The Impact of Wireless Sensors in Buildings Automation

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Abstract:, The automation of a building requires a huge number of cables that highly increase the installation costs. At the physical level, wireless plays an important role towards flexibility and self-configuration in building automation. With the use of wireless technologies it is expected to reduce total costs of ownership and maintenance in new building automation systems. Wireless systems could easy provide old buildings with relatively low cost, automation functionalities. The paper presents the state-of-art in this knowledge domain discussing the advantages and handicaps of wireless approaches in building automation.

Keywords: Building automation; wireless sensors; wireless communications; WiMax; Wi-Fi; Bluetooth; ZigBee; maintenance.

1. Introduction

The emerging technology of wireless sensors promises to enhance better monitoring in and around buildings [Malkawi, A. *et al.*, 2005]. Wireless data communication between the sensor and a viewing or storage location opens up a range of possibilities, not only because the ease and the low cost of sensors deployment, but also due to the true self-reconfiguration of a system without any rewiring that becomes possible as ever didn't before.

Together with other technologies like service oriented architectures and the use of agent technology, wireless at the physical level play an important role towards flexible and self-reconfiguring systems. In buildings, to help detect and diagnose faults, the wireless sensors can be placed on critical pieces of equipment. Efficiently, an automation system throughout the building allows you to use more sensing points in its lighting, heating, ventilation and air conditioning equipment and plug loads [Riaz, Z. *et al.*, 2006]. In emergency situations such as fires, deployment of wireless sensors can provide more information about the conditions within and around the building for security agents.

Using a variety of sensors in the environment of the building allows leverage a wide range of parameters interest to engineers, researchers, investigators or maintenance personnel. The most significant are such as temperature, relative humidity, light, carbon dioxide, carbon monoxide, energy consumption (power), smoking, occupation and flow rate.

A number of authors have discussed the use of wireless sensing for buildings automation and monitoring. For an office building, wiring costs (labor plus material) make up approximately 45% of the installed cost for a new building and nearly 75% of the installed cost for a retrofit application [Wang, Y. *et al.*, 2005].

The use of wireless sensors would greatly cut this cost through savings in the labor required to install the system.

The wired sensors could be installed in each space to be monitored. However, this measure requires a major effort and an additional set of wires throughout the building. In 2002, the estimated cost to the signal cable ranged from $ 2.20, per meter for new construction, to U.S. $ 7.19 for existing buildings [Kintner-Meyer, M. *et al.*, 2002]. Another example of the costs involved in wired systems can be found in a recent structural monitoring system, where up to 75% of total testing time and 25% of system cost involved the installation of signal wire [Wang, Y. *et al.*, 2005].

Transmitting the data wirelessly provides a significant benefit to those investigating buildings by allowing them to deploy the sensors and monitor the data from a remote location [Ganza, J. *et al.*, 1998].

It is clear that the industry has been watching closely to the use of wireless in buildings. However, doubts still remain about the ease of use, reliability and cost of wireless monitoring. Wireless systems have a number of disadvantages such as higher cost of equipment, eavesdropping of information, potential loss of the data stream transmitted over the radio frequency interference, are subject to electrical noise jamming (accidental or intentional) and the need for mandatory supply power to wireless devices. Although being aware of the disadvantages mentioned, the potential applications for wireless sensing abound.

2. Wireless Building Automation

The wireless network system for monitoring and building automation has several reasons alongside its use:

a) Sometimes, in specific applications, the use of wireless technology is required, such as when it is necessary that the device attached to the mobility equipment, such as in automobile or other mobile equipment. In industry within corrosive environment (chemistry), places with high vibration or elements in constant motion that can damage the cables. In these cases, wireless is almost a requirement for the application.
b) In some cases, the costs of using wiring are so high that revel to be a prohibitive solution, thus the need for the use of wireless technology is almost absolute. For example in the case of monitoring a large geographic area. The use of wireless devices would be a substantial economic advantage, but now with a more drastic approach: zero cabling costs.
c) Moreover, the availability to move sensors from one place to another without any rewiring higly improves the reconfiguration and flexibility os the system [Jammes, F. *et al.*, 2005]. Together with other technologies like service oriented architectures, web services and the use of agent technology, wireless at the physical level play an important role.

