are likely to have significant socio-economic impact on our society in the next decades.

2.1. Ubiquitous computing

A vision originally described by Mark Weiser in [8] is one where omnipresent computers serve people in their everyday lives at home and at work. It aims to develop systems that sense and interpret the state of the world and human activities in order to enhance the human experience. Current ubiquitous systems range from the nearly imperceptible ones that control lighting, heating, ventilation and physical security in indoor environments to hand-held interactive devices that automatically provide relevant information to users as they move around their homes. Systems are context-aware and adapt to changes in the environment.

Some more extensive applications developed in laboratories now working in ubiquitous systems indicate the potential benefits of ubiquitous computing. Such systems are constructed from networks of computers that can be carried, worn and installed pervasively in indoor and outdoor spaces. Their sensors enable them to detect their location and observe the state of their environment, whereas their actuators interact with environment and with human beings. Collected data about the state of the environment and its users are then further processed and knowledge can be discovered.

Sensors could measure force, sound, light, temperature and most other physical and chemical parameters. Such measurements can be used, for example, to detect human presence and activity, monitor air quality or determine vital signs and other parameters in healthcare. Sensors that acquire visual images are not excluded although their analysis and interpretation is currently limited by the image processing required and its resource costs.

The GAIA project at the University of Illinois [1] gives an interesting perspective for the future technical infrastructure of ubiquitous computing. Physical spaces become interactive systems, or in other terms, Active Spaces. Such environments are analogous to traditional computing systems; just as a computer is viewed as one object, composed of input/output devices, resources and peripherals, so is an Active Space. However, the heterogeneity, mobility and sheer number of devices makes the system vastly more complex. Applications may have the choice of a number of input devices such as location sensing system, mouse, pen, or finger and output devices, such as an everywhere display, monitor, PDA screen, wall-mounted display, speakers, or phone.

In contrast, the European Commission through the ISTAG group put forward the vision of Ambient Intelligence (AmI)[2], which is similar to the Weiser's ubiquitous computing idea. In AmI applications

[1] [GAIA project web page, University of Illinois, Urbana, IL. http://gaia.cs.uiuc.edu/]
[2] http://www.ercim.org/publication/Ercim_News/enw47/intro.html

people will be surrounded by intelligent and intuitive interfaces embedded in everyday objects and environment recognising and responding to the presence of individuals in an invisible way.

The ubiquitous computing and Ambient Intelligence visions strive for user-friendliness, efficient services, and support for enhanced human interactions with systems working in background, invisible to the users.

2.2. Wireless Sensor Networks

Even current handheld and other mobile computers are at least an order of magnitude too large for most of the scenarios envisaged for ubiquitous systems. And even if they were smaller, their cost, management demands and power consumption are incompatible with their deployment in the extremely large numbers required by many of the application scenarios.

Several research projects initiated around the year 2000 have developed extremely small, low cost and energy-efficient free-standing computers with a wireless networking capability suitable for deployment in large numbers. These sensor devices which sense and actuate in their environment not only operate individually, but collaborate together using ad-hoc communication to achieve a well-defined goal of supervision of some area or a particular process.

The most important of these developments was the 'mote' concept originated at the University of California at Berkeley. The name was coined to indicate that they can be regarded as a sort of 'smart dust' (dictionary definition: mote = something, especially a bit of dust, that is so small it is almost impossible to see). The products to date from these projects should be regarded as large-scale prototypes for the much tinier versions that can be expected in the coming years. Miniaturisation with MEMS fabrication is advancing with the goal of producing complete devices with dimensions of a few millimetres - small enough to be embedded in everyday objects or distributed throughout the environment with a cost of 0.5 Euros or less. We expect the Moore's law of doubling the number of transistors on an integrated circuit every 18 months to continue its trend. Although, nanotechnology developments will be required to solve the complex engineering problems in producing chips of sizes of nanometers.

2.3. Cooperating Objects

The classic concept of embedded systems combined with the notion of pervasive and ubiquitous computing and wireless sensor networks as systems that act and react on their environment are rather diverse systems. They create a coherent group of objects that need to *collaborate* to reach a common goal.

The conception of a future-proof system would have to combine the strong points of all three system concepts at least in the following functional areas [9]:

- control of physical processes as embedded systems are capable of doing today;
- have as good support for device heterogeneity and spontaneity of usage as pervasive and ubiquitous computing approaches have today;
- be as cost efficient and versatile in terms of the use of wireless technology as wireless sensor networks are.

The new system of *cooperating objects* consists of individual intelligent and state-full entities or objects that jointly strive to reach a common goal, which involves sensing or controlling of devices, and are dynamically and loosely federated for cooperation. A paradigm shift is envisaged with this vision. Systems will change from passive single agents instruments to pro-active cooperating agents.

The future development of cooperating objects support the broad vision of Sentient Computing put forward in the early 1990s[3]. This is the proposition that applications can be made more responsive and useful by observing and reacting to the physical world. It is particularly attractive in a world of mobile users and ubiquitous computers.

3. Methodology

Longer-term application visions clustered around a 10-year horizon are needed to offer motivation and provide a context for the evaluation of technology proposals in cooperating objects research.

We began the work for this study by eliciting long-term application visions from the participating partners in the Embedded WiSeNts project at an internal workshop. This yielded a useful initial set of application scenarios that are amongst those reported in this document. But we were aware from the start that although the design of cooperating object systems would require significant expertise and commitment, the originators of the visions and scenarios that precede them need not have an immense depth of technical knowledge. Indeed there is a risk that such expertise may obscure or limit their vision. For this reason, the process of envisaging future possibilities for applications based on cooperating objects was opened to a broader audience in two specially-organised Embedded WiSeNts open contests in which participants submitted short essays describing future applications.

In these events, a large number of submissions covering a broad range of topics from logistics to environmental monitoring were received. It is our view that a substantial proportion of them merit further study. Of course any such technology-based visions inevitably have a substantial risk of encountering roadblocks in the intervening years. The roadblocks may be due to lack of technical capabilities or to social, legal and ethical constraints.

For the purpose of comparison of our emerging visions with those of others, we examined other expert studies from the literature on the future of sentient systems and cooperating objects [6, 10, 3, 4].

