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tel. växel 020 722 111, fax 020 722 4374

VTT Technical Research Centre of Finland, Vuorimiehentie 3, P.O. Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 4374

VTT, Vuorimiehentie 3, PL 1000, 02044 VTT
puh. vaihde 020 722 111, faksi 020 722 6027

VTT, Bergsmansvägen 3, PB 1000, 02044 VTT
tel. växel 020 722 111, fax 020 722 6027

VTT Technical Research Centre of Finland, Vuorimiehentie 3, P.O. Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 6027

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# Abstract

This paper contains the Roadmap for Sensor Networks development at VTT. The work was conducted in the WiseNet (Sensor Networks) Key Technology Action (WiseNet KTA) project during 2006.

The approach to tackling the problem is two-sided: first, we illustrate the technologies suitable for wireless communication in general and, second, we consider three different fields of application: consumer, industrial and infra. These applications have been chosen due to our vision of the most promising fields of application in the future.

Most of the technologies can be used in all fields of application. However, there are specific types of communication standards for industrial applications. The use of technologies in different fields is a common interest when the technology revolution is going on at the same time as the cost of the components is decreasing.

The purpose of this report is to give a vision of the future with regard to research topics in the field of sensor networks. We do not give milestones in terms of years in which the technologies should be ready but we do try to describe substantial results in the selected topics.

# Contents

# 1. Introduction

Strongly distributed sensor and actuator networks are becoming more and more important in research and the future. It can be said that wireless sensor networks form the basis for the smart environment of the future. Many applications can be seen to rely on this technology. In the future, sensor networks will offer efficient tools to collect information critical for the maintenance and control of industrial processes, monitoring of the infrastructure and environment, and even monitoring of human health or performance in sports or during work.

The development of sensor networks requires knowledge in many fields of science and technology. Among others are the development of miniature scale, low energy and intelligent sensors, the development of networking and routing technologies. The 'know-how' regarding sensors and networking is not, however, sufficient for practical applications. Furthermore, deep knowledge of user requirements, modelling, and design techniques related to the area of application is required.

This roadmap is a result of the WiseNet KTA project conducted during 2006. Many knowledge centres and researchers have contributed to the document. Ilkka Korhonen, Marko Suojanen and Markku Pietikäinen were responsible for consumer applications. Mikko Sallinen was responsible for industrial applications and Hannu Maula for environment, infrastructure and building applications. Juhani Hirvonen was responsible for the roadmap and coordination of the whole project.

There are several other roadmaps covering the same area or some area of application within this roadmap. At the end 2006 the Embedded WiSeNts Consortium published The Embedded WiSeNts Research Roadmap [Marron et al., 2006], in which they present information on the research roadmap envisioned for Cooperating Objects. The Embedded WiSeNts project was created in September 2004 as a Coordination Action funded by the European Commission under IST/FP6. They define Cooperating Objects as small computing devices equipped with wireless communication capabilities that are able to cooperate and organise themselves autonomously into networks to achieve a common task.

Frost & Sullivan published Wireless Networks in Industrial Automation in their Technical Insights series, which examines the major technology trends in industrial wireless networks for industrial monitoring and process control, manufacturing, logistics, supply chain management, and machine-to-machine (M2M) wireless communications [Frost & Sullivan, 2006].

ISA – The Instrumentation, Systems and Automation Society – published Wireless Networks for Industrial Automation 2nd Edition [Caro, 2005]. The book is good state-of-the-art survey of wireless technologies in industrial automation.

# 2. Scope and contents of the document

We adopt the definition of sensor networks from Wikipedia, which states: “A wireless sensor network (WSN) is a computer network consisting of many, spatially distributed devices using sensors to monitor conditions at different locations, such as temperature, sound, vibration, pressure, motion or pollutants. Usually these devices are small and inexpensive, so that they can be produced and deployed in large numbers. The size and price requirements imply that the devices’ resources in terms of energy, memory, computational speed and bandwidth are severely constrained. Each device is equipped with a radio transceiver, a small microcontroller, and an energy source, usually a battery. Each devices relay information from other devices to transport data to a monitoring computer.”

The definition above is quite strict and we do not require that a sensor network fulfils all of the requirements. At the beginning of the project actuator networks were also included in the roadmap area. In this paper we focus on wireless sensor networks.

The project was planned to be application-driven and the most important application areas were identified as:

- Consumer applications
- Industrial applications
- Environment, infrastructure and buildings applications.

In this roadmap, ‘Environment, infrastructure and buildings’ covers the natural and built environments.

Although the project was planned to be application-driven, theories and technologies common to all areas will be covered. However, the following technologies were defined not to be within the focus of WiseNet:

- Development of basic radio technologies (NFC, RFID, etc)
- Development of network protocols as such
- Development of energy scavenging technologies
- Development of a new sensor
- Security.

This document is divided as follows. First we present some new business opportunities. Second, an overview of the current state of the art is presented. Third, we present future visions and challenges for each application area. Finally, we present challenges for theory and ICT tools.

# 3. Business opportunities

## 3.1 Consumer applications

There is no clear terminology for wireless sensor networks in the research community since it is a real challenge to define unique expressions in a multidisciplinary research field. As far as consumer applications are concerned, the items in the list below are regarded as some form of wireless sensor network:

- RFID sensors and readers
- Self-organizing wireless sensor networks consisting of dozens of sensors or more
- Personal point-to-point connectivity (e.g. Bluetooth devices, heart rate monitor)
- Cellular networks consisting of base stations and mobile phones.

These four fields have been developed almost in isolation from each other. It has been forecast that in the future fourth-generation network these separate fields will be merged into one heterogeneous hierarchical network that will provide seamless network services both locally and globally.

In consumer applications in particular, sensor networks are closely related to the following concepts:

- Ubiquitous computing
- Pervasive computing
- Ambient Intelligence
- Context awareness.

All these concepts use sensors and sensor networks as a sensing, communication, processing and analysis tool that performs the basic work to enable the application at hand. Sensors integrated with radio technologies, protocols and embedded software applied to a sensible application integrate in a smart sensor. Sensor network services and applications are the key factors for successful business in consumer applications.

### 3.1.1 Market forecasts of mobile phone sales and short-range radio technologies

In March 2006 Nokia raised its estimate for growth in worldwide mobile device sales to 15 per cent, saying 80 per cent of the increase will be in the emerging markets of Asia and Africa. Nokia estimated that the number of mobile phone subscribers will reach 3 billion in 2008. The market research company In-Stat estimated that there will be 2.3

billion mobile phone subscribers in 2009, whereas Ericsson has estimated the number to reach 3 billions before 2010. Currently, there are 2.2 billion mobile phone subscribers, and 800 million mobile phones were sold in 2005 [Prosessori, 2006].

Philips Semiconductors has estimated that half of the mobile phones on the market in 2010 will include an NFC chip. There are already many pilot tests of mobile payment with Nokia NFC shells going on. It is likely that many future NFC applications will be related to mobile payment. NFC is expected to gain ground in mobile phones within the next few years and can be used as a stand-alone wireless technology or combined with Bluetooth in applications with communication or interaction between mobile phones and ambient devices/objects [Prosessori, 2006].

In-Stat estimates that 150 million ZigBee radios will be shipped in 2009. According to the Semiconductor Applications Market 2006 by Future Horizons, the number of shipped ZigBee will be 150 million in 2006, increasing to 750 million in 2010. Currently, the total number of shipped ZigBee radios is 2.5 million. The first potential ZigBee applications are home automation, the control of consumer electronics devices, health monitoring and industrial applications [Prosessori, 2006].

The market research company ABI Research estimates that 500 million Bluetooth chips will be sold this year. The great majority of the shipped Bluetooth chips go to mobile devices but Bluetooth is also gaining popularity in the consumer electronics sector. For example, the coming game console Playstation 3 by Sony will be equipped with Bluetooth technology. The Bluetooth Special Interest Group (SIG) announced that the next-generation Bluetooth traffic will use WiMedia Alliance’s Ultra Wideband (UWB) technology in the physical layer. Freescale Semiconductors was the first company to demonstrate Bluetooth traffic using a 110 Mb/s UWB link at the end of 2005. UWB technology speeds up the data rate from 721 kb/s to 480 Mb/s. According to Bluetooth SIG’s plans, the first Bluetooth-UWB products will be introduced in 2007. The first Bluetooth upgrade will be performed this year with enhanced data rate (EDR) extensions that provide data rates up to 3 Mb/s [Prosessori, 2006].

Ultra WideBand (UWB) technology enables very high data rates (480 Mb/s) in personal area networks (radio range ~10 meters). IEEE didn’t succeed in the standardization work of IEEE 802.15.3a UWB due to two competing UWB technologies: MBOA and WiMedia. Staccato Communications forecasts that mobile phones equipped with UWB technology will appear in 2008. The most likely application area for UWB technology is heavy multimedia, e.g. video and digital television applications. There will be peripheral products in the market in 2006 that implement Wireless USB (WUSB) connections with UWB technology. There are 3.5 billion USB ports in the world, which promises huge markets for WUSB peripherals. Power limitation regulations for UWB devices are under development in Europe and Japan, whereas UWB devices are already in the market in the USA [Prosessori, 2006].