The use of wireless presents advantages and drawbacks as it will be illustrated below:

I. Wireless advantages

The main advantages of wireless are related to the reduction of wiring costs and increased flexibility:

a) *Reduced wiring communication*: Without wires, cost intensive wiring plans become obsolete. Labour-intensive cable installation costs will be dramatically reduced and there will be no more need for wiring maintenance tasks; The wire acquisition and labour-intensive cable installation costs will reduce dramatically and is no longer necessary for its maintenance activities.
b) *Reduced power cabling costs:* The sensors that utilize semiconductor technologies for low power, don´t need to be connected to a main power source, hence are avoided the use of power cables, since the sensors use internal batteries or harvest the energy from the environment.
c) *Enhanced reconfigurability*: The system reconfigurability is highly enhanced because with wireless there aren't the limitations of low flexible wired systems. Using the correct software architectures approaches, which are out of the scope of this paper, a new device that comes into the range of a wireless network can offer its services to the network and get new tasks allocated to it. This would be done automatically and transparently, not requiring a single physical connection.

II. Wireless handicaps

The structural and economic advantages are obvious and recognized, however, the business sector is still holding about moving to wireless technology, particularly in real-time systems. The wireless handicaps are as follows:

a) *Power Consumption*: The wireless sensor is a micro-electronics device that has to be fed with a source of limited power (e.g. <0.5 Ah, 1.2V). Therefore, it has a dependence with the power consumption. Additionally, sensor lifetime has also a strong dependence on battery life. Hence, power conservation and power management take on additional importance. In sensor networks though, power efficiency is an important performance metric, directly influencing the network lifetime. It is for these reasons that researchers are currently focusing on the design of power-aware protocols and algorithms for sensor networks. Power consumption can be divided into three domains: *sensing, communication, and data processing*.
b) Wireless communication: Cardeira [Cardeira, C. *et al.*, 2008] examine and discuses the advantages using wireless communications, such as, are subject to much more path loss (depending on the type of antennas used), do not support full duplex communications because when a device transmits, it is not able to receive on the same channels (no collision detection) and have the problem of the hidden terminal. The wireless communications are prone to reflection and diffraction, the destination station may be receiving many copies of the original signal. The physical layer overheads are higher than wired solutions because of extra training sequences necessary to establish communication. The probability of getting channel errors is higher as wireless communications waves are also subject to multipath fading.
c) Security and safety: As Cardeira [Cardeira, C. *et al.*, 2008] mentioned in is paper, there are security issues as wireless waves are easily detected by any receptor in the range for illicit eavesdropping. In spite of strict regulations about electromagnetic interference, in an industrial environment, strong motors, electrical discharges usually affect wireless communications too. They are issues in

safety, because wireless networks can be jammed unintentionally as by other equipment or by intentional criminal acts.

3. Wireless Communication Technologies

The most representative available technologies (for further details see [Cardeira, C. *et al.*, 2006] [Willig, A *et al.*, 2005]):

a) *WiMax*: It has a long transmission range (up to 50 km) at 75 Mbps rate per channel, but can also be used for last mile broadband communications. The interest on these lower bands is that the signals can easier penetrate non-metallic obstacles and most walls, enabling communications out of line of sight [Vaughan-Nichols, S., 2004].

~~b)~~ *Wi-Fi*: It is a very popular solution and the equipment costs are low, with a typical indoor range of 30 m or 90 m outdoor range. However, it incurs in more difficulty to go through walls, making its range shorter.

c) *Bluetooth*: The most common implementations are lower power ones which range can be up to 1 m or 10 m depending on the power class. Bluetooth devices require much less power than Wi-Fi, but the area covered and data rates are also much lower.

d) *ZigBee:* It operates in several frequencies used by most Wi-Fi and Bluetooth devices, presenting a comparable or slightly higher range (10-100 metres) and a lower data rate (20-250 Kbps). The main advantages of ZigBee are lower power consumption and network self reconfiguration. ZigBee devices are able to 'sleep' most of the time.

e) *UWB*: Ultra-Wideband is a technology where the communication is send by short-pulse electromagnetic waves, instead of the usual modulation of sine wave carriers [Fontana, R.J., 2004]. It is claimed that UWB might achieve rates up to 500 Mbps in a 2 m range (or 110 Mbps in a 10 m range) operating in the same bands as other communication systems without significant interference, but the hardware will consume just a few mW of power.

f) *NFC*: Near Field Communication (NFC) is a technology where an emitter provides a magnetic field and the receiver answers by modulating this field. The speeds are limited (106, 212 or 424 Kbps). The maximum operating distance is 1.5 - 2 m, however, only small distances 0-20 cm are usually considered. NFC requires comparably low power as Bluetooth V4.0 low energy protocol.

g) *RFID*: Radio Frequency Identification (RFID) is technology for a wireless transmission of device identification. They answer with a sequence of bits that defines its identification [Want, R., 2004]. RFID tags read the state of some attached sensors (temperature or a MEMS accelerator for instance) and have internal active power (for instance, harvesting the energy from the environment [Cardeira, C. *et al.*, 2006]) their use in automation may largely exceed device identification.

h) *GSM 2G and 3G*: The usual telecommunication Global Positioning System (GSM) services are evolving and providing larger coverage and higher rates with General Packet Radio Services (GPRS) or Universal Mobile Telecommunications Service (UMTS). The main inconvenient is that these technologies require an infrastructure of a service provider.

i) *Others*: Some other technologies where not considered, either because they are still immature or because their use in automation is not yet established as WiBro (Wireless Broadband), Digitally enhanced cordless telephone (DECT) and Infrared Data Association (IrDA - an organization of over 150 companies that provide common standard for infrared communication between different devices.