Finally, in order to identify the social implications of the visions that emerged from these activities and multidisciplinary research issues emerging, we shared the results of the above work with distinguished experts in that area at our final major event, an on-invitation workshop on social, legal and ethical implications of future cooperating objects applications.

The remainder of this section gives an overview of the three main events that were organised by the Embedded WiSeNts project in support of the Visions task:

- WiSeNts summer school competition (small-scale).

[3] Active Badges and Personal Interactive Computing Objects, R. Want, A. Hopper, IEEE Trans. on Consumer Electronics, Feb. 1992. Andy Hopper, Sentient Computing - abridged and updated version of the Royal Society Clifford Paterson Lecture, 1999. Computer Systems: Theory, Technology, and Applications: A Tribute to Roger Needham, Series Monographs in Computer Science, Pages 125-131, Springer, December 2003.

- The Sentient Future Competition (large-scale).
- Workshop on Social Aspects of Cooperating Objects Technologies.

3.1. Open Competitions

To elicit many of the visions reported here, we organised two open contests. An 'Application Visions' competition was held at the Embedded Wisents Summer School on Wireless Sensor Networks and Smart Objects, August 29 - September 3, 2005, Schloss Dagstuhl, Germany.

28 entries were received from the participants in the school. The winning entries and several others were considered of high quality by the judges. Thirteen, including the two winning entries are reproduced in Appendix A. The WiSeNts consortium sponsored the prizes for the first (high-end Apple iPod) and second winners (low-end Apple iPod). The competition was locally administered in Dagstuhl by members of the Embedded WiSeNts (ETHZ and University of Stuttgart).

This contest was seen as a useful precursor to a major competition entitled *The Embedded Wisents Sentient Future Competition (SFC)*. This was sponsored by Deutsche Telekom Laboratories with a generous donation of €10,000 for prizes. The competition was administered by members of the Embedded Wisents team with some external assistance in the judging phase.

The SFC competition was launched on 1 October 2005 with website, email and press publicity. Entries were invited with a closing date of 30 November 2005. The competition announcement, rules and results can be found in Appendix B.

The rules were kept as open as possible to encourage entries from a wide cross-section of people. We hoped that the competition would attract entries in many different formats and styles from ordinary members of the public across a range of disciplines and different countries.

The SFC competition attracted 79 entries in total. Judging was performed in two phases:

1. All entries were reviewed by a panel of 25 reviewers drawn mainly from the Embedded Wisents partners together with three industrial reviewers from Deutsche Telekom Laboratories (Germany) and Ubisense Ltd (UK). Each entry was reviewed by at least three reviewers who assigned a score based on four multiple-choice questions and added a short personal comment.

   Using those reviews and the aggregated scores, all entries were ranked and the top 25 were examined by two Embedded WiseNTs personnel to check for consistency in the reviewing. Then 6 entries were selected based on their scores and review comments for the 'short list', which was used in the second phase. Also, further 7 entries were selected to be mentioned as 'commendable'.

2. In the second phase, a panel of seven experts (four leading members of the Embedded Wisents team, one other distinguished academic and two industry experts) were each tasked to prepare a ranking for the 6 entries on the shortlist. They were also offered the option to include items from the 'commended' list. Finally, this panel held a telephone conference to reach decisions about the award of the three monetary prizes.

We are very grateful to all of the reviewers[4] for their careful and diligent assessments and especially to the members of the final judging panel for their time and effort dedicated. The entries were

[4] The list of the reviewers can be found in Appendix B

evaluated against the criteria of originality of concept, innovation and technical progress, and impact - social, economic and environmental. The panel announced the final results on the 15th January 2006. Prizes were awarded in a special session of the European Workshop on Sensor Networks (EWSN) 2006. Full details of the winning visions and other high-quality entries can be found in Appendix C. We summarise below the winner lists of both competitions. The next section reviews a selection of the most important visions collected from all sources including the open competitions.

Dagstuhl Summer School Competition:

- **1^{st} SCC: Small Child Care** *Zinaida Benenson (RWTH Aachen, Germany)* Category: Health Care.
- **2^{nd} Sensor Pearls** *Matthias Gauger (University of Stuttgart, Germany)* Category: Environmental Monitoring.

Sentient Future Competition:

- **1^{st} Large Scale Body Sensing for Infectious Disease Control** *Markus Endler (Pontifica Universidade Catolica do Rio de Janeiro, Brazil)* Category: Healthcare.
- **2^{nd} BIN IT! The Intelligent Waste Management System**

  . *David Schoch (University of Zurich, Switzerland), Matthias Sala (ETH Zurich, Switzerland)* Category: Environmental Monitoring.
- **3^{rd} Vision of Congestion-Free Road Traffic and Cooperating Objects**

  Ricardo Morla (Lancaster University, United Kingdom) Category: Transportation.

3.2. Social Workshop

The socio-technical goal is to achieve the smooth and reliable integration of humans and cooperating object technology. To achieve this, we need to understand the social, legal and ethical implications of such an inter-activity within future application scenarios.

Cooperating object applications reveal a set of multi-disciplinary design issues in areas that cross the engineering, social sciences, law, economics and psychology. The configuration of cooperating objects at the engineering level is focussed on efficiency and usability with the assumption of fixed functionality and generalised user.

In contrast, the design issues for social scientists and lawyers relate to the social adaptation of technology which can be explicit with handling of user expectations, control of situations and acceptability of systems.

To this end, we sought help of experts from social sciences, law, economics and psychology to expand on the visions in order to identify plausible scenarios and add social, legal and ethical impact evaluations of them. The help came in the form of on-invitation workshop held on the 1st and 2nd November 2006 in Berlin. The International Workshop on Social Aspects of Cooperating Objects Technologies was organised by the Centre for Technology and Society at Technical University of Berlin [5].

[5] http://www.embedded-wisents.org/workshop/

The social, legal and ethical issues that resulted from the discussion of the workshop are presented in Section 5.

4. Overview of Application Visions

108 applications entries were received in total from the open competitions. Out of this, we provide an overview ordered by application areas from the entries we consider are most interesting and could potentially affect the direction of research in the next years. These applications were also scored high by the judging panels of the competitions.

Whenever it is appropriate, we contrast the WiSeNts visions (identified in bold face and fully described in Appendices A, C with those envisaged in [6, 10, 3, 4].