Bluetooth dominates mobile local connectivity (range of 10 meters). In the mobile-centric approach the use of peripheral UI's is governed by several Bluetooth UI profiles. A low power version of Bluetooth is being developed (LEE) and will probably compete with ZigBee. Within a few years Bluetooth, USB, IEEE1394, UPnP (or IP-based networking) MAC/PHY layers will be replaced by UWB, providing convergent connection between consumer electronics, the PC segment and the mobile segment [Intel, 2005].

### 3.1.2 Possible applications in consumer segment

Commercial sensor and sensor network solutions have mainly focused on industrial, infrastructural, environmental, military and automotive applications. So far, there are few commercial sensor network products and applications in the consumer market. In this paper sensor networks are considered within a more general definition than in traditional approaches. From this point of view, mobile phones can also be regarded as sensors networked by a mobile network and, increasingly, through additional short-range connections. Mobile phones are also adopting more and more actual sensor capabilities. As a simple example, high mobile phone density inside the coverage of a GSM cell can give an indication of some important occasion (e.g. a rock concert or traffic jam).

The spatio-temporal density distribution of network nodes (mobile users or location-based services) can give information about activities inside the network coverage, even without necessarily disclosing the identity of any individual node member. The usefulness of this information naturally depends on its spatial and temporal resolution and accuracy, but also on related "side information" from other sources. The very basic information can at least serve as navigation help (to find or avoid the event). With additional information on the event or the network members, more sophisticated services are possible.

The business opportunities arise from collecting the generated data from a (e.g., mobile phone) network into a central database and exploiting it in consumer profiling, one-to-one marketing and providing new infotainment services. This can take place in a broader area (city) or more constrained space (shopping centre). In order to be able to distribute appropriate information to the right people, data mining techniques are needed (e.g. consumer profiling and segmentation). These new services are interesting for B2C companies that have a loyalty programme or CRM system implemented and also for many technology and service vendors. Even if actual personal profiling is not available or desirable, profiling can build on location, time, and social environment-based statistical modelling of consumers. In this case the location distribution data (geographic or other) from the network is essential.

Sensors are customarily thought to be low-power devices, but as their quantity may be large, the generated data volume to be processed, e.g. by data mining, could become very high. In low-bandwidth networks this may be a problem. Considering the processing-bandwidth trade-off and flexibility of the processing architecture, it would be desirable to start the data mining process at as low a level as possible.

Consumers themselves could also produce information that may help in focused marketing. They could attach textual descriptions, tips, or even rich content like multimedia to geographical locations (or a point otherwise defined in the network) to be distributed to other parties accessing their network. The content can either be made available for retrieval or it can be pushed to other parties. The former method is suitable for a limited or unlimited audience, while the latter can only be used inside a predetermined group. This group can form a virtual community built around some common interest with some agreed code of conduct and mutual network communications. Virtual communities may be an advantage to marketing because of their intrinsic pre-filtered interest profile.

A variety of 3G-enabled mobile phones are available in the market, WLAN is already integrated in some mobile phones and RFID shells or chips for mobile phones exist. Bluetooth is becoming more and more popular in mobile phones. The Garner Group estimates that about 90 per cent of mobile phones in Europe will contain Bluetooth by 2008. This enables consumers to communicate directly with each other via Bluetooth, e.g. when exchanging information or using some information or entertainment services. An example of such a service is the BluetoothDate dating service. Furthermore, according to eBIRD Scandinavia, 25 per cent of mobile phones in Finland contained integrated camera in 2005.

Together, these phone-to-phone communication channels and phone-to-server channels and sensors cause a set of consumer mobile terminals to act as a distributed ubiquitous network of sensors.

Wireless sensors are currently used in wellness and health care applications. The current state of the art includes the use of wireless on-body sensors (such as heart rate belts or foot pods) communicating with a wearable user interface (typically, a wrist-top computer) to monitor exercising, and a wearable intelligent social alarm system with a wrist unit including sensors (IST Vivago Wristcare) for independent living applications.

These applications are currently rapidly emerging. The majority, if not all, of these application scenarios are satisfied by a star-like network topology, where sensor is communicating with a master unit – little inter-sensor communication is needed.

Health care and wellness is a business sector that is growing faster than GNP in all OECD countries. In Finland there are successful companies utilizing sensors in fitness and sports (Polar Electro, Suunto), in independent living (IST) and healthcare (GE Healthcare). In addition, Nokia is looking for possibilities in this domain too. Gaming is another increasing sector.

There is clear market potential in sports and fitness applications utilizing wireless sensors, wearable user interfaces (such as wrist-top UIs), and handheld computers as storage and computing resources. The business opportunities in this field are demonstrated by the success of companies like Suunto and Polar Electro, which specialize in this sector.

The challenge in creating business models is to find cost-efficient solutions with good usability and easy configurability. Sensor technologies based on standards are likely to be the most successful in the market. It is hard for proprietary technologies to make a breakthrough in the market since the product sales volumes are high and companies manufacturing standard technologies are able to produce large numbers of units. Independent living is a sector with huge potential due to the increasing number of elderly people requiring support for independent living – however, the business is less mature than in the fitness sector.

The most interesting application areas include:

- fitness and sports
- games and game consoles
- physical and tangible user interfaces
- health care applications, such as chronic disease management and home hospital
- independent living applications for the elderly
- targeted marketing
- services for communities
- time and/or location-based information and entertainment services.

## 3.2 Industrial applications

The growth in business opportunities in sensor networks is highly related to the growth in embedded systems. There are forecasts of a huge increase in embedded systems around us. In this framework, sensor networks provide a measurement platform for advanced measuring systems.

An example can be given from the automotive industry: the whole industry in Europe has a turnover of around 500 B€ / year and employs 2.7 million people in the EU. Nowadays, 20% of the value of each car is embedded electronics. This percentage is expected to increase to 35–40% by 2015 [Artemis SRA 2006].

### 3.2.1 Possible applications in industrial segment

The large potential in the different application fields can be listed as follows:

- Machines and vehicles industry
- Manufacturing and process industry
- Human-centred automation
- Logistics
- Sensors and instrumentation.

One potential field of sensor networks is distributed maintenance and diagnostics of machines and vehicles. Due to the reducing price of sensor networks and the easier management of complex networks, building up such a system will be possible. This means that different parts or elements of the machines will include intelligence and decision making, and can operate separately. This kind of technology is application-independent and has a lot of business potential. The application potential relies on the following factors:

- Use of cheap and replaceable sensors in the industrial environment
- Sensor fusion: better use of current sensor networks, fusion of measurements
- Requirements of sensor networks for multi-parameter control problems
- Scalable middleware for industrial applications
- Optimization of wireless band
- Tools for managing and configuring sensor networks
- Real-time measurement systems
- Power management.

Examples of this kind of application are active control of noise and vibration. The potential in the manufacturing and process industry relies on the same technology as human-centred automation and logistics. At the moment it is possible to find large savings and simplicity in the logistics of the industry. There are a lot of stores that can be re-organized and have their complete logistics rebuilt using RFID technology. Every year a lot of bad decisions are made based on incorrect information about the location of goods in the supply chain.

A cross-technological approach will be required in all the application domains. To be able to build up a cost-efficient systems technology transfer from other application domains is a vital issue.

In the future, the requirements for sensing and observing the environment in the manufacturing industry will increase. These sensors will be used by humans in the production as well as by robots and other production machines. Requirements for the flexible use, such as the plug-and-play operations, of these sensors are needed. Use, replace and reconfigure of new sensors will be carried out, depending on the variation of the products.

## 3.3 Environment, infrastructure and buildings

In this roadmap, 'Environment, infrastructure and buildings' covers the natural and built environment.

For the time being we are experiencing a transition period in measurement technology. The single-sensor wired precision instruments are well established and commercialized. In environmental measurements, the typical price class is 10,000 € or more. The measurements are made at a few points and very seldom continuously. Sensors based on optical fibres have made permanent on-line measurements possible, especially in large infrastructures like dams and bridges, but this is still expensive and is only used when compulsory. This is why the new MEMS-based sensors and wireless sensor network technology has raised lot of hopes in these fields. "Instrumenting the world" and "100 nodes instead of one, without wires" may well reveal those hopes.

The new technology is still in the development phase and few companies are selling real products. Researchers are experimenting in laboratories and the goal of the end-user pilots is to justify the new technology and to demonstrate its potential. Wireless sensor networks will monitor contaminants in soil, air and water. They will support detailed characterization of carbon and water cycling and endangered ecosystems. They will serve as early warning systems for critical civil infrastructures and they will help to maintain its service level and security. Data from sensor networks will be combined with data from other sources, including space-borne data and existing databases.

