Smart Sensor Networks

Technologies and Applications for Green Growth

Presented by:-

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1. Introduction

Sensors and sensor networks have an important impact in meeting environmental challenges. Sensor applications in multiple fields such as smart power grids, smart buildings and smart industrial process control significantly contribute to more efficient use of resources and thus a reduction of greenhouse gas emissions and other sources of pollution.

This report gives an overview of sensor technology and fields of application of sensors and sensor networks. It discusses in detail selected fields of application that have high potential to reduce greenhouse gas emissions and reviews studies quantifying the environmental impact.

The review of the studies assessing the impact of sensor technology in reducing greenhouse gas emissions reveals that the technology has a high potential to contribute to a reduction of emissions across various fields of application. Whereas studies clearly estimate an overall strong positive effect in smart grids, smart buildings, smart industrial applications as well as precision agriculture and farming, results for the field of smart transportation are mixed due to rebound effects. In particular intelligent transport systems render transport more efficient, faster and cheaper. As a consequence, demand for transportation and thus the consumption of resources both increase which can lead to an overall negative effect.

This illustrates the crucial role governments have to enhance positive environmental effects. Increased efficiency should be paralleled with demand-side management to internalize environmental costs. Further, minimum standards in the fields of smart buildings and smart grids in regard to energy efficiency can significantly reduce electricity consumption and greenhouse gas emissions. Finally, this report also highlights that applications of sensor technology are still at an early stage of development. Government programs demonstrating and promoting the use of sensor technology as well as the development of open standards could contribute to fully tap the potential of the technology to mitigate climate change.

2. Sensor technology for green growth

Environmental degradation and global warming are among the major global challenges facing us. These challenges include improving the efficient use of energy as well as climate change. ICTs and the Internet play a vital role in both, being part of the problem (they consume energy and are a source of pollution) and have the potential to provide important solutions to it (ICT applications in other sectors have major potential to improve environmental performance).

Various examples illustrate the role of ICTs as a provider of solutions to environmental challenges: *Smart grids and smart power systems* in the energy sector can have major impacts on improving energy distribution and optimizing energy usage (Adam and Wintersteller, 2008). *Smart housing* can contribute to major reductions of energy use in hundreds of millions of buildings. *Smart transportation systems* are a powerful way of organizing traffic more efficiently and reducing CO2 emissions.

All these applications have one important attribute in common: They all rely on sensor technology and often on sensor networks. Because of the important impact of applications of sensors and sensor networks in meeting environmental challenges, this analysis has been developed in the context of OECD's work on ICTs and environmental challenges [see also DSTI/ICCP/IE(2008)3/FINAL and DSTI/ICCP/IE(2008)4/FINAL, and DSTI/ICCP/CISP(2009)2/FINAL for broadband investments in smart grids] and the WPIE's Program of Work 2009–2010. It is also a direct follow-up to the *Seoul Declaration for the Future of the Internet Economy,* issued at the close of the OECD Ministerial Meeting in June 2008, which invited the OECD and stakeholders to explore the role of information and communication technologies (ICTs) and the Internet in addressing environmental challenges.

The report opens with some technological fundamentals in describing sensor technology and sensor networks. This is followed by an overview of different fields of application. Selected sensor and sensor network applications are discussed as well as their environmental impact.

3. Sensors, actuators and sensor networks – a technology overview

Sensors measure multiple physical properties and include electronic sensors, biosensors, and chemical sensors. This paper deals mainly with sensor devices which convert a signal detected by these devices into an electrical signal, although other kinds of sensors exist. These sensors can thus be regarded as "the interface between the physical world and the world of electrical devices, such as computers" (Wilson, 2008). The counterpart is represented by actuators that function the other way round, *i.e.* whose tasks consist in converting the electrical signal into a physical phenomenon (*e.g.* displays for quantities measures by sensors (*e.g.* speedometers, temperature reading for thermostats).

Table 1 provides examples of the main sensor types and their outputs. Further sensors include chemical sensors and biosensors but these are not dealt with in this report. Outputs are mainly voltages, resistance changes or currents. Table 1 shows that sensors which measure different properties can have the same form of electrical output (Wilson, 2008).

Table 1: Examples of sensor types and their outputs

Physical property	Sensor	Output
Temperature	Thermocouple	Voltage
	Silicon	Voltage/Current
	Resistance temperature detector (RTD)	Resistance
	Thermistor	Resistance
Force/Pressure	Strain Gauge	Resistance
	Piezoelectric	Voltage
Acceleration	Accelerometer	Capacitance
Flow	Transducer	Voltage
	Transmitter	Voltage/Current
Position	Linear Variable Differential Transformers (LVDT)	AC Voltage
Light Intensity	Photodiode	Current

Source: OECD based on Wilson, 2008.