We used the taxonomy proposed in WiSeNts Study *D3.1.1 - Applications and Application Scenarios*. Since this taxonomy addresses applications that can be understood today, we felt the need to extend this set in order to deal with some longer-term visions. We added new areas namely *human augmentation* and *enhancing social interactions*. The former refers to all the ubiquitous cooperating object technology that can be employed to assist our daily activities. The latter area uses cooperating objects to establish or maintain social relationship among people.

4.1. Control and Automation

Cooperating objects would help to enable various forms of automated and distributed process control in indoor or outdoor environments. It is the vision of the next generation of organisations with focus on bridging physical world and the digital information space [3, 4].

The **Monitoring Tape, see Appendix B** vision is a long-term application which requires extremely small hardware in order to easily monitor the conditions of structural materials in bridges and buildings. The tape is easily applied to the area of interest, making construction and preventive monitoring accessible to everyone. There is a risk for using this system to spy on things or people if the sensors are tampered with to gather information on its immediate surroundings as opposed to the monitored structure itself. The sensory system is comprised of sensors capable of exchanging information with other neighbouring sensor systems.

Focus on hardware design of specialised sensors and their miniaturisation is expected in order to realise visions in this area. The development of software frameworks for energy-aware data collection should follow closely the sensor development. Although cooperation to achieve autonomous decisions is a major challenge, it is required in some of these visions.

4.2. Home and Office

These applications aim at improving the well being and space usage at home and office through the gathering of context information.

A key aspect for the design of a future sentient computing application is to provide ambient intelligence for non-expert users. Automatic, self-organising and self-managing systems will be essential for such ubiquitous environments, where billions of computers are embedded in everyday life. The vision of **Ambient Intelligence by Collaborative Eye Tracking** gives some technical insights on subconscious social interactions and indicates directions when other communication is inappropriate. Integration of eye tracking and sentient technology will create a powerful paradigm to control and navigate applications.

In contrast, K. Pister [6] envisages a similar scenario where houses and offices will be aware of our presence, and even orientation, in a given room. Lighting, heating, and other comforts will be adjusted accordingly. If someone is looking for a conference room, they will know which is the nearest available . And if someone is in an unfamiliar building, lighting will guide them, for instance, with a ribbon of arrows on the floor or the walls, annotated with the name of the room they are pointing to, and colour coded if there are two lost people whose paths may cross. Sensors are easy to defeat though, so security of these systems is a major roadblock for this vision.

Other visions, with more technical focus, describe a platform for globally-distributed cooperative sensing that would enable the development of novel applications at unprecedented scales. The **Cooperative Sensing** envisages the fusion of sensors with the omnipresent portable communication devices (mobile phones, PDAs, etc.) and network enabled personal electronics (music players, digital photo cameras, camcorders, etc.). On the assumption of massive penetration of this technology to the general members of the public, simple sensing capabilities will yield useful applications without significant impact on the cost of the devices.

Real-time algorithms for signal processing are needed. This may impose high bandwidth and processing power requirements in scenarios of low-resource cooperating objects. Location services including reliable and accurate localisation schemes for emergency situations need to be in place. Much more effort has to be put into the information processing side, where novel techniques for information fusion, outlier detection, and distributed calibration have to be developed. They should combine the multitude of low-quality sensory information into meaningful representation of the physical reality. These software systems need to be context aware with considerable attention to security and privacy issues.

4.3. Logistics

Visions in this application area foresee that the majority of goods and even some services sold in the market will be trackable from their production line to the delivery. Sentient systems will track the product throughout its life, sensing or reading data about its producers, the production methods used and the environment. It adds further information to each product including the identity of the main producers with their hourly wages, work required for the production and also any airborne sprays detected during the process. The products themselves will trigger alarms in case thresholds are reached (e.g. storage temperature above the limit).

This not only assists the inventory management for the food industry but also helps the monitoring and control of the quality of food. Government agencies, for instance, could receive reports of food recycling. What is most important all these tasks could be performed in real-time.

Fair trading could be realised and verified for products produced by people in third world countries to ensure that producers receive fair reward for their labour and investment (see the **Validated Fair-trade** scenario). To work properly, this scenario ought to have the right type of incentives otherwise entities in the chain can circumvent the validation system (e.g. switching off the sensors).

Another vision outlines a scenario where utilities will be differentiated by placing low cost wireless sensors into taps, lights, switches, heating systems and appliances. Utility companies could provide itemised billing and a whole host of value added services, well-being monitoring and remote control that might even allow the utilities to remotely enable/disable selected devices for whatever reason (please see the **Smarter Utilities** scenario).

The **Smart Labels** vision has some aspects that can be developed today and others that require further research. The basic idea is to make value chains – including production and inbound logistics, outbound logistics, sales and marketing, as well as maintenance and recovery – smarter by using smart labels, and particularly to overcome incompatibilities at the transitions from one phase to the other. These labels should include sensors for acquiring information about their environment.

A large number of mobile sensor systems are expected to communicate in these scenarios. Distributed location schemes need to be developed to avoid the overhead issues of a centralised back-end system. Fault tolerance is an important issue to be addressed. Further research and development on sensor design is required. In particular, small Micro-Electro-Mechanical Systems (MEMS) sensors that can sense chemical and meteorological conditions of the environment in which the product was produced. They should be embedded in flexible labels, similarly to the current RFID tag systems.

4.4. Transportation

Visions in this category should address the safety of road users and pedestrians. Often the envisaged sensor systems would gather data for real-time or ”close” to real-time information services provided by governmental agency and private organisations including insurance companies.

K. Pister [6] envisions that vehicles will be fully aware of the road conditions on a user’s favourite route home, not at the level of some traffic announcer telling that it is slow on a given motorway, for instance, but with detail of the instantaneous speed and history of every vehicle between the user and their destination, as well as the ones that are likely to get on the road, should the user choose to look at that detail. Most likely the user’s agent software will just tell which route to take, and how many minutes it will take.