The challenges in environmental and infrastructure applications lie in the following topics:

- Data analysis methods by fusing sensor network data and other data

- Good demonstration projects
- Good products
- Reliable vendors
- System-level integration
- Long battery life
- Good user interface
- Visualization.

### 3.3.1 Possible applications in natural and built environment

The environment, and especially the built environment, is a heavily regulated area in the EU and also globally. The increasing requirements for safety, service level and long-term sustainability will mean more and more measurements and new needs to prove that all the requirements are fulfilled. At the same time we have to adapt to the situation where our age structure is getting older and we will lose a lot of the workforce and experience when the baby boomers retire during the next ten years. The investments in the infrastructure will decrease and optimized life-cycle management of the infrastructure maintenance will be needed. These will all make the monitoring and measurement market flourish. The urbanization rate is 50% globally at the moment and it will rise to 80%, as it is already in South America. We are dependent on our urban infrastructure. A power blackout or water shortage will change a city into a catastrophic state in a few days.

The management of our critical infrastructure will need a lot of all kinds of sensor networks. New threats like terrorism and climate change with extreme weather conditions will place such technology in vital role in our early warning systems.

Potential areas of application are:

- Catchment area weather/rain monitoring
- Coastal seabed monitoring
- Groundwater monitoring
- Contaminant monitoring
- Bioreactor monitoring
- Combined sensor network-remote sensing environmental monitoring
- Underground infrastructure monitoring
- Road and traffic management
- Bridge management
- Railway and road tunnel management
- Multi-utility tunnel management

- Water network management
- Power network management
- Flood management.

Let's take three examples:

- *Management of Helsinki Energy's Multi-utility Service Tunnels*

  Helsinki Energy and Helsinki Water have concentrated their main power lines and water mains and some other utilities in downtown Helsinki into the tunnels.

  The length of the tunnels is 40 km, and after some years it will be over 50 km. Multi-sensor networks with over 10 k nodes will be needed for proactive risk management and security purposes.

- *Management of Bridges*

  All new, large bridges will have permanent monitoring systems when they are constructed.

  The problems are the old, small bridges that are situated scattered in remote locations.

  They are the major bulk of the bridges and have deteriorated badly. An integrated monitoring and management system will be needed for those bridges, where wireless sensor networks could have an important role. This is global problem.

- *Ecosystem monitoring for carbon flux estimation*

  At present, carbon flux can be estimated using heavy and expensive measurement stations, but the measurements cannot represent large regions.

  Information relevant to carbon flux monitoring can be acquired using satellites with total area coverage but lower accuracy than in-situ measurements.

  Development of low-cost wireless sensors for in-situ carbon flux measurements and the combination of this data with space-borne data could drastically improve our understanding of the functioning of the ecosystems.

# 4. Technological basis

## 4.1 Wireless communication technologies

Wireless instrumentation cannot be based on a single solution for all applications – a variety of technologies must be used. This is due to the wide spectrum of data rates and transmission ranges needed in the applications. In addition to standardized technologies, there are a lot of proprietary solutions available. Even though they might have some attractive features, most industrial users prefer standard-compatible products that can be bought from several manufacturers.

In the following, a short survey of potential technologies is given.

### 4.1.1 Bluetooth, IEEE 802.15.1

Bluetooth is a general purpose WPAN solution for small form-factor and low-cost devices. It was originally meant for cable replacement between computers, peripherals and mobile phones. In addition to two-point connections, master-slave *piconets* can be formed with up to 8 devices. Piconets can be combined further to build wider *scatternets*.

Bluetooth uses the 2.45 GHz RF technology and can cover a communication range up to about 10 m with 0 dBm transmit power. The bit rate for the standard version 1.2 in the physical level is 1 Mbit/s, offering a maximum user data rate of 721 kbit/s. In the standard version 2.0, the physical level bit rate is 3 Mbit/s, corresponding to a maximum user bit rate of 2.1 Mbit/s.

The basic Bluetooth is too power-hungry for some applications, such as wireless sensors. To overcome this problem, Ericsson introduced a lighter version of the standard called Bluetooth Lite in 2003. Another step in the same direction is the Bluetooth Low End Extension, or BT LEE, demonstrated by Nokia in Tekes' WIRSU project. With minor modifications to the Bluetooth chip, BT LEE achieves a major saving in power consumption and cost of the chips embedded into small devices. The concept also enables dual-mode Bluetooth chips, i.e. standard and LEE functionality in the same chip.

Another trend in the future Bluetooth evolution is higher bit rates, which is based on the adoption of a UWB radio interface from WiMedia Alliance or UWB Forum.

### 4.1.2 ZigBee, IEEE 802.15.4

ZigBee is a technology promoted by ZigBee Alliance, a large industrial association. The medium access control and physical layers are standardized by IEEE 802.15.4, and higher layers are defined by the Alliance in the ZigBee Specification.

ZigBee can be considered a competitor for Bluetooth. While its bit rates are lower than Bluetooth, it aims for better flexibility, lower power consumption and lower cost. It is claimed to be a technology for a wide range of building automation, industrial, medical and residential control, and monitoring applications.

Based on the 2.4 GHz RF technology, ZigBee can reach data rates up to 250 kbit/s. To maintain compatibility with earlier low-end systems, some of the channels use the 915-MHz band for America and the 868-MHz band for Europe. These auxiliary channels have bit rates up to 40 kbit/s and 20 kbit/s respectively. The communication range goes up to 100 meters. The network topologies include star, cluster tree and mesh. A network can have up to 65,000 nodes.

IEEE has founded an official task group, TG4a, to prepare a supplementary standard IEEE 802.15.4a. Its target is to provide communications and high-precision location capability, high aggregate throughput, and ultra-low power consumption. A baseline draft specification includes two optional physical layers: (1) UWB impulse radio with high-precision ranging, and (2) the chirp spread spectrum introduced by Nanotron Technologies.

The main initial markets of ZigBee are in home, building and industrial automation, and rather more in fixed installations than in mobile phone applications. Frenzel lists the top 12 ZigBee applications [Frenzel, 2006] in the January 2006 issue of Electronic Design:

1. *Monitoring and control of lights, HVAC, and security in commercial buildings*
2. *Industrial monitoring and control, with sensors and actuators in manufacturing, process control, farming, environmental, and other areas*
3. *Automatic meter reading (AMR) with load management, enabling the utility industry to cut costs and save electrical and gas energy*
4. *Oil and gas production, transmission, and exploration with supervisory control and data acquisition (SCADA) as well as other telemetry*
5. *Home monitoring and control of lights, HVAC, security, and other systems*
6. *Medical and health monitoring of patients, equipment, and facilities*
7. *Military, with battlefield monitoring and robotic control*

8. *Automotive, with sensor networks to report on the status of all systems*
9. *Consumer, with remote control of toys, games, TV, stereo, DVD, stereo, and appliances*
10. *Computer peripherals, such as the mouse, keyboard, game controllers, and printer*
11. *Active RFID, with battery-powered tags for shipping, tracking, and storing larger items and asset management*
12. *Machine-to-machine (M2M) communications between devices via the Internet.*

### 4.1.3 WiMedia, IEEE 802.15.3, IEEE 802.15.3a

The WiMedia Alliance has supported the preparation of the standard IEEE 802.15.3, which defines the MAC and PHY layers for high-rate wireless personal area networks. Even though the major applications of WiMedia are in high-speed wireless multimedia, some industrial applications might also use it.

The first standard IEEE802.15.3 is based on the 2.45-GHz radio technology, achieving bit rates up to 55 Mbit/s with communication ranges up to 50 meters. However, this standard has not gained commercial success.

An alternate PHY layer definition is under development in co-operation with Ecma. The key feature is the modulation method, which is now uses the Ultra Wide Band technology, more precisely Multiband-Orthogonal Frequency Division Multiplexing, MB-OFDM. The bit rates go up to 480 Mbit/s. There is a convergence layer for interoperability with several upper layer protocols, such as wireless USB, wireless 1394 and Bluetooth.

### 4.1.4 UWB Forum, IEEE 802.15.3a

UWB Forum is a rival of WiMedia, consisting of a different group of industrial companies. It also has connection with the standardization group IEEE 802.15 TG3a. The target application is similar: “a universal wireless technology with the performance to connect consumer electronic multimedia products”. A new standard is being prepared, with two modulation methods under consideration: (1) Direct-Sequence Ultra-Wideband (DS-UWB), and (2) Multiband-Orthogonal Frequency Division Multiplexing (MB-OFDM). The bit rate will be up to 480 Mbit/s and the communication range up to 10 meters at 110 Mbit/s and 2 meters at 480 Mbit/s. The Common Signaling Mode (CSM) concept is used for interoperability and coexistence with different UWB technologies.

