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Article

The Sensing Internet—A Discussion on Its Impact on Rural Areas

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Abstract: This paper is based on the experience of introducing wireless sensor networks (WSNs) into the building industry in Denmark and in a rural area of Greenland. There are very real advantages in the application of the technology and its consequences for the life cycle operation of the building sector. Sensor networks can be seen as an important part of the Internet of Things and may even constitute an Internet of Sensors, since the communication layers can differ from the Internet standards. The current paper describes the case for application, followed by a discussion of the observed adaptive advantages and consequences of the technology. Essentially, WSNs constitute a highly sophisticated technology that is more robust in a rural context due to its extremely simple installation procedures (plug and play) allowing the use of local less-skilled labour, and the possibility of reconfiguring and repurposing its use remotely.

Keywords: Internet of Things; sensing internet; wireless sensor networks; internet of sensors; robust IT; rural areas; remote areas; building sector

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1. Introduction

The Internet of Things (IoT) is described and discussed in the lecture notes by Lee *et al.* [1]. The authors conclude that the IoT can be very diverse, depending partly on the sub-technologies applied. The current work supports this way of thinking as mentioned in the abstract. The research focused on smart buildings in the context of smart cities with smart energy, smart transport, *etc.* Figure 1 illustrates the connections between various applications in this and other work by the author, including smart buildings and smart cities with a focus on energy.

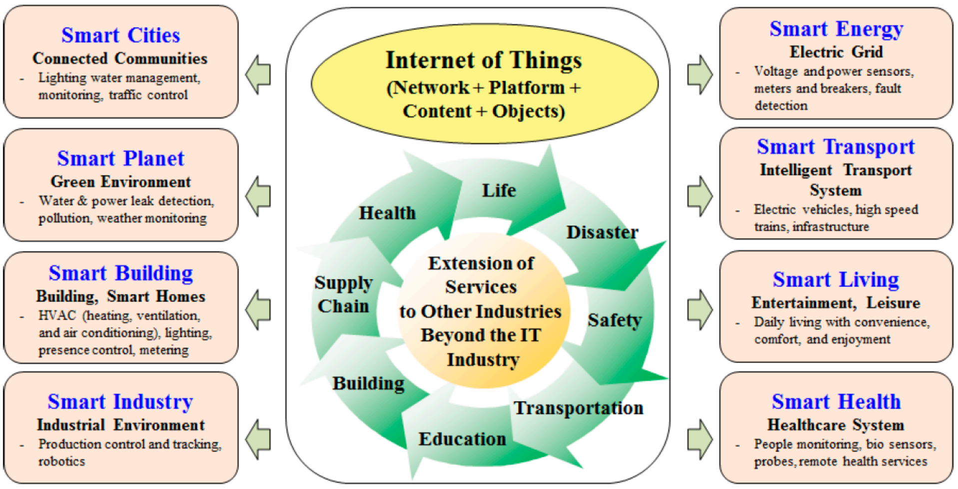

Figure 1. The Internet of Things applied in research by the current author. Source [1].

Like system control, the IoT could be split into the communication part (the Internet), the sensing part (the Sensing Internet), and the controlling part (Remote Controlling). In this way, the Sensing Internet denotes the enormous potential of the IoT, increasing the common understanding of it. On the other hand, understanding the IoT as a “service” [2] suggests the meshing of sensed data with all other kinds of Internet-related components.

The use of sensors within the IoT combined with the concept of Big Data [3] seems to be an important aspect of current research efforts. Neto *et al.* [4] propose a solution to the challenge of finding, retrieving and utilizing sensor streams in a stable manner. Trilles *et al.* [5] propose a whole open platform for designing a sensing IoT based on wireless sensor networks (WSNs), as applied in the current research. It should be noted that Kotsev *et al.* [6] have presented an alternative approach based on the internet standards.

WSNs are now widely used due to their flexibility, adaptability and potential simplicity. Simplicity is only possible for very well-designed setups, and it demands quite a lot of work, because of the great flexibility of the technology and its lack of maturity. But keeping things simple is seen as a necessity in this paper.

A previous paper described WSN technology and proposed its application in the building sector as an alternative to Radio Frequency Identification—RFID technology [7]. The introduction of WSN technology was aimed at improving the overall performance and quality of the sector. On basis of an analysis of the commercial hardware available, it was concluded that wireless sensor technology has not yet developed to its full potential with respect to applications in the building sector. Other studies dealing with this topic have been mostly theoretical (based on computer simulations, e.g., [8,9]) or pilot studies without full scale implementation of the technology (e.g., [10–13]). Current research is changing this situation rapidly, as the following examples show: an anti-collision solution for crane groups based on WSN and IoT technology [14]; a logistics solution that could be applied on building sites [15]; and an application for the management of fire emergencies [16]. However, these are proposals based on research and not yet commercial solutions.