4. Power Requirements

The main task of a wireless sensor in a sensor field is to detect events, perform quick local data processing, and then transmit the data.

Sensing power varies with the nature of applications. Periodic sensing might consume lesser power than constant event monitoring. The complexity of event detection also plays a crucial role in determining energy expenditure. Higher ambient noise levels might cause significant corruption and increase detection complexity.

Of the three domains, a sensor expends maximum energy in data communication. This involves both data transmission and reception. It can be shown that for short-range communication with low radiation power (~0 dbm), transmission and reception energy costs are nearly the same - mixers, frequency synthesizers, voltage control oscillators, phase locked loops (PLL) and power amplifiers. All consume valuable power in the transceiver circuitry. It is important that in this computation not only consider the active power but also the start-up power consumption in the transceiver circuitry.

The energy consumption in data processing is much less compared to data communication. Assuming Rayleigh fading and fourth power distance loss, the energy cost of transmitting 1 KB at a distance of 100 m is approximately 3 joules, the same as that for executing 3 million instructions by a 100 million instructions per second (MIPS)/W processor [Pottie, G., 2000]. Hence, local data processing is crucial in minimizing power consumption in a sensor network.

Therefore, reducing the supply voltage is an effective means of reducing energy consumption in active state, since the reduction of tension gives us quadratic gains. On the other hand, it affects the peak performance of the processor.

Significant savings in energy can be obtained by recognizing that peak performance is not always desired and therefore the processor voltage and frequency of operation can be dynamically adapted to the needs of instant processing.

The technologies can enable increased autonomy and reduced power consumption of devices and, secondly, to find alternatives to power the sensors, such as:

a) *Battery*: The use of batteries in wireless sensors is the most conventional, but is only interesting if the power consumption of the device allow a battery life between 3-5 years or more.

b) *Microwave*: RFID passive technology is one that uses the microwave. The sensor takes the energy it needs to operate from communicate electromagnetic waves [Want, R., 2004].

c) *Energy harvesters*: These devices convert some form of energy present in environment into electrical energy that they need to operate. The energies available in environment come from mechanical motions, using piezoelectric materials or by using a temperature differential [Kintner-Meyer, M. *et al.*, 2005] [FerroSolutions, 2006].

5. Wireless as a future solution for building automation

A number of articles in the literature have discussed the use of wireless sensing for buildings automation and monitoring. Within a residence, Healy [Healy, W., 2004] examined the use of wireless sensing devices to monitor conditions and find that the sensor networks were easy to set up, but required more programming than desired for easy deployment.

Wills [Wills, J., 2003] discusses the move towards wireless technologies for control applications in buildings, foreshadowing the move by the BACnet committee of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) to work with the ZigBee wireless standard committee [Adams, J., 2003] to implement wireless communications in building controls.

Raimo [Raimo, J., 2006] discusses the emergence of mesh networking for connecting controllers in a building. To low data rate monitoring, Ruiz [Ruiz, J., 2007] discussed a range of ways to implement various wireless applications in buildings from voice communications.

For buildings to be monitored for research, wireless data transmission provides a significant benefit, i. e., allows the implementation of sensors and monitoring data in a remote location.

However, there are some limitations in the universal use of wireless sensors. The key is communication and energy. The latter, substantially restricts its use and autonomy, and their use dependent on the technology of power supply and consumption and on the amount of data processing and communication.

To build a wireless sensor network several components of hardware and software are needed. The principal component of the system is the wireless sensor device. This component consists of: the physical sensors; a microprocessor (to analyze the raw data signal and generate the data message); a radio frequency transmitter (to deliver the data); and a power source. The microprocessor on each sensor device can be programmed to ensure that all sensors in a given region work as a coherent system.

In a wireless sensor network, there are device sensors wirelesses capable to sending information to another sensor device in a mesh network, however, most applications just involve the delivery of data and information from each sensor device to a central data collection point. This point is typically a computer that store data and software required to ensure that data sent by the wireless transmitter is interpreted, displayed and stored in a usable form.