### 4.1.5 NFC – Near Field Communication

A new interconnection technology, Near Field Communication (NFC), was launched by Sony, Philips and Nokia with the establishment of the NFC Forum In March 2004. The NFC Forum is a non-profit industry association for advancing the use of NFC short-range wireless interaction in consumer electronics, mobile devices and PCs. In co-operation with Ecma, the NFC Forum will promote the implementation and standardization of NFC technology to ensure interoperability between devices and services. As of the beginning of 2006, over 50 members have joined the NFC Forum.

Near field Communication (NFC) is a short-range (max. 20 cm) wireless point-to-point interconnection technology that has evolved from a combination of earlier RFID contactless identification and interconnection technologies (ISO14443A/MIFARE/ FeliCa). It enables users of handheld electronic devices to access content and services in an intuitive way by simply “touching” smart objects (e.g. sensors, RFID tags, other handheld devices) – that is, connecting devices just by holding them next to each other. The communication is based on inductive coupling. The 13.56 MHz carrier frequency is used and the maximum data rate is 424 kbps.

NFC-enabled devices can emulate both RFID readers and tags. In addition to this there is an NFC-specific communication mode, NFCIP-1, defined in the ECMA-340 standard. This mode is intended for peer-to-peer data communication between devices. The NFCIP-1 mode is divided into two variants: active mode and passive mode. In active mode both participants generate their own carrier while transmitting data. In passive mode only the initiator generates a carrier during communication and the target device uses load modulation when communicating back to the initiator in a similar way to passive RFID tag behaviour. This makes it possible to save power in the target device, which is a useful feature if the target device has a very restricted energy source, such as a small battery.

### 4.1.6 IEEE 1451 standard for smart sensors

One problem for sensor manufacturers is the large number of networks on the market. It is too costly to make unique smart transducers for each network type. However, by using digital communication schemes networked transducers can eliminate a large number of lengthy parallel analogue wiring and thus reduce the installation, maintenance and upgrade costs of measurement and control systems.

The IEEE 1451 standard has been developed to address the above issues. The objective of the standard is to establish a common communication interface for smart transducers.

This would make it easier for transducer manufacturers to develop smart devices and interface those devices with networks, systems and instruments.

As defined in the IEEE 1451, the digital interface to access the data is based on two elements: a smart transducer interface module (STIM), and a transducer electronic data sheet (TEDS). The interface allows the system to retrieve information on the sensor type and functional parameters, as well as to adjust these parameters. The output of the sensor will then be a digital value properly scaled and calibrated.

The sensor manufacturers will take advantage of the standard in their new products. It is also possible to apply the standard to old sensor products with external adapters.

### 4.1.7 Other wireless technologies

Even though there are several standard radio technologies for wireless local connectivity in sensor applications, non-standard technologies will have an established position in applications that call for some specific features, such as lower energy consumption, better immunity to eavesdropping or longer communication ranges, than the standard technologies can offer. Examples of commercial non-standard technologies are Dynastream ANT wireless personal area network, EnOcean radio transceivers, Espotel ERF radio network, Aura Communications LibertyLink inductive transceivers, and Ident Technology Skinplex capacitive body area network.

Infrared communication is commonly used in devices with local communication capability, such as remote controllers, mobile phones and other portable devices. The most prominent standard organization is the Infrared Data Association, which was founded in 1993 to promote interoperable low-cost infrared data interconnection standards that support a walk-up point-to-point user model. The Infrared Data Association has defined several standards, such as IrDA Data, IrDA Command and Control. IrDA Data is recommended for high-speed, short-range line-of-sight point-to-point cordless data transfer. IrDA Data supports data transmission up to 16 Mbit/s (100 Mbit/s under development) with a minimum communication range up to 1 m. Mobile phones with IrDA connectivity typically incorporate a lower bit rate version of the IrDA Data. IrDA Control supports data transmission at 75 kbit/s and a minimum communication range of 5 m with pointing capability.

## 4.2 Consumer applications

The fundamental problem in consumer applications is that it is really difficult to find suitable applications that could be very widespread and considered useful by people. This is specifically true for consumer applications. It is a challenge to find consumer applications that could provide something totally new and useful for consumers. Although the goal is to find some application scenarios from wireless sensor networks, the technology issues shouldn't be forgotten. Application technologies are introduced in the following chapter.

### 4.2.1 Applicable technologies

In consumer applications the central platform is typically a mobile device, e.g. a mobile phone, a PDA, or a PC. When considering sensor network applications in the consumer segment, PDAs typically have more alternative radio solutions to connect with sensors than mobile phones have. The connectivity to sensors in a mobile phone is typically restricted to Bluetooth technology. There are also some RFID and NFC solutions in the market but these technologies are not as common as Bluetooth. On the other hand, it is foreseen that mobile phones, in adopting internal sensors like thermometer, compass, acceleration sensors, etc., are taking more versatile roles in sensor applications. The internal camera can be seen as the first sensor breakthrough (even though it may differ from the conventional notion of a simple "sensor"). Leopold et al, consider the applicability and suitability of Bluetooth technology to sensor networks in their paper "Bluetooth and sensor networks – a reality check" [Leopold et al., 2003].

The mobile phone can be regarded as the most natural personal device in wireless sensor network applications. In addition to GSM/GPRS/3G connectivity, today's high-end mobile phones are typically equipped with Bluetooth and IrDA for local connectivity. Nokia and some other mobile phone manufacturers have shown great interest in adding NFC connectivity to mobile phones, which will probably be counterbalanced by a reduction in IrDA-enabled phones in the future. For sensor and other energy-limited applications, Nokia has also shown interest in modifying the current Bluetooth radio for low-end applications (Bluetooth LEE). There have also been plans to embed WLAN, ZigBee and long-range RFID technologies in mobile phones, but Nokia, as a market leader, has not shown much interest in adding these radio interfaces into mobile phones in the near future. However, there is at least one small mobile phone manufacturer that has introduced a phone that has ZigBee radio (Pantech & Curitel). There are other personal devices as PDAs and laptops that have USB interfaces. There are ZigBee modules on the market that can be plugged in to the USB port. This makes a personal device a gateway to a wireless sensor network based on ZigBee technology.

At the beginning of 2005 Nokia established a SensorPlanet platform in co-operation with the leading edge sensor network research groups of American and European universities (Berkeley, UCLA, Colorado, Copenhagen, EPFL, to name a few). The result of SensorPlanet is a global test platform for mobile-centric wireless sensor network research. [SensorPlanet, 2006]

Nokia provides its partners with free mobile devices equipped with a SensorPlanet SIM card. All the data from the mobile devices is gathered into SensorPlanet servers at Nokia. Research groups can carry out any research using the devices but Nokia should be informed and receive the data. The applications created by the research groups should be open source [SensorPlanet, 2006].

It is necessary to have a wireless communication medium in consumer applications since consumers find wires annoying in, e.g., in fitness applications. Gateway devices in the sensor network may be wired due to the need for a power supply but if the gateway is wearable, it should be wireless. Wireless connectivity calls for very low power consumption since operation without changing batteries should last for several months or years, depending on the application. Consumer applications call for energy scavenging solutions that enable operation without batteries in the long-term.

### 4.2.2 State-of-the-art in wireless sensor network research

This chapter describes a few research projects that utilize wireless sensors or sensor networks in consumer applications. Most of the presented projects are focusing on fitness and wellness applications.

#### 4.2.2.1 Wireless Motion Bands by Nokia Research Center

Laurila et al., in their conference paper “Wireless Motion Bands”, present a wearable sensor device prototype called Motion Band. Motion Bands can be strapped to any body part to track body motion and full body poses and gestures in real-time. Motion Band collects measurement data from 3D accelerometers, 3D magnetic sensors and 3D gyroscopes, and after pre-processing transmits data to a mobile phone that operates as a central unit. Data is transmitted using a Bluetooth connection. There can be one master (mobile phone) and seven slaves (Motion Bands). The authors consider Bluetooth a suitable solution for real-time body motion tracking due to the high data rate and low latency. They have developed a custom protocol on top of Bluetooth’s RFCOMM protocol that divides the sensor data into packages. Body part orientation is calculated in the Motion Band’s MCU, which reduces the workload of the mobile phone. The authors regard interactive training, expressive sports and active gaming the most interesting applications in consumer markets. The next step in their research is to perform end-user tests in the wellness, fitness and gaming applications. Their future goal is to build completely transparent wearable sensor solutions and applications that people find inspiring [Laurila et al., 2005].