Wireless sensor and actuator networks (WSANs) are networks of nodes that sense and potentially also control their environment. They communicate the information through wireless links "enabling interaction between people or computers and the surrounding environment" (Verdone *et al*., 2008). The data gathered by the different nodes is sent to a sink which either uses the data locally, through for example actuators, or which "is connected to other networks (*e.g.* the Internet) through a gateway (Verdone *et al*., 2008). Figure 1 illustrates a typical WSAN1.

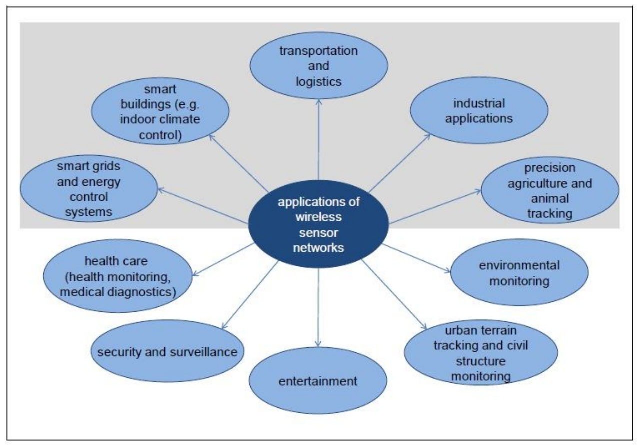
Sensor nodes are the simplest devices in the network. As their number is usually larger than the number of actuators or sinks, they have to be cheap. The other devices are more complex because of the functionalities they have to provide (Verdone *et al.*, 2008).

A sensor node typically consists of five main parts: one or more sensors gather data from the environment. The central unit in the form of a microprocessor manages the tasks. A transceiver (included in the communication module in Figure 2) communicates with the environment and a memory is used to store temporary data or data generated during processing. The battery supplies all parts with energy (see Figure 2). To assure a sufficiently long network lifetime, energy efficiency in all parts of the network is crucial. Due to this need, data processing tasks are often spread over the network, *i.e.* nodes co-operate in transmitting data to the sinks (Verdone *et al.*, 2008). Although most sensors have a traditional battery there is some early stage research on the production of sensors without batteries, using similar technologies to passive RFID chips without batteries.

4. Fields of application of wireless sensor networks

There are numerous different fields of application of sensor networks. For example, forest fires can be detected by sensor networks so that they can be fought at an early stage. Sensor networks can be used to monitor the structural integrity of civil structures by localising damage for example in bridges. Further, they are used in the health care sector to monitor human physiological data (Verdone *et al.*, 2008). The following sections outline selected applications of wireless sensor networks.

Figure 3: Fields of application of wireless sensor networks



OECD based on Culler *et al.*, Heppner, 2007, 2004, Verdone, 2008.

Figure 3 shows the most important fields of application. The upper part of Figure 3 shows fields of application discussed in more detail in this study as they have a high potential to tackle environmental challenges and reduce CO2 emissions. The fields of application in the lower part of the figure are briefly discussed in Appendix A1 to give an overview of further interesting fields of application.

5. *New and advanced grid components*

New and advanced grid components allow for a more efficient energy supply, better reliability and availability of power. Components include, for example, advanced conductors and superconductors, improved electric

storage components, new materials, advanced power electronics as well as distributed energy generation. Superconductors are used in multiple devices along the grid such as cables, storage devices, motors and transformers (DOE, 2003). The rise of new high-temperature superconductors allows transmission of large amounts of power over long distances at a lower power loss rate. New kinds of batteries have greater storage capacity and can be employed to support voltage and transient stability (SAIC, 2006).
Distributed energy is often generated close to the customer to be served which improves reliability, can reduce greenhouse gas emissions and at the same time expand efficient energy delivery (DOE, 2008). Furthermore, most of these alternative energy generation technologies close to customers such as solar panels and wind power stations are renewable energy sources. These technologies, *e.g.* solar panels, small hydro-electric and small hydro-thermals can be operated by consumers, or small providers.

Smart devices and smart metering

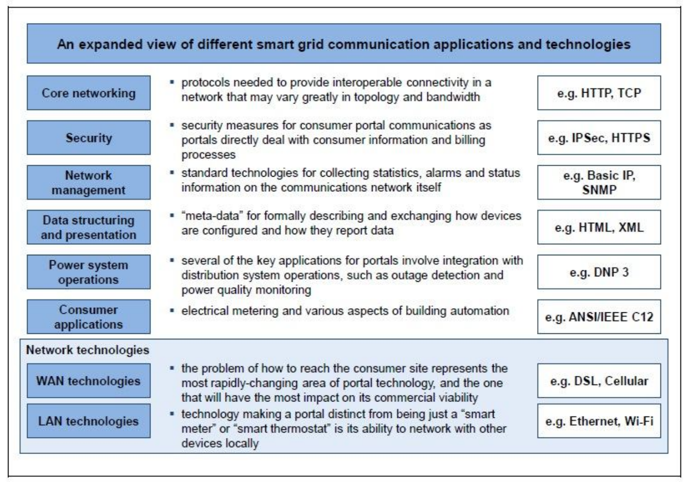
Smart devices and smart metering include *sensors and sensor networks*. Sensors are used at multiple places along the grid, *e.g.* at transformers and substations or at customers' homes (Shargal and Houseman, 2009b). They play an outstanding role in the area of remote monitoring and they enable demand-side management and thus new business processes such as real-time pricing.