Although the building sector is rather reluctant to introduce extensive new technologies in the proposed way, the basic infrastructures are already in place to receive them in a country like Denmark.

The Internet is everywhere, and skilled personnel are available with competence in installation, for measurement and on the software side. Planning WSN introduction in Greenland brought up some new considerations with respect to all these issues. The current paper provides some observations and a discussion on the degree to which the Sensing Internet, represented by WSN technology (bearing in mind that these are not the same thing) can be robust in rural areas.

2. Case Description

A previous paper described the WSN technology and proposed its application in the building sector as an alternative to RFID technology [7]. It was found that the implementation of such sensor technology would increase the quality of buildings, improve process efficiency, and lead to numerous improvements in all aspects of a building's life cycle, from its design and construction to its operation, renovation and eventual demolition. This is due to the availability of information on the state of all the components involved. In this way, the new technology can decisively improve the whole value chain of a building. The research made an effort to understand the technology and prove the concept in building sector applications. Based on these earlier investigations, this paper does not demonstrate new technological solutions, but rather discusses the advantages that the introduction can have for the given sector, and therefore how the introduction of the IoT can also lead to great advantages for society as a whole.

The application of WSN technology in buildings in Denmark was investigated by Orthmann [17] and [18]. There is need for skills, solutions and technologies that match the given case, but Orthmann showed that there are no barriers to the implementation of the technology as such. Wired power supply proved superior with respect to robustness, so the final installations in the tests referenced by Orthmann were based on wired power supply, but with WSN communication. The applications were laboratory trials preparing the full-scale installation in Denmark and Greenland.

A full-scale installation was planned for a dormitory in cooperation with ARTEK, the Centre for Arctic Technology in Sisimiut, Greenland. WSN seemed relevant due to its high flexibility. The case is presented here with observations with respect to the introduction of the Sensing Internet in rural areas.

The building and its ventilation scheme are shown in Figure 2.

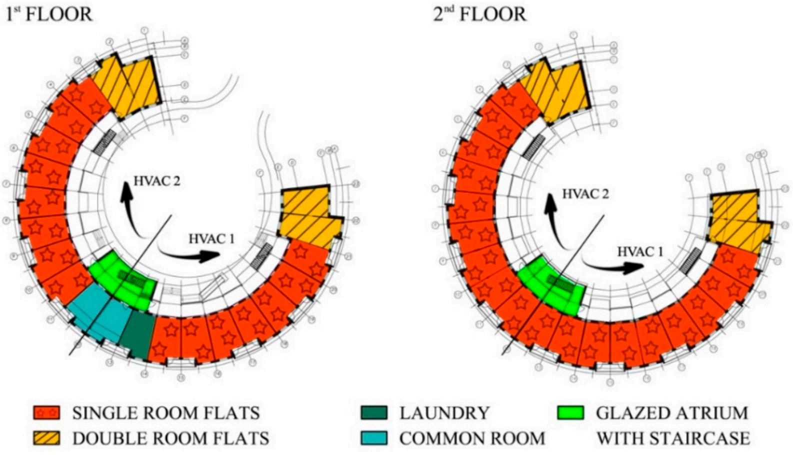

Figure 2. Layout of building, which was to be split into two similar-sized sections for experimental purposes.

Previous studies undertaken in this building have shown that the poor design of the ventilation system constantly causes the building to over-ventilate [19], which in such a cold climate means a significant increase in energy use. So renovation seems essential with energy savings as a motivating driver. The basic idea of the installation was to add CO_2 control to an existing ventilation system. The setup would be applied to various control schemes, from an all-building control down to individual room control.

The whole system was designed remotely in Denmark on the basis of reported information, drawings and design manuals. Due to a conference in Sisimiut, where the building is located, the author had a chance to see the installation on site. It turned out that the ventilation system had stopped functioning because the heat exchanger had burst due to icing approximately one year earlier. This very important information was not communicated in time, which would have stopped the project and the resources would have been reallocated. On the other hand, we would not have had insights for the current paper.

2.1. Hardware and Software Architecture

WSN technology was chosen partly because it enables hot-plugging of new sensors into the network. This is an important aspect that supports the discussion below on the robustness and simplicity of the WSN technology. For the WSN topology, the choice was between a mesh layout, which would give great flexibility, and a star layout, which brings simplicity. We chose the latter. The wireless communication protocol, Zigbee, was applied because of its openness and energy efficiency, although a fully open protocol might be preferred.