#### 4.2.2.2 The Bluewand as an interface for ubiquitous and wearable computing environments

Fuhrmann et al, in their conference paper "The Bluewand as Interface for Ubiquitous and Wearable Computing Environments", present a Bluewand, which is a pen-like device that can be used to control other Bluetooth devices by hand movements. Bluewand detects orientation and movement in space using accelerometers and gyroscopes. Rotations are detected by three orthogonal vibrating gyroscopes. Lateral movements are tracked by two accelerometers. The data from these sensors is transmitted via Bluetooth to a device that can interpret movements and execute corresponding commands. They think that the Bluewand is best suited to applications that only require a limited set of commands or for the controlled devices that don't have a natural place for the human-computer interface. Feedback to a user is provided by Bluewand's vibrator and by sound via earphones and by vision on a display unit in a controllable device. Bluewand is equipped with a button and an IR-LED that can transmit codes for pairing the Bluewand with a controllable device [Fuhrmann et al., 2003].

Fuhrmann et al. built a customized Bluewand Bluetooth stack that was designed to support their application scenarios. In one application scenario the Bluewand periodically makes a Bluetooth inquiry to find the Bluewand-controllable devices nearby. If the found devices have audio feedback (e.g. mobile phone), the devices that support the audio are searched too (e.g. Bluetooth headset). Then the Bluewand creates an authenticated connection to a headset by sending the information to connect a mobile phone. In this way a mobile phone can efficiently pair with the headset without having to make an inquiry. Via this connection, the mobile phone sends audio feedback on the commands triggered by the Bluewand [Fuhrmann et al., 2003].

#### 4.2.2.3 Giving the Caller the Finger

Marti and Schmandt introduce their unique finger sensor system in the paper "Giving the Caller the Finger: Collaborative Responsibility for Cellphone Interruptions". They have created a system in which a cell phone decides whether to ring by collecting votes from the participants that are in a conversation with the party being called. When there is an incoming call, the mobile phone first determines who is in the conversation by using a network of wearable Conversation Finder sensor nodes that are worn by every person. The mobile phone sends a broadcast message to all the Conversation Finder nodes within range. If the queried nodes determine that they are in conversation with the node whose user is receiving the phone call, they are asked to send a directed message to their finger rings, which activates the vibration alert in each ring. Then the wireless finger rings start vibrating in the hand of each person in the conversation. Nobody knows whose phone is about to ring when the vibration alert is activated, but each participant has the possibility to prevent the call anonymously by touching the finger ring. If nobody touches the finger ring, the phone will ring. They carried out a user study that resulted in more vetoes during a collaborative group-focused setting than during a less group-oriented setting [Marti & Schmandt, 2005].

The Conversation Finder nodes have a short-range radio, dual microprocessors and a microphone and send periodic "heartbeat" messages to indicate presence and "talk" messages to indicate that the user is currently speaking. Each node listens to the radio messages from nearby nodes and the algorithm classifies the sensor nodes into different classes. Each node will provide the information listed below [Marti & Schmandt, 2005]:

- The number of participants in the user's conversation
- The ratio between listening and talking for each participant
- Is the user the talker right now?

#### 4.2.2.4 Sensing to support physical fitness

Lester et al. present their activity recognition system in a paper entitled "Sensing and Modeling Activities to Support Physical Fitness". They have designed and implemented a wearable multi-modal sensor device and developed classification techniques for the recognition of ten activities with ~95% accuracy. Their sensor platform, the multi-modal sensor board, has seven sensors that measure the following quantities: audio, 3-axis acceleration, barometric pressure, temperature, humidity, compass heading and light level. The data can be transmitted to an iPaq or laptop using a wired link and to a cell phone or laptop wirelessly using the Bluetooth connectivity of Intel Mote (iMote). The platform can sample and transmit data to a Nokia cell phone for 8 hours with two 200 mAh Li-ion batteries. Using iPaq, it can continuously sample and store data for about 12 hours. Currently, their platform is able to recognize the following ten activities with better than 95% accuracy [Lester et al., 2005]:

The platform has been utilized in obesity, COPD (Chronic Obstructive Pulmonary Disease) and physical activity research projects. The goal of the COPD research is to detect the onset of a pulmonary event in patients with the COPD by looking for reductions in the amount of activity a person performs. With early detection, it might be possible to provide preventative treatment, avoid emergency room visits and extend patients' lives [Lester et al., 2005].

Researchers are developing a new sensor platform based on iMote2 that has an IEEE 802.15.4 radio on board. The new platform will allow real-time data analysis in physical activity applications. They are going to perform V02 measurements. The total energy expenditure is measured along with the rate at which the energy is used during various physical activities [Lester et al., 2005].

#### 4.2.2.5 Recognizing and discovering human actions from on-body sensor data

Minnen et al. present their activity detection system in "Recognizing and Discovering Human Actions from On-body Sensor Data". Their research platform identifies interesting user gestures through a combination of acceleration and audio sensors placed on the user's wrists and elbows. Their research goal is to learn high-level human behaviours from low-level gestures observed using on-body sensors. They have developed an algorithm that utilizes the sensor framework to automatically discover recurring behaviours. The on-body sensors are based on ETH Zurich's PadNets, which are equipped with two 3D accelerometers and two microphones. The accelerometers were placed on the user's wrists to capture the gross motion of the hands, while the microphones were placed on the wrist and upper forearm of the right arm. Because the distance between the microphones is constant, the intensity difference between the microphones can be used as a rough indication of the proximity of an audio source to the user's hand [Minnen et al., 2005].

#### 4.2.2.6 Pervasive gaming

Magergurth et al. have written a good overview of pervasive gaming applications in "Pervasive Games: Bringing Computer Entertainment Back to the Real World". As an example of a smart toy, they describe Zowie playsets, which are physical toys with embedded sensors and connectivity to a computer. Integrated sensors track the 3D motion and rotation of the playing pieces and the state of the pieces is transmitted to a computer application via a serial port. Magergurth describes an AffQuake as an example of affective gaming. AffQuake by MIT uses a direct physiological input from a player – e.g. a player's galvanic skin response is measured and the player's avatar in the game reacts in the same way as a player. A very interesting example of augmented reality games is Human Pacman, where the player is the Pacman collecting cookies in a maze trying to avoid Ghosts (other players) that are trying to kill the player. Players with head-mounted displays (HMD) see virtual cookies scattered in a maze-like manner over the real physical game area. The cookies are shown from the first-person perspective of the player, depending on the physical position and head motion. The Pacman player sees the cookies on the footpath as though she were a real Pacman in a maze and could simply collect the virtual cookies by walking through them. If the player finds a Bluetooth-embedded box in the game area, he/she becomes Super Pacman, who can kill Ghosts for a limited time. Players kill each other by touching the capacitive sensor attached to the opponent's backpack. The Helper can connect to the game server through the Internet and view the game "live" in virtual reality form from any angle and distance. Every movement in the physical world is immediately reflected in the virtual realm. Even when the Pacman becomes Super Pacman, the Helper sees a change in the 3D graphic model. The Helpers can actually communicate with the Pacman or Ghost in real time via bidirectional text messaging. While Helpers use the computer keyboard for text input, Pacman and Ghost communicate and respond to their Helpers by using the Twiddler, a hand-held input device. The communication that takes place could either be chat or discussion on the winning strategy. Such interactions could promote social cooperation and establish relationships between humans who are operating across different contexts [Magergurth et al., 2005].

### 4.2.3 Commercial consumer products

#### 4.2.3.1 SenseWear armband

Bodymedia is an American company that designs wearable body monitoring devices and services for collecting continuous physiological information from individuals. An example of their wearable product is a SenseWear® PRO2 armband based on SenseWear armband technology. The SenseWear® PRO2 armband is BodyMedia's second-generation, low-cost wearable body monitor. The multi-sensor array of the armband collects continuous data coming directly off the skin of the wearer's arm. The data can be transferred to a computer using either Wireless Communicator or a standard USB cable. Worn on the back of the upper right arm, the armband can gather an array of physiological data and derived lifestyle information, such as energy expenditure, duration of physical activity, number of steps, sleep/wake states, and more. The SenseWear® PRO2 armband also has an event button that can be used to allow users to timestamp specific events and track events important for research. The armband employs a 2-axis accelerometer that records body movement, a temperature sensor that detects changes in skin temperature, and a GSR (galvanic skin response) sensor that measures minute changes in the electro conductivity of the skin. Continuous data can be stored for up to 7 days at a time. The data can then be uploaded to a PC or to a secure web site using one of the InnerView™ software applications. Each armband is powered by an AAA battery [Bodymedia].

BodyMedia is working on advanced technologies that will detect patterns in an individual's behaviour and provide them with personalized advice. As the algorithms continue to be refined based on real data being collected, the degree of personalization will also improve. For example, the armband may be able to identify that having a regular exercise time helps the user sleep better [Bodymedia].

#### 4.2.3.2 t6 wrist-top computer and pod products by Suunto

Suunto is a Finnish manufacturer of sports instruments for a variety of sports, including skiing, hiking, diving, sailing and golf. Suunto has focused on sports activities where advanced measurement technology, data processing and specific algorithms are needed. The Suunto t6 wrist-top computer and a few pod products have been selected as an example of consumer products that utilize sensors.

