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AN EFFICIENT WSN BASED ENERGY HARVESTING SYSTEM USING EMBEDDED SYSTEM

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ABSTRACT: This paper presents a case study of a wireless sensor network (WSN) to support energy management utilizing Web services and middleware technologies. The approach presented proposes the integration of WSNs with Ethernet/Internet/XML/Web Service communications into a 'knowledge and information services' platform to support energy management which can be accessed via a Web service to support inhabitant actions to reduce energy demand. It is based on the idea of collecting energy information using various wireless devices operating with different communication standards. This is important as there are various communication standards developed for WSNs including ZigBee, 6LoWPAN, Wi-Fi, WirelessHART and ISA100.11a. The hardware components which are needed for a system using one specific communication standard cannot be used directly within another system, due to differences in firmware, radio components, communication standards, and in some cases profile parameters. This is problematic because the components of different systems cannot be mixed and used in combination in order to take advantage of the most useful aspects of products from multiple vendors. The concept and initial testing of the WSN presented in this paper goes beyond current approaches as it uses various wireless devices operating with different communication standards, which can support Web based services for building managers, owners and inhabitants.

KEYWORDS: Wireless sensor networks, communication standards, energy management, building

INTRODUCTION:

The pledge of the European Union (EU) to cut the annual consumption of primary energy by 20% by the year 2020 (European Commission, 2008) has contributed an increased demand to reduce the energy consumption of buildings. This implies the necessity of a conscious way of thinking and actions regarding efforts to reduce energy consumption throughout the whole lifecycle of buildings (Crosbie et al, 2010). To this end European Commission funds research projects in this area. The work presented in this paper is part of the output of one such project entitled IntUBE – 'Intelligent use of buildings energy information' (IntUBE, 2009). The overall aim of the IntUBE project is to intergrate the information and communication technologies (ICTs) used in the design and operation of buildings to support improvements in the energy performance of buildings and the measurement of that performance. Within this field of research the exploitation of the potential of wireless sensor networks (WSNs) to facilitate intelligent energy management in buildings, which increases occupant comfort while reducing energy demand, is highly relevant. In addition to the obvious economic and environmental gains from the introduction of such intelligent energy management in buildings other positive effects will be achieved. Not least of which is the simplification of building control; as placing monitoring, information feedback equipment and control capabilities in a single location will make a buildings' energy management system easier to handle for the building owners, building managers, maintenance crews and other users of the building. Using the Internet together with energy management systems also offers an opportunity to access a buildings' energy information and control systems from a laptop or a SmartPhone placed anywhere in the world. This has a huge potential for providing the managers, owners and inhabitants of buildings with energy consumption feedback and the ability to act on that information. In recent years, wireless sensor networks (WSNs) used for environmental monitoring, health monitoring (Lynch and Loh, 2006) and industrial monitoring has been widely recommended as a means of reducing the energy consumption and CO2 emissions (Srivastava, 2010). WSNs are also highly flexible. Thus they rapidly enable the deployment of temporary infrastructures in a retrofit scenario to perform measurements for a predefined time period in order to monitor energy usage and improve energy efficiency (Guinard et al, 2009). This recent interest in WSNs has resulted the development of various communication standards to support them, including ZigBee, 6LoWPAN, Wi-Fi, WirelessHART and ISA100.11a. The hardware components which are needed for a system using one specific communication standard cannot be used directly within another system due to differences in firmware, radio components, communication standards, and in some cases profile parameters (Baronti et al, 2007). This is problematic because the components of different systems cannot be mixed to take advantage of the most useful aspects of products from multiple vendors. The research underpinning this paper attempts to overcome this problem. It involves a case study of the development and initial testing of a WSN to support energy management using wireless devices operating with different communication standards. The basic idea is to collect information related to building energy performance, using various wireless devices from different vendors operating with different communication standards, that is stored on distributed repositories accessed via a Web service. This research is motivated by the demand for energy reduction, the lack of interoperability between different sensor systems, and a desire to explore how to use Web services to present inhabitant energy feedback