Similarly, some of the visions received from the open competitions describe scenarios where co-operating vehicles will be aware of dangers and pro-active in making semiautonomous decisions. Proactive safety systems will be in place in every car. The co-operation will allow sensors in each vehicle to monitor the environment condition with in-loco air quality measurements (e.g. nitric oxide, carbon monoxide, etc). The Kyoto protocol will be supported by extensive monitoring of gas emissions - a required task to make our environment more sustainable. The EC ISTAG reports [3, 4] detailed a similar vision to make transport in Europe more economically, socially and environmentally sustainable. This requires the commitment of different sectors of the society including travellers (they may need to change their behaviour), manufacturers of vehicles to equip them with the latest traffic and pollution monitoring and road safety technology, and the government in the investment and management of transport infrastructures.

Traffic congestion in urban areas will be mitigated by advanced congestion-based charging which will be supported by pervasive distributed traffic monitoring system. The **Supportive Road** scenario (see Appendix B) put forward a scenario where sensors installed on the roads assist in various traffic applications including road congestion avoidance and safety of drivers. Also, a few non-critical applications will emerge allowing people to exchange their favourite audio tune with other vehicles travelling together.

Similarly, the long-term vision **Congestion-Free Road Traffic** takes a step further to propose a technical solution to address traffic congestion. It explores the concept of dynamic time-space corridor that can be negotiated between cooperating vehicles to guarantee congestion-free journeys from departure to arrival.

To fully address the safety of road users, the technology should be developed to all road users. Consider the case that a system in a vehicle after exchanging information with other vehicles to avoid a collision, instructs the driver that an action should be taken, say turn to the left. Such a decision would not make sense if other vehicles (e.g. motorcycles or bicycles) and even pedestrians were not part of the decision making process.

Towards this goal, the **Sentient Guardian Angel** proposes the use of wireless sensor networks to address dangerous traffic situations for elderly pedestrians, children as well as for disabled persons. Communication between the networks of the participants is used to detect the threat at an early stage giving adequate warnings using suitable audible/visual actuators, alerts and instructions to the ones involved.

Keeping records of a vehicle's service history is always important for re-use of vehicles. An used car, for instance, could give a detailed list of the parts that have been replaced or repaired over the course of its lifetime [5]. Other information such as the amount of gas emissions could be added to this list so that sellers could get commercial advantages due to any reduced historical gas emissions, which is likely to be taxed higher in the future.

Significant investment in technology and infrastructure is required. The cost of instrumenting road infrastructure may be apportioned by governments and private organisations such as insurance companies for keeping information on drivers driving history. Privacy is a major concern here and will be analysed in Section 5.2.

These scenarios present a different system perspective than the current transportation applications surveyed in the WiSeNts study *D3.1.1: Applications and Application Scenarios*. Unlikely the ad-hoc and infrastructure-less characteristics, some of the visions call for a pre-established infrastructure of sensor nodes deployed in major roads. For instance, base stations every 1 to 5 Km and high-bandwidth backbone network. The sensor systems vary from one scenario to another but it would include vehicle passing detector, structural material integrity, motion sensors and video capturing systems. Actuators are also discussed in a form of vibration, audible and visual (e.g.s LEDs). Most of such an information should be provided in real-time. In some scenarios, a third-party may be needed to establish trust relationship between consumers and companies.

4.5. Environmental Monitoring

Environmental monitoring applications are of crucial importance for the scientific community and society. Thousands of square kilometres of geographical area may be supervised and duration of this can be years. Application scenarios envisage that cooperating objects will monitor vegetation growth and air/water quality (see **Pearl sensors**), oil spills and will coordinate (e.g statistical sampling and data filtering) to create a big picture of natural spaces. Because of the large-scale aspect, natural disasters such as prominent flooding and earthquakes could be anticipated through improved models of the global environment. Authorities would be alerted and actions taken quickly to respond to natural disasters. More sensors will tell accurately what the weather will look like.

Plantation swarms would be monitored individually or as a group and controlled to prevent outbreaks and disastrous economical losses that follow in the trail of, for instance, the desert locust in Africa and western Asia (see the **LocuSent scenario**). Invasive insects could be controlled in regions where they have no natural predators.

Also, the management of the population's waste could be efficient and sustainable leading to higher life quality and less costs for the city authorities. Financial incentives may be employed to encourage the correct disposal (see **BIN IT! The Intelligent Waste Management System**). Carbon emissions and absorption would be measured or estimated in order to charge/ration citizens according to their consumption. Individuals can receive carbon debits for their use of energy and carbon credits for clean energy that they generate, for example, by investing in wind farms and for carbon-absorption activities including trees and other vegetation planted or invested in. Carbon debits are then converted to a tax on the individual. The direct benefits are increased environmental and public health gains. There exist the risk, however, of privacy loss and fraudulent interference with sensor systems (see **Zero Carbon City** scenario).

Systems designed for these applications are to be very robust, and localisation is an essential task. Since the nodes are unattended in this class of applications, the system must be power efficient and fault tolerant. Furthermore, long lifetime of the network must be preserved while the scale increases in order of tens or hundreds, and solar panel for energy should be considered. With regard to sensor types, the following measurements should be considered: vehicle emissions, vegetation growth, monitoring of water quality, implantable sensors for animals, sensors for biochemicals , for instance, using Bio-MEMS (continuously in contact with the blood), gas emissions for forest fire monitoring - to cite a few.

4.6. Health and Fitness

Merging wireless sensor technology into health, medicine and fitness applications will make life much easier for doctors, disabled people, patients and overall population. They will also make diagnosis and consultancy processes faster by patient monitoring entities consisting of sensors. Those sensors will provide the same information regardless of location and automatic transitions from one network in a clinic to the other installed in patient's home will be available. As a result, high quality healthcare services will get closer to the patients. The benefits of this will be clear, although short-comings are expected too. For example, employers can demote employees based on an analysis of biomedical data (biosensors data and genetics information).

The European Commission through the ISTAG reports on the vision of well-being in the ageing society [3, 4]. The vision is the one where new paradigm of personalised healthcare will support EU citizens in living healthy lives, minimising time in hospital, at local doctors or in care homes. Europe's increasingly elderly population will be able to live more independently in their home environment. The service envisaged is pro-active where more personalised and preventive health care is employed as opposed to reactive methods such as treatment for the elderly.

The application scenarios foresee critical diseases diagnosed by means of tele-monitoring of individuals with specialised biosensors, with some of them implanted in the human body. K. Pister [6] goes further to envision that there will be no unanticipated illness. In his vision, sensor implants will monitor all of the major circulator systems in the human body, and provide the monitored individual with early warning of an impending flu, or save their life by catching cancer early enough that it can be completely removed surgically.