Suunto t6 accurately records how the user's body performs during exercise, enabling later analysis and planning with the Suunto Training Manager. By comparing the measured exercise load to the user's personal fitness level, Suunto t6 tells the user if the session improved the user's condition or not. Suunto t6 measures seven key body parameters: heart rate, respiration rate, ventilation volume, oxygen uptake, energy consumption, training effect and EPOC (Excess Post-exercise Oxygen Consumption).

POD products communicate with the wrist-top computer using wireless ANT technology. The transmission range is 10 meters. Foot POD operates on a AAA-battery. The weight of both Foot POD and Bike Pod is low at 45 grams and 16 grams respectively [Suunto].

#### 4.2.3.3 IST Vivago WristCare

International Security Technology is a Finnish healthcare technology company that develops automatic personal security systems that monitor and analyse the users' activity levels. The Vivago WristCare is the world's first 24-hour wireless security device. The Vivago WristCare analyses and transmits data on the user's activity level and triggers alarms when necessary. The system can be used at home, in institutions (assisted living) and in hospitals. During the first four days of use, the unit adapts to the user's normal activity level by measuring movement, skin temperature and skin conductivity. If the WristCare registers a significant change in the user's activity level, it automatically sends an alarm to the alarm recipient. The activity curve transmitted by the Vivago WristCare is used to support care activities with, for instance, the monitoring of sleep/wake rhythms. The wrist unit can also be used as a monitoring solution for users with dementia as well as a security system for care personnel.

The Vivago WristCare is based on IST BODYCODE technology that consists of sensors and algorithms that allow body signals to be monitored and analyzed automatically and continuously.

In addition to the wrist unit, the Vivago home system includes a base unit that is connected to the telephone network. The base unit wirelessly receives the data from the wrist unit and transmits alarms and notifications to the alarm recipient. The alarm can be transmitted as a voice or voice and text message to any telephone - for example to a friend or nurse (through the IST Gateway router), or to a 24-hour call centre. The alarms can also be routed to multiple recipients, depending on the time of day. The Vivago wrist unit provides a considerable degree of extra security for users living alone; the user can always press the alarm button if help is needed, although the wrist unit will automatically trigger an alarm if the user is unable to do so [IST].

#### 4.2.3.4 Clothing+

Clothing+ is a Finnish company that specializes in developing and producing wearable technology. Their aim is to provide innovative approaches to everyday problems by creating wearable solutions that are easy and logical to operate. Their swim distance tracker is described here as an example of a sensor product. The swim distance tracker operates by counting the number of turns the swimmer makes using a built-in electronic compass. The distance is automatically calculated by multiplying the length of the pool with the number of turns made. The preset value of the tracker is set for a 25-meter pool but the value can be changed to 50 meters. The swimmer attaches the tracker to his swimsuit, presses Start, and starts the exercise. The distance of the five most recent exercises is saved. Cumulating tracker stores the distances during a week, month or a total season. The distance tracker also stores the overall total distance [Clothing+].

#### 4.2.3.5 FRWD

FRWD Technologies Ltd is a Finnish company that designs, develops and markets high-quality sports computers for outdoor and action sports enthusiasts, top athletes and professionals. SPORTS2 is the new generation of FRWD and came on sale during the summer of 2006. It is a sports computer that records parameters from the user’s performance, e.g. route, speed, distance, heart rate and altitude. The sports computer allows real-time performance monitoring using either an FRWD Wrist Display and W series recorder or an FRWD Mobile Player and B series recorder. Both B and W series recorders have the following features [FRWD]:

The FRWD Recorder is attached to the athlete's upper left arm or to his back. Just before the performance, recording is started by pressing the Recorder Key down. When the exercise has been completed, the Recorder Key is pressed again and the whole performance is recorded. The W series recorder has a wireless 2.4 GHz PC and Wrist Display connection with a 5-meter operating range. The B series recorder has a wireless Bluetooth connection for communicating with a PC and Symbian S60 mobile phone. The connection is based on Bluetooth V2.0 with a 10-meter operating range and 115.2 kb/s baud rate. The B series recorder can send location data that is compatible with the most popular navigation softwares, e.g. TomTom and Navicore. Real-time performance monitoring can be monitored from the FRWD Wrist Display or the FRWD Mobile Player installed in a mobile phone [FRWD].

The Wrist Display has one operating button and other button for backlight. The Wrist Display displays five functions: speed and heart rate, distance and duration, altitude and heading, body economy and normal watch operation. The operating range of the Wrist Display is 1.5 meters. Audio signals provide the user with feedback on the Wrist Display functions. With a coin battery, the operating time of the Wrist Display is six months. After the exercise the recorded data is downloaded to FRWD Replayer PC Software, where the performance can be replayed, analyzed and compared. With the recorded data, the performance can literally be relived through animated 2D/3D-graphics and seen on a map. An analysis of an outdoor sport experience, such as speed, distance, routes, altitudes and heart rate, is made on a computer. Performances can be sent and received by e-mail. Routes, profile graphs and numerical data can be printed or exported to Excel or Google Earth. Graphs of aerobic and anaerobic thresholds and heart rate target zones can be displayed. The training effect value of the performance is analyzed by using EPOC, respiration rate, oxygen consumption, ventilation, heart rate and energy expenditure data. These parameters give valuable and comprehensive body information on recovery after a workout for both keep-fit enthusiasts and athletes [FRWD].

#### 4.2.3.6 Integrated training system by Polar Electro and Adidas

Polar Electro, a market leader in heart rate monitoring products, and Adidas, one of the world's leading sports brands, have formed a partnership that will introduce the world's first completely integrated training system. They are integrating Polar monitoring equipment into Adidas apparel and footwear in the Project Fusion. The integration of an adiStar Fusion range of apparel (t-shirts, long sleeve shirts, bras, women's tops), an adiStar Fusion shoe, Polar's s3™ Stride Sensor, a Polar WearLink™ transmitter, and a Polar RS800™ Running Computer allows the products to become part of the athlete [Adidas-Polar].

Special fibres bonded onto the Adidas tops collaborate with Polar's Wear Link™ technology to eliminate the need for a separate chest strap to monitor heart rate. The connection to the shirt is made by snapping the tiny Polar WearLink connector onto the front of the shirt. The data is sent to the Polar RS 800™ wrist-mounted running computer, which displays and records all information in real time [Adidas-Polar].

The adiStar Fusion shoe has a cavity in the midsole that can house the very light Polar s3™ Stride Sensor, making it easier to use, more comfortable and more consistently accurate than top-of-shoe systems. The s3 Stride Sensor wirelessly communicates with the running computer. Information like speed and distance, chronograph functions and heart rate are also shown on the RS800™ in real time. After the exercise, the data can be downloaded onto a computer so the exercises can be easily managed and analyzed. Based on initial estimations, the price of the entire system – Polar RS 800™, Polar s3™ Stride Sensor, adiStar Fusion top and adiStar Fusion shoe – will be around 640 Euros / 680 Dollars. The products have also been available as separate pieces since the spring of 2006 [Adidas-Polar].

#### 4.2.3.7 Iqua's Smart Badge

Iqua Ltd is a Finnish company that develops exclusively designed accessories for the mobile telecommunications market. They have developed a smart ID badge – Iqua Smart Badge – that combines card holder identification and wireless call management, and hands-free functions in an ID badge holder. The Smart Badge has a vibration alert and the possibility for 3-way conference calls, and it supports redialing of the last number called and the answering or rejecting of incoming calls. It enables 40 hours talk time and 600 hours standby time. The Smart Badge can be used with any brand of Bluetooth mobile phones that support the Headset or Hands-free profiles [Iqua].

## 4.3 Industrial applications

### 4.3.1 Applicable technologies

It is expected that the instrumentation systems in factories will continue to use wired backbones with wired sensors and actuators. However, the systems will be supplemented with wireless sections whenever feasible or mandatory. Examples of such special needs are instrumentation of places difficult to access, mobile connections for operators to offer remote monitoring, temporary systems for process experiments, or logistic control of products moving in the process.

Totally wireless sensors are hard to accomplish due to the need for power supply. Most wireless sensors will still use wired power feed, and only a minority will use batteries or energy scavenging from the environment. The power cable does not destroy the idea of wireless sensing; it is relatively easy to distribute a standard power voltage around the factory. When a new wireless sensor is installed, only a short cable from the nearest power line tap is required.

However, nowadays, using advanced power management and efficient batteries, the typical duration of a sensor node is a few months. The problem in this kind of work is that no general solution for energy harvesting can be found and each system has to be designed individually.

There are on-going projects for the measurement of industrial processes. The goal is to make predictive maintenance based on the measurement from the sensor network. The customers are the process and metal industries.

In the manufacturing applications, technologies for measuring the data in the automation isles are being developed. The goal is to create a plug-and-play architecture for a flexible sensor and actuator network. This will be later implemented in industrial demonstrations. There are also studies on utilizing the sensor measurements by fusion from different types of sensors from different locations and time periods.