Libelium's Waspmote sensor platform formed the foundation of the setup, selected for its modularity, which made it possible to build custom nodes for specific purposes. The possibility of configuring the final solution for energy efficiency was another major factor in this choice. The experimental setup consisted of three different types of node, all provided by Libelium Comunicaciones Distribuidas S.L, Zaragoza, Spain, (each designed for a specific purpose), a signal amplifier, and damper actuators to control the airflow.

Central Node: The central node creates the wireless network, constituting a router for message-passing and for recording data from the network in a persistent local storage. Moreover, the central node enables online access and remote control. The central node selected for this experimental setup was the Meshlium ZigBee-PRO-AP, (Processor: 500 MHz (x86); RAM memory: 256 MB (DDR); Disk memory: 8 GB; System: Linux, Debian; OLSR mesh communication protocol; Security authentication: WEP, WPA-PSK, HTTPS and SSH access).

Sensor Nodes: The sensor nodes were to monitor the CO_2 concentration in each flat and send the data to the coordinator node. The proposed system contained 18 sensor nodes (one in each flat). The main components of the nodes were: Waspmote ZigBee PRO, Gases Sensor Board v2.0, and CO_2 sensors. Furthermore, each node had a 6.6 Ah battery and 2 GB SD card. For experimental purposes, each node was to be powered from the electricity grid as a backup.

Control Node: The control node (Waspmote ZigBee PRO) receives commands from the central node and adjusted the supply and exhaust damper positions (and thus air flows) by means of two actuators (Belimo TF24-SR, BELIMO Holding AG, Hinwil, Switzerland). The voltage range given by the control node is 0–3 V and the actuators require a signal from 0–10 V, so an amplifier was needed. For this purpose, a programmable relay (Siemens LOGO! Siemens AG, Munich, Germany) was used, which is already a part of the building's inventory.

Sensors: TGS 4161 solid electrolyte sensors, Figaro USA, were selected as the CO_2 sensors, with a range of 350–10,000 ppm and an accuracy of ±20% at 1000 ppm. Their response time for accurate measurements is 1.5 min. The following equations describe how the voltage measured by the TGS 4161 sensor can be converted to gas concentration (ppm):

$$\text{delta\_emf} = (\text{baseline} - (\text{volt}/\text{gain})) \times 1000 \tag{1}$$

$$\text{ppm} = \text{pow}(10,((\text{delta\_emf} + 158.631)/62.877)) \tag{2}$$

where: baseline is the voltage at 350 ppm, gain is the calibrated gain of the sensor, and volt is the output voltage of the sensor.

In the case, all the sensors were tested and calibrated in parallel with a highly accurate and calibrated CO_2 sensor.

Software: The software applied was the open-source electronic prototyping platform, Arduino [20], which collected the measurements, computed the control values for the ventilation, and communicated them to the actuators. As mentioned above, the wireless communication was based on the Zigbee protocol [21]. From the router to the IP network, standard internet protocols were applied.

2.2. Economic Aspects

Excluding the Belimo actuators and Siemens LOGO! relay (which were already installed in the building), the retail price of the wireless solution was €8000 (see left half of Figure 3). For comparison, the price of the wired solution would be €16,000 (see right half of Figure 3).

It was expected that the installation would reduce the heat demand of the actual ventilation unit by 50%. This would have yielded an annual energy saving of approximately 15 MWh/yr or €1600/yr at the current heat price (€107/MWh). The return on investment for the wireless and wired solutions is shown in Figure 3.

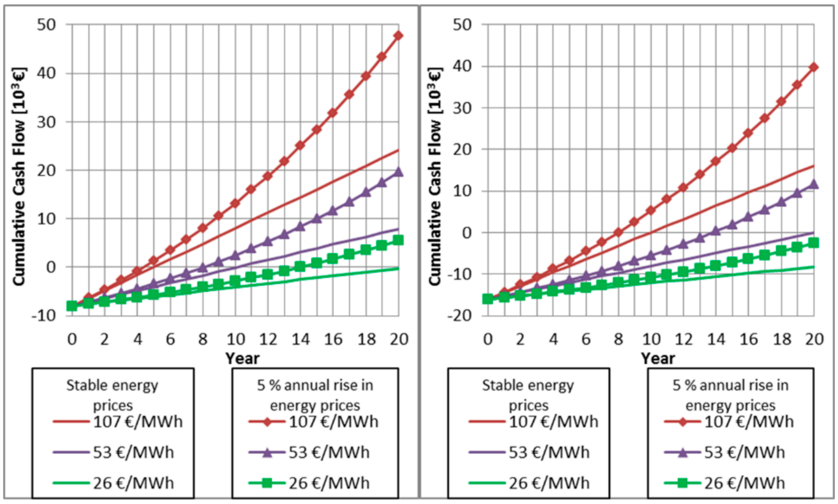

Figure 3. Return on investment for the wireless solution (**left**) and the wired solution (**right**).