The **Intelligent Pills** vision envisages the scenario that patients swallow pills that activates upon reaching the stomach. The clear benefits are the efficient use of medicine, less waste, and better dose, tailored to the patient needs. The intelligent pill takes measurements of the level of chemicals in the stomach and blood and releases the optimal quantity of medicine needed to alleviate the symptoms of the patient. The pill is built of biodegradable material and it is small enough to be expelled from the body.

Small sensors and actuators in our clothes through smart fabrics will sense our physiological signals and movements in order to understand our health conditions. This should provide historical data to aid in achieving precise diagnosis. Computers should be able to interpret when we perform a physical activity, for instance, walking or jogging. Patients and doctors will be easily located inside hospitals.

Enhanced experience in fitness exercises will be achieved with useful feedback systems (e.g. audible and haptic) from tiny computers embedded in sports clothes and equipment. Entertainment systems for audio and video ubiquitous in mobile phones will be part of the overall body personal system. We will communicate with our clothes, watches and other accessories and they will cooperate with other user's cooperating objects.

An extension of the system will allow physiological signals of child's body to be constantly monitored from various points. Parents can make sure their children are thermally comfortable and healthy. (see **Body area sensor network for small children scenario**).

Within large-scale application, monitoring of infectious diseases may be possible. At first, cattle should be monitored with cooperating objects. The system will then be extended to humans at some point in time (see **Large scale body sensing for Infectious Disease Control**).

In this application area, localisation is an prime issue because it is critical to determine where the person is. The reliability and the minimisation of the delay between the source of the event, and the other end-point of the system is also important. The context and the person activity in the measuring time are also relevant. These applications should require minimal maintenance, use of biodegradable materials, and new biosensors. The energy harvesting from the body heat seems conceivable.

4.7. Security and Surveillance

Sensors and embedded systems provide solutions for security and surveillance concerns. These types of applications may be found in varying environments such as deserts, forests and urban areas - to cite a few. Communication and cooperation among networked devices increase the security of the concerned environment without human intervention. Natural disasters such as floods or earthquakes may be identified earlier by installing networked embedded systems closer to places where these phenomena might occur. The system should respond to the changes of the environment as quick as possible. Security and surveillance require real-time monitoring technologies with high security cautions. The mediums to be observed will mostly be inaccessible by the humans all the time and hence robustness takes an important place. Furthermore, maintenance may not be possible also in these applications and then power efficiency and fault tolerance must be satisfied.

The personal safety is improved with cooperating objects. K. Pister [6] envisages that personal belongings that are worth more than a few dollars will know their owner. The user will be able to find it whenever they want it. Stealing cars, furniture, or other valuables will be unusual, because any of a user's valuables that leave their house will check in on their way out the door, and produce a sound if removed without permission.

Another scenario addresses the issue of people carrying weapons and other potential hazards that could potentially lead to incidents such as terrorist attacks. It envisages that this could be monitored and detected by cooperating objects deployed within cities. Warnings could be sent to the police and people concerned (see **Human Security Network**).

4.8. Education, Training and Entertainment

A potential future application area is education. It is possible to provide more attractive lab and classroom activities involving cooperating objects. The scenario is characterised by a high dependency on the context. Activities will aim at merging embedded systems into the education methods. Thus, the systems must be cost effective, affordable by many users and should have a high degree of automation.

The **Self-learning Children** sensor network is a middle-term vision whose aim is to enable a person, for instance, to sit at the playground and let their children to play. The system should notify the parents only when situations that might possibly harm his children occur. The decision if a situation might be dangerous should be taken by the sensor network autonomously based on previous experience. Similarly, the long-term **Small Child Care** scenario creates a smart environment around a child, enabling trusted people including parents, teachers, doctors and police to gain information about the child and to interact with them by means of their surroundings. Parents will be able to locate their children with location systems and cooperating objects sewn into their clothes [5].

In the area of physical education, the UK Sesame project's vision[6] is one in which athletes and coaches are continuously provided with precise and relevant information about their performance, their body state and posture, presented in a form determined by sport-specific training requirements based on a careful analysis of coaching methods and coaches information needs.

4.9. Human Augmentation and Leisure

It refers to all the ubiquitous cooperating object technology that can be employed to assist our daily activities. The vision **Agnostic Algorithms of Creation** explore the possibilities of interference among two distinct but almost identical dimensions by letting things that happen in the virtual world to reflect themselves in reality.

A **Sensor Network for our Brain** is a long-term vision that proposes the possibility to better influence the storage of information and the communication in our brain.

[6] http://www.sesame.ucl.ac.uk

Finally, the **Father in Womb** vision considers to transport some of the mothers experiences as a pregnancy woman to the father, allowing him to follow the embryo growth, movements and sensations, providing mechanisms for interaction between both.

On the leisure side, the EC ISTAG vision [3, 4] on new media paradigms for digital leisure aims at developing new forms of content and experiences for global networks. The next 20 years is foreseen as the place for opportunities to embrace and support new forms of digital media which are more interactive and intuitive than the ones available today. In addition to the currents media forms - text, photos, audio and video - the future will reserve space for multimedia and multimodal experiences, including systems that evoke the sense of touch and smell, sights and sounds. These systems should support new forms of social interaction, novel means of creative and artistic expression.

4.10. Enhancing Social Interaction

Ubiquitous devices will present a reality enhanced with added textual and visual information to assist our daily activities (see the **Agnostic Algorithms of Creation**).

Individuals will know more about the personality type of other people through the cooperation of embedded sensory systems in our clothes and other accessories. Our social behaviour in a given situation and context will be profiled (see the **Personality Sensors** scenario). Our eyes and face expressions will be tracked and understood (see **Ambient Intelligence by Collaborative Eye Tracking**). Perhaps individuals will tend to interact more with other people.

Those applications falling within the previous category and this one pose new technical requirements including advances in wearability of tiny sensors and design of body implantable devices that are powered through energy harvesting. Cooperation is a challenge observed in scenarios for enhancing interactions among people.

4.11. Challenges Emerging from the Visions

The sections above discussed a number of ideas for future applications. The technical challenges one faces span across areas such as sensor miniaturisation, real-time data collection and feedback, ad-hoc cooperation - to cite a few.