Several authors [Lynch, J.P., 2007] [Pottie, G., 2000] [Akyildiz. I.F., 2002] [Estrin, D. *et al.*, 2002] [Hill, J. et al., 2004] [Szewczyk, R. *et al.*, 2004] [Aziz, Z. *et al.*, 2006] have pointed out the recent advances in wireless technology and deployment of systems easier. Of particular note is the use of mesh networking. Mesh networking describes a topology of a sensor network in which each sensor device communicates with its neighbors and can relay messages from that neighbor through the network (A contrasting topology would be a star network, in which each sensor node communicates directly to a base station that collects the data). The benefit of the mesh networking scheme lies in the fact that each wireless sensor need only communicate with a neighboring sensor device as opposed to directly to a base station. The most advanced mesh networking schemes allow the sensors to arrange themselves in an ad-hoc manner, so that the routing path of a message can change if an obstruction prevent communication between two sensor devices or if another radio enter the network. This type of system adds robustness to the sensor network and permits it to be easily expanded. The downside of such system is the increased complexity in the software (and corresponding increased cost of the system) and the fact that each sensor device serves as a repeater and therefore consumes more energy.

6. Wireless and maintenance

In general, service and maintenance operations require mobility and maintenance of a building are critical to the success of the reliability for security, energy supply, hazardous situations (such as fires), comfort (such as ventilation, air conditioning, internal air quality and lighting) and special equipment (such as those are in hospital, data center, and military building). Using the wireless network as a source of information for maintenance enhances their use. Wireless devices can identify the need for a maintenance operation, program resources for the proper moment for each system, equipment or sensor and efficiently reduces maintenance costs of any system or equipment.

Location aware wireless sensors do provide additional information about their location. This information could gathered wirelessly by the PDA of a personnel crew. For maintenance operations it is very convenient for the operator to carry with him a wireless palm device or similar equipment that would guide him directly to the equipment that needs assistance. With these devices operators can feed data to the system and it also becomes possible to use the PDA to guide the operator to a specific sensor or actuator taking into accounts the new possibilities of location awareness systems [Cardeira, C. *et al.*, 2008]. The operator would be guided to the specific sensor or actuator to check it or perform any operation maintenance on it.

Using a wireless network, technicians will be able to order parts, report faults and schedule higher-level maintenance from any location.

7. Conclusions

Emerging wireless sensor technology promises to enable enhanced conditions monitoring in and around buildings. Wireless data communication between the sensor and a viewing or storage location opens up a range of possibilities, not only because of the ease and the low cost by which the sensors can be deployed, but also due to the true self reconfiguration of a system without any rewiring that becomes possible as ever didn't before. As already mentioned, together with other technologies, such as service oriented architectures and devices, wireless networking, physically, they play an important role in the flexibility and self-reconfiguration systems. Wireless sensors could be placed on critical pieces of equipment in buildings to help detect and diagnose faults. Buildings lacking a whole building automation system could use more sensing points to more efficiently control its lighting, heating, ventilating, and air-conditioning (HVAC) equipment, and plug loads. In hazardous situations such as fires, deployment of wireless sensors could provide more information about the conditions within and around a building for first responders.

A wireless sensor network consists of various pieces of hardware and software. At the heart of the system is the wireless sensor device. These pieces of equipment (sensors and microprocessor to analyses the raw data signal) generate the message, a radio frequency transmitter to deliver the data, and a power source. This piece of equipment consists of the physical sensors, a microprocessor to analyse the raw data signal and generate the data message, a radio frequency transmitter to deliver the data, and a power source.

When considering sensing of the building environment, a large range of constituents could potentially be of interest to engineers, researchers, investigators, or maintenance personnel can use a variety of methods to monitor conditions in a building by measuring. Of these, the most significant are likely to include temperature, relative humidity, light, carbon dioxide, carbon monoxide, energy consumption (power), smoke, occupancy, and flow rate.

Wireless systems, however, have their own set of disadvantages, such as higher equipment cost, the potential for radio frequency interference to damage the data stream, and the need to provide power to these "wireless" devices.

Although being aware of the disadvantages mentioned, the potential applications for wireless sensing abound. With the use of wireless technologies it is expected to reduce total costs of ownership and maintenance costs in new building automation approaches. Wireless systems could easy provide to old buildings, at relatively low cost, automation functionalities that are characteristics of new buildings.

The biggest challenge for the engineers, researchers or investigator team is developing a reliable energy source for the wireless sensors and it is clear that the industry is very curious about the use of wireless in buildings. However, doubts still remain about the ease of use, reliability and cost of wireless monitoring

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