The price of the wired solution is higher, partly due to the use of different CO_2 sensors. The Vaisala sensors use more accurate technology and do not require such frequent calibration (the manufacturer guarantees 5% accuracy over the course of five years). On the other hand, the wireless solution allows remote calibration on a frequent basis, as required by the sensor manufacturer, which means that such accurate sensors are not needed.

The price for the installation of the wireless sensors has not been included in the calculation because it would have been carried out by the researchers. However, installing the wireless solution only requires attaching the sensor nodes to a wall in each flat and connecting the central node to the internet (the rest is done remotely). This is clearly less labour-intensive than wiring each sensor through the finished building while it is in use. Moreover, it does not require highly skilled professionals to do this work.

The actual payback period will strongly depend on the real energy savings and will also be affected by the energy price. The price is expected to rise every year, which will further shorten the payback period.

In this setup, all the preparations were made in Denmark (but it could be done anywhere in the world) to be shipped as a do-it-yourself kit that can be added to the existing building automation.

3. Results and Discussion

The current paper originated in the work of implementing WSNs in the building sector, which would dramatically improve the value chain of this sector. There are a number of reasons for this:

- By designing WSNs in ways which make repurposing possible, a sensor can be reused during the life cycle of buildings, reducing costs to almost zero. However, this requires remote access for reconfiguration.
- As a consequence, large savings can be made on building monitoring and automation.
- The quality of components, assembly, operation, maintenance, renovation, and many other aspects of the buildings can be improved by utilizing the data from the WSN sensors.
- Procedures for building site management and building facility management can be improved.
- … and much more.

The current paper examines the application of WSNs as representatives for the Internet of Things. They show economic advantages compared to wired solutions. The energy consumption of the WSN is important for this comparison, and since there were power lines close to the installation points, the sensors were designed with wired power supply.

A lot of WSN technology is still at a product level that demands rather a lot of adjustment to fit a particular solution, especially for non-programmers. So it seems unrealistic to expect remote sites to have the skilled labour to do the necessary adaptation of the components involved. The alternative is a procedure whereby the solutions are prepared by skilled personnel in advanced organizations, and then shipped to the remote site for installation by less skilled personnel on site.

The introduction of sensors in the larger context of the IoT can increase the value of the technology even more by enabling remote configuration, surveillance, control and, not least, the avoidance of mashups in the ever more complex overall systems and services. This would be a game-changer in building services.

Extending this view with the developments in big data, the overall technology mesh will enable the introduction of smart solutions, introducing external factors such as weather and energy prices into the control strategies and improving the overall efficiency and economic benefit.

The main observation in this paper is that high technology and the Sensing Internet can be applied even in remote areas such as Greenland. This opens up new opportunities for such remote areas. Telemedicine is one of the obvious applications, building automation another.

A second discussion that the current paper opens up is the relationship between complexity and robustness. A prime strength of WSN is its flexibility, which means that sensors can join and leave the network without it being necessary to reconfigure the setup. This makes WSN technology especially robust compared to alternatives.

The Sensing Internet is a rather complex, sophisticated, advanced and multi-technological solution. Such complexity in a geographically and technologically distributed system implies dependence on all parts functioning in a stable way. In the extreme conditions of Greenland, the robustness of technology can sometimes be a surprise. Here is an example: the heat exchanger is a well-known piece of technology that is widely applied and could be called low-tech. It would normally be evaluated as robust and stable technology. However, in extreme climates like the Arctic, such technology fails; in the above-mentioned case, the liquid in the exchanger froze, resulting in leakage and total failure. Comparing this simple technology with a complex setup such as the Sensing Internet with WSN, one might expect that this high-technology would certainly fail. But it is not that straightforward. With the application of sensor technology and IT-technology, it is possible for unskilled labour to replace components easily, which makes the life-cycle performance rather robust. With remote intervention, the technology installed can be monitored, maintained, and thereby kept robust and stable.

Traditionally, the use of advanced technology in remote areas has depended on being able to fly in highly skilled specialists to install and configure the solutions on site. The consequences can be serious when technology fails because of the lack of specialists on site.

To get the full picture, it must be said that there are also drawbacks in the solutions presented; similar to the heat exchanger example, the Internet can also be fragile in remote locations. If it fails, part of the overall solution fails too. However, backups and local buffer solutions can be established to bridge such difficulties, and in the setup presented, the solutions would run independently, collecting sensor and log data locally, waiting for the Internet to restart and synchronize the relevant data and states.

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Conflicts of Interest

The author declares no conflict of interest.

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