WIRELESS SENSING AND INTELLIGENT BUILDINGS The current situation Present day intelligent buildings are highly adaptable to changing environmental conditions. They have automated systems, including wireless sensor monitoring, to facilitate energy efficient, comfortable and cost effective environments by optimising structure, systems, services, building management and their interrelationships (Grondzik et al 2010). In the context of the future 'Internet of Things', Intelligent Building Management Systems can be considered part of a much larger information system. This system is used by facilities managers in buildings to manage energy use and energy procurement and to maintain buildings systems. It is based on the infrastructure of the existing Intranets and the Internet, and therefore utilises the same standards as other IT devices. Within this context reductions in the cost and reliability of WSNs are transforming building automation, by making the maintenance of energy efficient healthy productive work spaces in buildings increasingly cost effective. Wireless sensing in commercial and office buildings has lead to a greater awareness of the condition of buildings and their systems: As it provides information necessary for those in charge of building operation and maintenance to recognise limits and non-functioning equipment and systems and prioritise building maintenance tasks etc. based on costs and other important factors (Brambley et al, 2005, Menzel et al, 2008). The main benefits of this are: An increased lifespan for equipment/electric appliances;• An improved building environment for occupants;• Economies of scale gained from monitoring, tracking and responding to the status of multiple• building assets from centralised or regional locations; The ability to detect impending faults and therefore minimise energy usage associated with facility• assets and increase reliability while reducing costs; Lower energy and operating costs leading to an advantageous return on investment. For example• energy management systems based on WSNs can save an average of 10 % in overall building energy consumption and the energy savings can be as high as 30% depending on occupancy (LunWu Yeh et al, 2009).

AN INTEGRATED APPROACH INTEGRATING WSNS WITH ETHERNET/INTERNET/XML/WEB SERVICE

communications The approach to WSN presented in this paper seeks to integrate WSNs with Ethernet/Internet/XML/Web Service communications into a 'knowledge and information services' platform to support energy management, that can be accessed via a Web service to support actions to reduce energy demand. This system is piloted by the deployment of WSNs in an office building using the communication standards ZigBee and 6LoWPAN. These standards are embedded into a large number of products suitable for home automation and building automation. The WSNs consists of commercially available low cost devices with small size and low power, which are integrated with computation, sensing, and radio communication capabilities. In the approach presented in this paper these elements include nodes with integrated sensors measuring temperature, light, and humidity and combined power switches and energy meters. The latter are used both as remote power control switches and as devices to measure voltage, current, frequency, load and power consumption associated with the electronic equipment to which it is attached. Data from the sensors are stored in distributed repositories, such as a gateway and internal/external servers. The two sensor networks do not have the interoperability to communicate with one another, but the possibility of controlling switches and gathering, analysing and presenting sensor data from both of the installed wireless sensor networks on Web user interfaces accompanying the WSNs, as well as on an adapted Web site makes the system function as a whole. 3.2 Overview of sensing and sensing parameters 3.2.1 6LoWPAN Wireless Sensor Network The 6LoWPAN subsystem is formed by one server, two routers, and ten battery driven sensor nodes, see Fig. 1. The server, which stores both sensor data and network information, is connected to the Local Area Network (LAN) and provides a Web Interface, which displays data from the sensors and the network. Through this interface the user is able to manage and control the wireless network.