The WiSeNts Roadmap [9] discusses such issues in detail. In particular, the Roadmap gives an overview of the social issues associated with the future use of cooperating objects. It made the observation that if things of daily use are part of cooperating objects or if cooperating objects can monitor the behaviour of people with various types of sensory systems the information on an individual becomes much more continuous and comprehensive.

In contrast, it also touches the problem of a big brother who knows everything about people who are then unaware of who knows what. If these and other social issues are not fully addressed it is very questionable whether or not cooperating objects will find broad acceptance.

This whitepaper adds further details on this issue with an analysis of the social, legal and ethical impact of cooperating object technology in future applications.

5. Social, Legal and Ethical Issues

The major goal of the social workshop held in Berlin in early November 2006 (see Section 3.2) was to identify and discuss the grand challenges emerging on the social side of the cooperating objects technologies, and related technologies like ubiquitous and pervasive computing.

The workshop covered a wide range of relevant social aspects within four thematic areas:

1. What are the expected implications for market structures and the basis of legal governance, especially concerning questions of privacy and security?
2. What do we know about user expectations and emerging practices of usage, and which methods are suitable to assess them?
3. What are the possibilities of designing human-machine-interaction in a reasonable way, especially when technical autonomy has to be balanced with the requirements of human intervention?
4. What are the possibilities of managing large scale distributed systems, if the involvement of humans is considered?

In what follows we provide an overview of these issues and potential directions for research to address them. In the following, citations to the workshop speakers' contributions are made by names in italic. Further details and full attributions can be found within the workshop report in Appendix D.

5.1. Relevant Technical Characteristics

We observe that most of the issues discussed within the above themes arise from a range of technical characteristics of cooperating objects. We will focus on autonomy, complexity and reliability.

Autonomy A cooperating object as technically defined in the WiSeNts Roadmap [9] is a single entity or collection of entities consisting of sensors, controllers (information processors), actuators or other cooperating objects that communicate with each other and are able to achieve, more or less autonomously, a common goal.

Such a definition implies a certain degree of autonomy which highly depends on the application domain. In semi-autonomy, systems provide information through advanced interfaces to assist users in their decision making process. In contrast, in fully autonomous scenarios, objects gather contextual information and make decisions on behalf of the user.

Decker discussed further the autonomy concept under three aspects, which are all tightly coupled and at various levels of abstraction. Technical autonomy refers to the ability of a machine to execute certain actions using its internal control system. The second level, personal autonomy, refers to the ability of individuals to perform actions in the area of reasoning, but not necessarily morally correct. The third level, ideal autonomy, is where individuals execute actions in the area of reasoning but referring to moral criteria.

IBM's autonomic computing vision closely relates to the first and second definitions. The vision is one in which the computing systems can manage themselves given high-level objectives from administrators [7]. This vision has biological connotation since human autonomic nervous system governs our heart rate, body temperature and other vital functions without the central control of our brain.

Complexity Complexity is believed to arise from the highly distributed nature of cooperating objects as heterogeneous systems that need to communicate and cooperate (semi- or) autonomously. The deployments of such systems will be either with some form of federated control or totally decentralised.

The interaction between objects may create systems that have no designer. Even when well-engineered subsystems are integrated, the outcome of the interactions among them can be unpredictable. One reason being that the number of system states increases exponentially with the number of systems integrated. The other is that cooperating objects may be required to inter-operate in circumstances that were not originally intended by their designers.

Weyer believes that this complexity generates new uncertainties and risks since the system can be out of control. He observed that the aviation industry is a pioneering sector of the society for issues of distributed control and its complexity. The major problem presented was the collision of airplanes, which remains an unresolved issue. A number of different systems are used in different countries, which makes inter-operability between them a hard problem to address.

Reliability The cooperating object systems should produce reasonably predictable outcomes within some defined thresholds, and steps outside the thresholds should be controlled. The unexpected behaviour of the system is an issue. Thus, reliability and dependability are major technical issues associated with complexity. These create social and legal implications.

Failures of cooperating objects are inevitable. Hildebrandt observed that the self-healing characteristic of fully autonomous systems [7] implicitly mean unpredictability by nature so that they need self-correcting of undesirable situations.

Another issue identified which can have an impact to the reliability is the rate of technology penetration. The road safety application is an example. Cooperating objects installed in vehicles may assist drivers in their decisions, which can be for instance braking, turning or reducing their speed. Other road users potentially without the technology should not be excluded from the decisions taken by the vehicles cooperating objects. They need to be part of the decision making process or otherwise it will be difficult to justify the system.

Restrictions due to hardware and power consumption mean that conventional reliability engineering techniques such as hardware redundancy will have limited applicability in future cooperating scenarios. Also, these objects are supposed to exist closely coupled with the environment and so will be subject to a wide range of largely unpredictable inputs and changes in the context.

5.2. Privacy

Cooperating objects used in the application areas discussed in this document can sense and actuate in the environment. To achieve this goal, these systems collect as much as data as possible as it may help to decide on the context now or sometime in the future.

But the privacy issue demands minimal data collection with well defined purposes for the period of time the data is deemed necessary. Because of this conflicting goal, it was observed in the workshop that ubiquitous cooperating objects and privacy are at odds.

Meints suggested that miniaturisation of devices to achieve the vision of cooperating objects will make it easier to hide systems but the issues of interaction and explicit consent would become intensified. Users must be informed and give explicit consent for data collection and processing under the data protection law in European countries.

To shed light on this issue, the following broad questions were raised in the workshop:

- Social aspect: how do people perceive privacy? In particular, do they really care about privacy? Are they willing to trade privacy for useful cooperating object services?
- Technical aspect: how do we achieve privacy within cooperating objects scenarios? Should privacy be an issue in the design space of such systems?
- Legal aspect: what policies should be used to protect collected personal data of individuals?

At the moment, the general members of the public do not seem to be concerned about privacy even with the fact that they are constantly monitored with CCTV systems literately anywhere in some European countries.

A vast amount of personal data are collected today with web-based systems. Google Mail holds personal data enclosed in email messages of their users and process it, for instance, to display context-related advertisements of sponsored products and services. Such data if correlated with the Google search results can certainly tell a lot about the user's personal life.