## 4.4 Environment, infrastructure and buildings

### 4.4.1 Applicable technologies

In environmental (natural and built) applications, sensor networks will scale from satellite networks to wireless mems/nems-based networks. The character of the application will determine whether a wired or wireless sensor network or a combination is needed. In buildings and tunnels where a permanent power supply is available, it is also used. Gateway devices in the sensor network could be wired whenever possible. Environmental conditions may demand special requirements. The real promise for the future is the cheap mass-produced wireless sensor networks that are easy to install ad hoc and have very low power consumption or energy scavenging solutions.

# 5. Future visions

In this chapter, we introduce visions of sensor networks in three fields of application. The visions are described in two or three steps by giving some sub-goals to control the progress of the development. The timing of these steps is open, but some rough estimations for the short-term period can be between 1–3 years, medium-term 2–4 years and long-term 4–8 years respectively.

Most of these visions are based on a substantial background in the application area, and the wireless operation can be seen as a remarkable benefit. In the three different application fields there will be also other applications not mentioned here, and we do not take any responsibility for other fields.

## 5.1 Consumer applications visions

This chapter describes the vision of consumer applications in 2010–2015.

### 5.1.1 Wireless body sensor network consisting of wearable BAN sensors and a mobile device

It is expected that wireless sensors will be in widespread use in consumer applications in 2015. People will have many personal devices (laptops, mobile phones, PDAs, mp3 players, tablet PCs and wrist computers) that will communicate seamlessly with each other. Increasing memory densities will enable ever-increasing storage of multimedia content in consumer devices. For example, mobile devices will have tens of Gigabytes of memory to record everything from the user and the environment (voices, noise, location, temperature, skin conductivity, etc.), whereas the memory of laptops and PCs will approach the Terabyte level [Seppä, 2006].

Wireless body area networks are being taken into use in some niche areas in the form of wearable sensors – e.g. foot and arm sensors, wrist computers and smart clothing. Several sensors can be integrated into mobile devices that enable multi-modal user interfaces for controlling the smart environment. Collaborative user interfaces are easily distributed between everyday devices and mobile devices. New applications based on RFID sensors will appear. The significance of the position and location information will increase. Independent living applications for the elderly have emerged due to the increasing number of elderly people. The health status of the user can be analyzed with sensors in the mobile device. Computer games are both mentally and physically interactive: players have wearable sensors and the game pads have sensors to detect hand movements. Typical future visions describe a world full of sensor nodes that are self-configurable; thus the network has a dynamic topology. However, in consumer applications it is unlikely that there will be thousands of sensors in a dynamic network. Typically, only a few external sensors are needed and the user terminal may have internal sensors. Sensor network applications in the consumer market will have master-slave or star topologies.

**Short-term steps to the vision:**

In the short term the first devices to utilize sensors will be mobile phones and game pads. Internal sensors that measure environmental conditions – e.g. air pressure, temperature and humidity – are already integrated into mobile phones

**Long-term steps to the vision:**

In the long term there will be many WBAN solutions that will utilize on-body sensors to monitor health and physical condition status. The highest market increase is likely to happen in health and fitness applications.

**Steps to vision:**

- Research on deployment of sensor network
- Implementation of real-time mobile applications that analyze and utilize sensor data.

### 5.1.2 Technical solutions for long-term health and wellness monitoring

**Target:**

Development of viable methods for long-term monitoring of health and wellness in real-life settings. This includes easy wearability and management of personal wireless sensor networks, mobile phone-centric data collection, signal processing, wellness history presentation for self care, and integration of wellness data with patient information databases. Easy WSN management includes maintenance-free units requiring energy scavenging and low-power wireless sensors and sensor platforms. The focus is on stress and weight management, and monitoring of wellbeing of the elderly.

Development of low-power wireless (RFID) sensors with memory capacity capable of storing several measurements.

**Medium-term steps to vision:**

Mobile phone-centric field trials with embedded or external sensors. Construction of a gateway to integrate sensor network protocols with mobile phone.

**Long-term steps to vision:**

Wellness monitoring carried out by a wearable system that includes an easily portable UI unit /gateway device (wrist unit, pendant), which may communicate with a mobile device online, and process and store data. Development of sensor tags capable of storing a series of measurements. Physical selection should be included as a means to manage the configuration and measurements of peripheral devices.

### 5.1.3 Context sensing using wearable sensors and data fusion

**Target:**

Sensors are embedded in everyday gadgets like mobile phones and their accessories, and sports computers. The key challenge is to transform the increasing amount of raw sensor information into knowledge that is either usable for computer applications or directly human interpretable.

The context information (i.e. any information describing the situation) can be used in different ways by different applications – e.g. for automatically keeping a diary, for automatically adapting the user interface or user profile, for automatically recommending a service or information for the user, etc.

**Weaknesses, limitations:**

Lack of mobile user terminals and real-time analysis tools. The sensors should be small-sized and waterproof, and they should tolerate movement. The location of the sensors should be optimized according to the application.

**Medium-term steps to the vision:**

Making use of data available from the user's own wearable sensors using a wireless sensor network. This involves real-time data pre-processing, analysis and classification in a portable device. The target is to turn the raw sensor data into higher-level knowledge.

**Long-term steps to the vision:**

Making use of all data available via wireless networks: data from the user, nearby users and objects, data available via servers and services, etc. The target is to combine data from many users and the environment into higher-level "group" or "area contexts".

## 5.2 Industrial applications visions

It is expected that the use of sensor networks in industry will expand. At the moment there are only a few real applications, mainly due to the strict requirements for safe operations and criticality in operation, even if several demonstrators have been built. However, these issues will be studied and solutions will be provided in the near future. Another issue is time criticality, which is important in many control applications. The increasing bandwidth of the transferred data will help the development of these communicating platforms, especially for industrial use. Fast development of hardware, especially chips and their performance, will also provide increasing computation power, which will enable on-line analysis and decision making in the nodes of the distributed sensor network. The overall data handling capacity will increase and history information – e.g. measurements – will be utilized in more detail. Power consumption is another challenge for many applications but in the future there will be solutions to harvest energy for the whole lifetime of the network. In the future, sensors will utilize and share common data in the network, not just analyze their own measurement. Plug-and-play and easy-to-reconfigure operations will help the adjustment of the network for best and efficient use.

The technology in industrial applications will be based on the common technology used in other applications, such as RFID, ZigBee, UWB, Bluetooth and IEEE 1451 standard for smart sensors. It is possible that there will be special versions of these technologies for industrial use that focus on the special requirements.

**Short-term steps to the vision:**

The current measurement systems that are mainly based on the point-to-point measurement topology will be replaced by simple networks. These networks will be able to utilize the measurements from all sensors and not crash if one or a few sensors or appliances are out of operation. The overall reliability of the networks will be improved as well as the speed of the communication.

**Long-term steps to the vision:**

In the long term there will be flexible sensor networks that can be either manually or automatically reconfigured locally or remotely. The sensors and appliances will generate their own power for the whole of their lifetime. The sensor networks will operate on several levels: locally – e.g. around the user in BAN – and with the environment around the user at the same time. The user will be able to utilize the information obtained from all the levels.

### 5.2.1 Active sound control

**Target:**

Active control of sound environment based on wireless sensors. Applications include:

- active control of sound in cabins (cars, moving machinery)
- active improvement of sound insulation of aircraft fuselage
- active noise control in ventilation ducts
- active noise control in building elements (walls, windows).

**Medium-term steps to the vision:**

Demonstrations and prototypes utilizing wireless sensors in suitable applications.

**Long-term steps to the vision:**

International-level knowledge for researching and developing wireless applications for active control of sound.

### 5.2.2 Vibration measurement and control

**Target:**

Remote-controlled vibration exposure monitoring for work machines; test if a wireless accelerometer and equipment can be used to actively control a rotor; intelligent vibration control using the newest MEMS sensors and FPGA platforms; web-based database for employers to continuously monitor vibration exposure.

**Medium-term steps to the vision:**

A platform family for fast application tailoring.

**Long-term steps to the vision:**

Internationally significant knowledge of wireless sound and vibration control.

### 5.2.3 Human-centered automation

**Target:**

Re-configurable, plug-and-produce equipment: robotics and human operators, safety and productivity, changing sensor and equipment topology, moving equipment and operators, adaptation to new situation, context awareness (ambient intelligence); dynamic production management, smart manufacturing.

**Medium-term steps to the vision:**

Increase knowledge of potential technology, benefits, constraints, mobile robotics and automation; use of real-time production data.

**Long-term steps to the vision:**

Application design guidelines with new technology, customer service.

## 5.3 Infrastructure, buildings, and environmental applications visions

Sensor networks will continuously and extensively collect spatial and temporal (4D) information from all the critical, dynamic phenomena and processes of the built environment in the same way as information is collected nowadays using single point-measurements. The application of sensor networks will enable us to move towards smart/intelligent data-driven monitoring, modelling and management systems for the built environment, and all the maintenance and repair needs can be timed and focused by optimizing the desired level of services and investment needs.