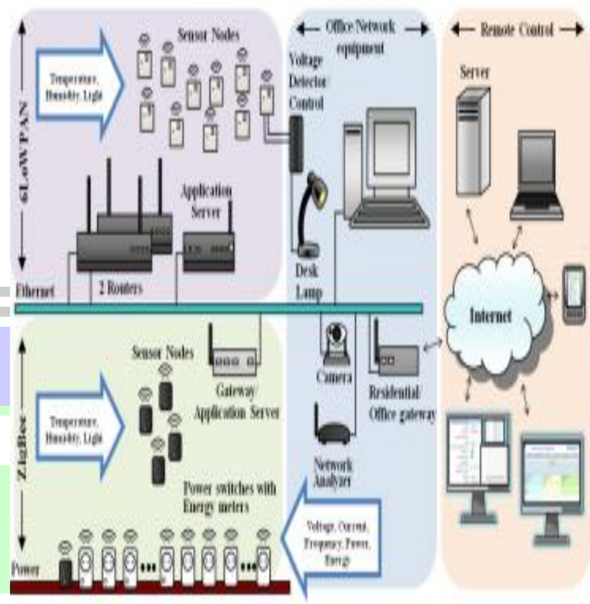

FIG. 1: The wireless sensor network concept

Access to the network from the server goes through the two parallel working routers. These routers manage the routing between the sensor nodes and the IP network connected to the server. Deploying two routers in the same network of sensor nodes will scale the throughput of the network. Each router is able to take over the other router's tasks in cases of a non-operational router, which increases the redundancy and reliability of the network. All the ten sensor nodes include integrated temperature, humidity and light sensors, and communicate with routers and each other using mesh routing protocols. The indoor operation range is approximately 50 metres. Built-in expansion ports make it possible to connect the sensor nodes to different external sensors, switches, and actuators. To utilize this range of use one of the 6LoWPAN sensors in the pilot network was connected to a device functioning as a relay controlling the mains to a desk lamp, as can be seen in Fig. 1. From the server's Web interface the lamp was remotely switched on and of

ZIGBEE WIRELESS SENSOR NETWORK The ZigBee WSN depicted in Fig. 1 is composed of devices from different vendors. The gateway functions both as a server storing network data and a connection point between the network nodes, the

LAN and the external server. It has the coordinator role in the ZigBee network. A Web user interface running on the gateway enables the user to set up and manage the gateway and the WSN. Several battery-driven wireless sensor nodes with internal sensors to measure temperature, light and humidity are deployed in the network. These nodes are able to form mesh networks and can operate within an indoor range of about 40 metres. They function as end-devices in the ZigBee WSN. Another sensor node is equipped with a power socket and has a router function in the network. A number of remotely controlled ZigBee devices with relays are used as switches to power external equipment, such as table fans, desk lamps, etc. These devices, which act as routers in the WSN, are plugged into power points. They are also used as meters for measuring the voltage, current, frequency, power consumption and load of the attached equipment. For testing purpose to actually see what's happening when controlling the switches from the Web site, a network camera has been connected to the LAN. This camera displays on the Web site live monitoring of the electronic equipment connected to the power lines by wireless controlled switches. All the wireless network devices belonging to both sub-networks are located in various rooms at the same floor in the office building, as can be seen in Figure. The room 301 is a laboratory, 313 is a kitchen, 312A functions as a server room, and the others are small offices. Most of the walls are non loadbearing walls and glass, but the server room are surrounded by brick walls.

Measurement Parameters and Sensor Node Data Environmental parameters (i.e. temperature, humidity and light) are important factors for deciding whether equipment (such as fans, electric heaters or lamps) should be switched on or off in a wireless monitoring network used for energy management in buildings. The 6LoWPAN sensor nodes include a sensor for measuring temperature and relative humidity. This sensor has a temperature range of -40°C to 123°C with an accuracy of approximately ± 0.5°C at 25°C, and a relative humidity (RH) accuracy of ± 3.5% at 20-80% RH. Another sensor measures the illuminance in visible range and has a maximum photosensitivity of approximately 0.3 A/W at a 550 nm wavelength at 25°C. The sensor nodes used in the ZigBee WSN have a temperature sensor operating in the range of -18°C to +55°C with an accuracy of ± 2°C. The integrated ambient light sensor operates with a 360 nm to 970 nm spectral bandwidth and with peak sensitivity at a wavelength of 570 nm. The humidity sensor has an operating range of 0 to 100% RH and an accuracy of ± 3.5% RH. An example of sensor parameters from the Web user interface of the 6LoWPAN WSN is shown in Table 2. Each sensor node is listed with the accompanying information of the latest sensor data as well as the time of the sensor readings.