Users' perception of privacy may change in the future with higher penetration of cooperating object technologies. Users may become fully aware of the privacy issues as more personal data are collected from various sources.

Ben Allouch pointed out that some studies ordered by a few high-tech companies suggest that if people get more advantage out of a product or service they may not care about privacy. Although this is purely the viewpoint of a company striving to put their products in the market, it helps to set the context for the following question: is there a trade-off between privacy and benefits of technology?

Collecting medical and fitness training information could be beneficial to the individuals in order to early detect any disease. Because of this people may allow the disclosure of such information to other parties which could include employers. We may have to address the issue, however, that employers could be using medical data in their staff promoting or demoting decisions.

A similar scenario is the hypothetical example of 'pay-as-you-live' insurance that envisages companies which will calculate the personal health risks on the basis of monthly monitoring of data. Smoking a single cigarette would increase the premium, jogging in the park or gym decrease it [5]. As part of the service contract, the user would trade the privacy of their personal data for paying less premium monthly. Of course, this scenario raise ethical question for eligibility of insurance claims: what diseases should be covered by the insurer?

Scenarios of cooperating objects in transportation raise the question of whether vehicles should be allowed to track the position of other road users because of the necessary data communication for road safety and traffic management applications.

5.3. Responsibility and Liability Construction

Cooperating objects can sense and actuate in the environment adaptively. To achieve this, systems should communicate autonomously and achieve their goals reliably.

Further consequences of the technical characteristics of cooperating objects are:

- *Lack of transparency:* the cooperating objects are likely to be obscure with respect to processes, existing data and extracted knowledge. This issue is due to the physical miniaturisation of devices, the autonomy and requirement for hiding the complexity of the system from the users.

- *Shift of control:* the application scenarios can potentially shift power in our society, from the users to a set of (semi or fully) autonomous entities in the form of cooperating objects.

These two consequences make very difficult (or almost impossible) the task of identifying responsible entities in cases of system failures. Responsibility is the basis for legally *constructing liability*. Law experts believe this is a roadblock for the future development and commercialisation of such technologies.

Responsibility may dissipate within the application [11] or disappear completely due to autonomy, complexity and distributed/decentralised control. *Hilty* presented some case studies from the aviation sector to exemplify the issue. The first world's fly-by-wire airplane (A320) crashed into a forest in 1998 (Habsheim - France) because the computer assumed the pilots were trying to land, while they were making a low and slow-speed pass for an air show. The responsibility in this case was very difficult to establish. There was no single cause of the accident, all technical systems did exactly what they were supposed to do. In particular there were no coding errors in the software.

Hildebrandt offered a subjective explanation for why it may be impossible to establish responsibility. The ability of being aware of one's own consciousness is an important characteristic of humans. It is the rare capacity of humans to put things in perspective and reason about possible actions. Unlike humans, the researcher argues that autonomic computing objects that cannot reflect about their own actions cannot be blamed, everything the object performs happens via 'autonomic computing', i.e. without any central control. So how could someone construct liability in cases of system failures?

The problem of finding responsibility accentuates with autonomous control of robots. The common design practice today is for robot systems to be constructed as *black boxes*, which can only be assessed with reference to its overall behaviour. These objects normally learn using internal states and environmental information collected from their sensory devices. Within this, learning robots should be distinguished from those without machine learning capabilities because the use of learning algorithms might influence the liability for damages caused.

It is extremely difficult, however, to precisely gather the environmental context, especially in face of unforeseen circumstances. The technical question is how can robots anticipate and deal with them?

Should we ever reach the point where actions of a machine are unpredictable because of their learning systems and lack of transparency, the law may claim that no basis can be found to make the system liable to their actions.

5.4. Digital Divide

Cooperating object technology may accentuate the problem of digital divide, which is the gap between those with access to digital technologies and those without.

The issue of education is key here. People may be reluctant to access the technology even when it is made available to them. This seems to be a bigger problem in developing countries, which in some cases lack the fundamental education system for their children. Some may argue that in other countries, children are growing up with technology in their daily lives. This is a favourable situation to achieve technology-literacy.

A new dimension of this issue is the automated discrimination processes which means that those individuals with access to cooperating object technologies could face discrimination on the basis of income, race and social class. This creates a new issue which is a social divide but among those who use the technology. *Toepfer* exemplified this with the scenario where two users walk in an intelligent room. Both have different preferences for ambient temperature. While one prefers 18C, the other feels more comfortable with 22C. For whom should the system optimise the temperature - for the premium customer who pays more for the service, or should it reach a compromise? Other similar examples can be found in the home and office and transportation application visions.

5.5. Ethical issues

Ethics is referred to here as the moral principles for maintaining basic human rights and other social constraints. The fundamental question that arose from the workshop is how we can achieve the right balance between human and machine agency in order to prevent the rise of machines and the dehumanisation of users within the long-term applications?

This is a rather broad question which is pervasive to all social and legal impacts discussed above including privacy, liability, sustainability and justice to avoid the digital divide.

Although answers to these issues are rather specific to domains of applications and social-cultural contexts, ethics should be treated as the guiding question for a thorough discussion.

5.6. Sustainability of technology

The scenarios considered here envisage a large number of almost invisible computers cooperating to achieve a common goal. Once cooperating objects are installed, it will be difficult to replace them. For instance, sensors to measure trees health (see Zero Carbon City vision) will not be easy to be replaced. Not only is there the technical risk of making these systems work reliably but it could lead to major environment and health problems.

Hilty pointed out that some studies by Swiss universities concluded that pervasive computing might make the electronic waste problem almost intractable. There are three types of environmental impacts of the technology [11]:

- First order: effects of the physical existence of the technology
- Second order: indirect environmental effects due to its power to change processes

- Third order: environmental effects of the medium or long-term adaptation of behaviour or economic structures due to stable availability of the technology and services it provides.

Technological systems should not decay at the same rate as today. Technology needs to become sustainable. Today we throw it away and purchase new ones. Users will need to learn how to re-use technology in a modular way. Engineers need to design systems that can be re-used by combining pieces of existing systems. The approach of re-use could be implemented with loans of systems to their users as well. This could generate a cycle of use similarly to what happens in other sectors (e.g. vehicles). The issue of sustainability of technology needs to be tackled at the technical and political levels to be effective.