**Medium-term steps to the vision:**

In the first phase the sensor networks will be applied and their cost-effectiveness and reliability will be tested in relatively simple monitoring and early-warning systems for the critical sub-volumes of the built environment. The wide-ranging use of sensor networks in built environment applications will really start after the positive experiments from these first pilot-type studies.

**Long-term steps to the vision:**

Only the development and integration of smart monitoring, modelling and management systems with the sensor network in the particular application will make it possible to truly exploit the benefits of sensor networks in improving the level and reliability of services in properly timed maintenance, economical optimization and predicting the life-span maintenance needs. The maintenance of the built environment will become easier and be adjusted to decreasing economic and human resources without losing the high level of services.

### 5.3.1 Development of sensor networks for built environment applications

**Target:**

Reliable and low-energy sensor networks for Built Environment applications

**Medium-term steps to the vision:**

Low energy concepts will work.

**Long-term steps to the vision:**

A software infrastructure will exist for sensor network management, diagnosis and maintenance work, and software tools to integrate them into the management systems of the built environment.

### 5.3.2 Sensor networks in infrastructure management

**Target**

Remotely controlled sensor network-based early-warning systems implemented for monitoring people, fires, moisture, air flow and plumes. Wireless sensor network pilots are planned to start in an underground infrastructure environment.

**Medium-term steps to the vision:**

Commercial remote control software for sensor networks is available and applied.

**Long-term steps to the vision:**

Commercial fault tolerant sensor networks are available for Infrastructure Management.

### 5.3.3 Sensor networks in natural environment

**Target:**

Wireless and wired sensors monitor functioning of the ecosystem. The data from in-situ sensors is combined with space-borne data to achieve "wall-to-wall" information coverage. The ground-based sensors measure temperature, moisture, rain, vibration, gas compound, or they can be imaging sensors. The applications include ecosystem monitoring for carbon cycle studies, agriculture, forestry and security.

The sensors have a spatial context, i.e. their map coordinates are known. This makes it possible to combine the sensor data with any other data that also has coordinate information, such as satellite imagery.

**Medium-term steps to the vision:**

Make use of data available from the present sensor networks, including, e.g., the Helsinki Test Bed data and available satellite imagery. Introduce to the network data from a limited number of additional, preferably in-house-developed, wireless sensors for environment monitoring.

**Long-term steps to the vision:**

Develop a comprehensive environment monitoring system with industry and users for a specific application.

### 5.3.4 Common processing and distribution system for multi-source *in-situ* and earth observation data

**Target:**

To unify the processing chain and define common interfaces and formats for both input data and output data. The result is a standardized process that can easily be modified for new data and applications.

**Medium-term steps to the vision:**

**Long-term steps to the vision:**

## 5.4 Technology and theory visions

### 5.4.1 Sensor network design, modelling, analysis, and implementation

**Target:**

An open framework that integrates various (e.g. vendor-specific) tools and enables their use for effective sensor network application design and analysis, and which enables integration of various modelling tools.

The framework will form a common basis with most of the work done in sensor networks first in Finland and later internationally.

**Medium-term steps to the vision:**

- Framework definition and architecture,
- Implementation of the basic parts of the framework
- Integration of state-of-the-art vendor-specific (e.g. ZigBee) development and analysis tools.

**Long-term steps to the vision:**

- Completion of the framework.

### 5.4.2 Multimodal interaction

**Target:**

Developing techniques and applications utilizing multimodal interaction e.g. voice input, voice output, physical browsing (touching, pointing, scanning), gesture recognition and visual feedback

**Medium-term steps to the vision:**

Development and implementation of prototypes and applications that utilize different modalities. Functional and inexpensive pointing technology for selection and reading of passive tags is still missing. Development tools needed at all levels to handle a variety of optical, RFID and short-range radio technologies. Development and implementation of 900 MHz / 2.4 GHz passive, long-range sensor tags. Pointing implemented with photosensitive sensor.

**Long-term steps to the vision:**

Functional speech and gesture recognition prototype with application, tested with large-scale field studies. Pointing with MEMS retroreflective components.

### 5.4.3 The spatial uncertainties in geometrical measurement systems

**Target:**

Ability to analyze measurements and utilize them in planning and other applications. Bayesian-form modelling of spatial uncertainties from a multi-sensor network will be used. The number of sensors will be free and method will be non-application-dependent.

**Strengths:**

Wide experience in methods and different applications, mainly sensor-based robotics.

**Medium-term steps to the vision:**

Middleware for managing the measurement concept, including semi-autonomous features.

**Long-term steps to the vision:**

Middleware software with real-time properties, including fully autonomous features; distributed computation in powerful mobile platforms; plug-and-play options for sensors.

# 6. Summary and conclusions

## 6.1 The main obstacles

The main obstacles to the application of the sensor networks appear to be the following: methodology and tools for sensor network engineering, maintenance-free sensor nodes, and methodologies and tools for “closing the loop”.

### 6.1.1 Methodology and tools for sensor network engineering

Typical questions in the *design phase* are:

- How many nodes do we need to cover area X?
- Where and how do we place them to assure realistic connectivity and proper redundancy?
- What kind of power management strategy would be best for this case?
- Will the transmission across this type of wall work?
- How does desired global behaviour translate into a (power optimized) set of individual behaviours for components?

Typical questions in the *deployment phase* are:

- Which deployment procedure is best at this site for minimized deployment costs?
- How precisely should we locate the nodes?
- If we wish to add some nodes ... how much “hand operation” is needed?
- Does the network work as planned? Reliability, connectivity, bit rates, synchronization, routing, uniformity of power consumption …?

For *operation/monitoring* just one example: How much energy is remaining on node X? Can we be sure of it?

In the long run the network will grow incrementally over long periods of time and there will be heterogeneity of hardware/software solutions, manufacturers, and software and service developers.

For the time being, sensor node vendors will offer restricted tools for their own products. Similarly, research institutes and universities have developed tools (e.g. TOSSIM, PowerTOSSIM, and EmStar) for various tasks but they are inadequate and incompatible. A design and analysis of the network in such a way that allows integration of models of the operational environment are also needed.

### 6.1.2 Minimum maintenance sensor nodes

Maintenance costs are one of the major obstacles that prevent the market penetration of sensor networks applications. If this problem is not solved, the sensor networks are bounded to remain mostly academic and the emergence of larger scale applications will be prevented. Efficient energy harvesting and power management techniques are the key elements in creating minimum maintenance, or even maintenance-free, sensor networks.

### 6.1.3 Closing the loop

For the time being, sensor networks are fine for sensing, but they are not ready for actuating. To close the loop, a better understanding of which control applications are good for sensor networks and how the networks can be improved to enhance the spectrum towards more challenging requirements in terms of reliability, availability, real-time, and consistency in space and time – such as industrial and control applications – is required.

## 6.2 Final conclusions

The research in wireless sensor networks is very dynamic, and the expectations of the applications and business potential are very high. For this purpose, we have given a perspective on state-of-the-art wireless sensor networks from the application point of view.

We have also identified the main obstacles in the application of the sensor networks that should be addressed by research in order to push this technology even further.

We have also listed several application visions. It is the task of industry and the research community to realize these visions.

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# Sensor Networks Roadmap

Abstract

This paper contains the Roadmap for Sensor Networks development at VTT. The work was conducted in the WiseNet (Sensor Networks) Key Technology Action (WiseNet) project during 2006.

The approach to tackling the problem is two-sided: first, we illustrate the technologies suitable for wireless communication in general and, second, we consider three different fields of application: consumer, industrial and infra. These applications have been chosen due to our vision of the most promising fields of application in the future.

Most of the technologies can be used in all fields of application. However, there are specific types of communication standards for industrial applications. The use of technologies in different fields is a common interest when the technology revolution is going on at the same time as the cost of the components is decreasing.

The purpose of this report is to give a vision of the future with regard to research topics in the field of sensor networks. We do not give milestones in terms of the years in which the technologies should be ready but we do try to describe substantial results in the selected topics.

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Strongly distributed sensor and actuator networks are becoming more and more important in research and the future. It can be said that wireless sensor networks form the basis for the smart environment of the future. Many applications can be seen to rely on this technology. In the future, sensor networks will offer efficient tools to collect information critical for the maintenance and control of industrial processes, monitoring of the infrastructure and environment, and even monitoring of human health or performance in sports or during work.

The development of sensor networks requires knowledge in many fields of science and technology. Among others are the development of miniature scale, low energy and intelligent sensors, the development of networking and routing technologies. The 'know-how' regarding sensors and networking is not, however, sufficient for practical applications. Furthermore, deep knowledge of user requirements, modelling, and design techniques related to the area of application is required.

This roadmap is a result of the WiseNet project conducted during 2006.



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