Connectivity and Reliability Survey To succeed in deploying the wireless sensor network in the offices, it is important to make sure that the packets of data are successfully delivered between the nodes in the system. The distance between the transmitter and receiver, building structure and interference are some of the issues affecting the signal attenuation in the wireless sensor network communication. In literature several researchers (e.g. Guinard et al, 2009) presented optimization methods for optimal WSN deployment in the built environment. Interesting metrics for assessing reliability in building applications are RSSI (Received signal strength indication), LQI (Link quality indication), Packet delivery rate (PDR), and packet error rate (PER) (Jang and Healey, 2010). The reliability of the 6LoWPAN WSN has been investigated with one router and 9 sensor nodes deployed in the network since the other router and one sensor node stopped functioning. The server and router were moved from room 310 to the laboratory 301, see Fig. 2. The measurements are obtained from the Web user interface of the network. Two types of tests are presented. First seven sensor nodes were placed at the same table as the router to not interfere in the communication with the two sensor nodes used in the test. These were placed in the same distance from the router, but in different locations. Sensor node B was located in one of the offices while sensor node A was located in the corridor outside the particular office. The Signal Strength [dBm] of the sensor nodes and the Link Success [%] which is defined as the number of successfully sent packets divided by the number of send attempts between a node and its parent were measured. The results are presented in Table 5. The distance between the router and the two sensor nodes were increased, and the signal strength was seen to be weaker the larger distance, and the more walls the radio signal were passing through. At a distance of 20m the sensor nodes were out of range for communication and a new sensor node, C, were placed in the corridor between the router and the nodes A and B. This sensor node was then passing signals from Router_01 to A and B and we also saw the multi-hop communication when the sensor node inside the office, B, was receiving its signals from both A and C. More sensor nodes were placed out in the corridor to study the connectivity between the nodes. In the second test the server and router were still placed in the laboratory 301. The sensor nodes were located in the offices, kitchen, and server room as can be seen from Fig. 2, except for the one not functioning (room 310). The distance from the router to each sensor node were measured and is showed in Table 6. This table also shows information of current, minimum and maximum values obtained during 1 day of measurements from the Web user interface regarding Parent signal strength, Link success rate (number of successfully sent packets divided by the number of send attempts) and distance from the sensor node to its parent. Not surprisingly, the results showed that the longer distance between the transmitter and receiver, the weaker Average Parent Signal Strength. However the number and types of walls and building equipment also affects the signal strength. As an example, the "Server 312A" with a distance of 9m from the router has poorer signal strength than the "M 306" with a 10 m distance. The reason for this is that the Room 312A is a server room with brick walls, ventilation equipment and metal racks containing servers. According to Jang and Healey, 2010, metallic materials and brick walls create an environment with lower range of reliability than for instance plywood, and gypsum. As previously stated, optimization methods can be used to determine the best node location once environment design is available e.g. from a BIM (Building Information Modeling).

CONCLUSION:

This paper presented the case study and initial testing of a wireless sensor network (WSN) to support energy management utilizing Web services and middleware technologies. The experimental work presented illustrates that a combination of commercially available WSN from different vendors operating with several communication standards can be employed to monitor and measure real time data such as temperature, light, humidity and power consumption. A single Web site was developed to illustrate the concept of how monitoring sensor parameters and energy measures stored in different repositories could be used. This demonstration illustrated that it is possible to remotely switch on/off electrical appliances from this Web site utilising the integrated Web user interfaces of each of the WSNs. The open architecture of the concept allows for easy and continuous updates and unlimited expandability. Therefore, the model's design allows for its application in a large number of building categories.

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