6. Conclusions

Scenarios for longer-term applications are needed to offer motivation and provide a context for the evaluation of technology proposals in cooperating objects research. This document discussed future applications and their social, legal and ethical impact on our society.

The open competitions provided a useful technique for gathering visions. The social workshop extended it with the identification of relevant social and legal issues that must be addressed in order to ensure the smooth and reliable integration of humans and cooperating objects in these applications.

The discussion revealed a set of multi-disciplinary design issues in areas that cross boundaries between engineering, social sciences, law, economics and psychology. More research is needed drawing on these disciplines in the design of distributed object applications. The requirements for research on the technical issues of cooperating objects are covered in the WiSeNts Research Roadmap [9].

Ethics is pervasive to the scenarios for cooperating objects. The participants of the workshop agreed that it should be the guiding question to ensure the social compatibility of scenarios for privacy, liability, sustainability and justice.

Below we highlight the major issues identified and provide a brief discussion on possible directions for multi-disciplinary research.

6.1. Privacy-compliant system design

The privacy issue demands minimal data collection with well defined purposes for the period of time the data is deemed necessary. Users must be informed and give explicit consent for data collection and processing under the data protection law in European countries.

At the moment, general members of the public do not seem to be concerned about privacy even with the fact that they are constantly monitored with CCTV systems literately anywhere in some European countries. Users' perception of privacy may change in the future though with higher penetration of cooperating object technologies. Users may become fully aware of the privacy issues. It is important therefore to begin discussing the issue and the solution space which spans across areas such as economics, legislation and engineering.

Studies suggest that if people get more more advantage out of a product or service they may not care about privacy. *Kubler* believes that data are negotiable economic goods and customers should receive compensation from their service providers based on levels of disclosure of private data.

In contrast, the German studies [2] conclude that there are a few legal approaches that can be used to address this issue but there is no pure solution in the legal domain. Technical solutions such as data minimisation, purpose binding of data collected and controlled identity management should be used as well.

The important message is the consensus that early adoption of privacy in the design of systems should be encouraged. Privacy should not be dealt with as an add-on function to the system with data filtering and minimisation [10]. From an economic standpoint, if privacy is not addressed at an early stage later corrections through regulatory measures can be expensive to implement.

The design, however, must not be rigid and should be adaptive to consider enforcement of new legislation. Some companies have already claimed that addressing privacy in the system design of AmI brings cost and complexity to the overall system. But the lack of compliance to the data protection legislation is a non acceptable financial risk for any company [2].

6.2. Responsibility and Liability Construction

The cooperating object technology is likely to demand further legal measures for the areas of data privacy and dependability of systems.

Legal implications largely depend on the level of autonomy of the cooperating object scenarios. Are they there to provide information to assist users in their decision making process (semi autonomous)? Or are they there to make decisions and take actions on behalf of the user? The latter is of most concern.

Full autonomy brings the issue of *transfer of control* from the users to a set of autonomous entities in the form of cooperating objects. Such a shift of control and the near impossibility of identifying responsible entities in cases of failure make any *construction of liability* an extremely difficult task. The global context with systems deployed in different countries makes the issue even harder to deal with. Law experts believe this is a roadblock for the future development and commercialisation of cooperating objects technologies.

Clear specification of functionality of systems is a key aspect here. Complexity is believed to arise from the highly pervasive and distributed nature of the system and it needs to be addressed in the design space of the cooperating objects systems. Distributed control could also raise the issue of dissipation of responsibility. The aviation industry have shown that is extremely difficult to establish responsibility for accidents that involve complex distributed computer control.

One of the approaches would be to hide from the users the inherent complexity of the system. But there is a compromise to achieve. The system itself is likely to be composed of miniaturised devices (physically invisible) and the more the functional details are hidden, the less transparent the system becomes. Lack of transparency in the processes, existing data and extracted knowledge is a major legal implication.

The functionality of cooperating objects must thus be transparent to the users and 'black boxes' designs must be avoided. Changes and the results of processes must be properly documented.

For instance, the learning algorithms of intelligent cooperating objects must be clear to their users.

However, care must be taken here. Even if the user knows about the internal system of an object (assuming the user is educated enough for this) the learning process can still result in unpredictable autonomous systems.

Transparency then becomes a broader issue. The system needs to indicate what it has identified as worth learning and propose a plan of actions to deal with unexpected circumstances (which are the ones to cause the most problems).

This seems to be a step well beyond the concern of transparency raised for data privacy and liability construction. It is only when privacy issues with respect data collection and processing are solved that the issue of transparency of machine learning systems can be fully addressed. This is a long-term issue that deserves further investigation though.

6.3. Reliability and Dependability

Cooperating objects are supposed to exist closely coupled with the environment and so will be subject to wide range of largely unpredictable inputs and changes in the context.

In light of inevitable failures of the systems one approach is for the cooperating objects to advertise their current status so that applications may adapt and continue to provide best-effort functionality in these situations. This is the concept of Dependable Systems for Sentient Computing as advocated in [1].

A dependable system can provide, at any time, a specification of current system performance and status, often associated with levels of confidence. Dependability is then the property that provides the necessary support to tell how reliable, how available and how safe the system is.

Dependable applications would analyse such results and quality measures before taking any action which can be critical as for example in healthcare where actuators perform medication and other procedures.

6.4. New Types of Human-machine Interfaces

To achieve the full vision of cooperating objects while addressing the legal issues one needs to balance the autonomy of these systems with human intervention.

On a technical and social perspective, the design of human-machine-interaction that takes into account such a balance is a major challenge. New types of user interfaces are needed to support such an interaction between humans and almost invisible autonomous objects.

Research on cooperating objects should strive to design systems and user interfaces that fulfil real users needs and expectations. *Shapiro* suggested that the research community in ubiquitous computing seem to be creating solutions for problems that either do not exist or are not useful.

The palpability concept presented by *Shapiro* relates to the usefulness of ambient intelligence systems applied to real world applications. In this framework, invisibility is complemented with visibility and automation with some form of user control. There is a balance in many of the radical concepts of ubiquitous computing application scenarios. This is likely to affect positively issues previously discussed such as liability construction.

A method for achieving palpability is to involve the user throughout the design process of systems, for instance, through ethnographic studies to fully understand the user's needs.