Spread over the grid, sensors and sensor networks monitor the functioning and the health of grid devices, monitor temperature, provide outage detection and detect power quality disturbances. Control centres can thus immediately receive accurate information about the actual condition of the grid. Consequently, maintenance staff can maintain the grid just-in-time in the case of disruptions rather than rely on interval-based inspections.
Smart meters at customers' homes play a crucial role. They allow for real-time determination and information storage of energy consumption and provide "the possibility to read consumption both locally and remotely" (Siderius and Dijkstra, 2005). Further, they also provide the means to detect fluctuations and power outages, permit remote limitations on consumption by customers and permit the meters to be switched off. This results in important cost savings and enables utilities to prevent electricity theft. Electricity providers get a better picture of customers' energy consumption and obtain a precise understanding of energy consumption at different points in time. As a consequence, utilities are able to establish demand-side management (DSM) and to develop new pricing mechanisms. Energy can be priced according to real-time costs taking peak power loads into account and price signals can be transmitted to home controllers or customers' devices which may then evaluate the information and power accordingly (DOE, 2003). Customers thus become more interactive with suppliers and "benefit from an increased visibility into their energy consumption habits" (IBM, 2007). They are aware of actual power costs rather than only obtaining a monthly or even yearly electricity bill. To date, a number of OECD countries (Italy, Norway, Spain, Sweden and the Netherlands) have mandated the use of smart meters.

Integrated communication technologies

Information provided by smart sensors and smart meters needs to be transmitted via a communication backbone. This backbone is characterized by a high-speed and two-way flow of information. Different communication applications and technologies form the communication backbone. These can be classified into communication services groups (EPRI, 2006). Figure 6 provides an overview of these groups as well as brief descriptions and examples.

Figure 6: Overview of smart grid communication applications and technologies



OECD based on EPRI, 2006 and SAIC, 2006.

Utilities have the choice between multiple and diverse technologies in the area of *communication network technologies*. Usually, several network technologies are deployed within a smart grid. The following paragraphs provide an overview of different wide-area networks (WAN) and local-area networks (LAN). The distinction between WAN and LAN technologies is made in this context to differentiate between networks used to reach the customer and those at customer sites (EPRI, 2006).
Wide-area network technologies provide a means for a two-way information flow in the smart grid. Multiple technologies are available which provide both broadband and narrowband solutions for the smart grid, resulting in a highly fragmented market. Table 3 presents the main WAN technologies as well as their strengths and weaknesses for their deployment in the smart grid. The choice of WAN technologies will depend on factors such as reliability, low-cost, security and the network infrastructure that is already available. It

is likely that utilities will rely on several network technologies when they build smart grids as they have to cope with differences in geography, population densities as well as availability and competition of different network technologies in their services areas. Some of these will require broadband, some will not..

6. Conclusion

This report gives an overview of sensor and sensor networks applications and their impact on the environment. It discusses selected fields of application which have a high potential to tackle environmental challenges and reduce greenhouse gas emissions.

A review of different studies assessing the environmental impact of ICTs and especially sensor and sensor networks reveals that these technologies can contribute significantly to more efficient use of resources and an important reduction of greenhouse gas emissions. Government policies and initiatives are crucial in fostering the positive environmental effects of the use of sensors and sensor networks in different fields and are an essential part of strategies to radically improve environmental performance (see also DSTI/ICCP/IE(2008)3/FINAL). However, rebound effects have to be taken into account, and increased efficiency due to the use of sensor technology should be paralleled with demand-side management which internalises environmental costs, for example by raising CO2 –intensive energy and fuel prices. In the field of smart buildings, minimum standards of energy efficiency can be a major factor in reducing electricity use and greenhouse gas emissions.

In general many applications in promising fields are still at an early stage of development. Joint R&D programmes and implementation projects can promote the use of sensor technology and contribute to industry-wide solutions and the development of open standards. Finally, the use of ICTs and especially sensor technology is sometimes relatively expensive, for example in the agriculture and farming sector in terms of farmers’ economic considerations. Governments can encourage the use of ICTs and sensor technology through conservation programmes and by accentuating the environmental dimension of ICTs in agriculture and farming.