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Towards a Wireless Sensor Platform for Energy Efficient Building Operation

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Abstract: Currently, the IT-support for energy performance rating of buildings is insufficient. So-called IT-platforms often "built" of an ad-hoc, inconsistent combination of off-the-shelf building management components, distributed data metering equipment and several monitoring software tools. A promising approach to achieve consistent, holistic performance data management is the implementation of an integrated, modular wireless sensor platform. This paper presents an approach of how wireless sensors can be seamlessly integrated into existing and future intelligent building management systems supporting improved building performance and diagnostics with an emphasis on energy management.

Key words: computer-based monitoring and maintenance of infrastructure; wireless sensor platform; energy efficient building

Introduction

Limitations of current building energy management systems lie in their 'wired' infrastructure preventing the retrofitting of existing buildings with improved energy management systems, and in the unreliability and inaccessibility of the environmental and energy related data across a fragmented information management infrastructure. Most of the available wireless sensor motes are not optimized in terms of functionality or form factor for use in a dedicated building management environment. Typically, these motes have a single sensor function which cannot be easily customized.

This paper describes the design and initial setup of a wireless platform to support building performance & diagnostics with an emphasis on energy management.

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1 Building Operation and Facilities Management

Building operation is an important part of facilities management (FM). FM is defined as[1] "… the management of buildings, physical plants and services. FM-services are considered to be divided into so called 'hard services' and 'soft services'" According to the classification of professional bodies (e.g. GEFMA[2], BIFM[3]) hard services are defined as technical building management, such as technical object management, operation, maintenance, energy management, supply systems, etc. Soft services can be divided into infrastructural building management (e.g. space management, cleaning, relocation, etc.) and commercial building management.

1.1 Efficient operation and user satisfaction

The business models for building operation and FM have changed over the past two decades. The share of the traditional "owner = user" model is dramatically declining; i.e. today the owner-role is separated from the operator-role and the user-role. Many users prefer to lease space according to the market requirements of their core-business instead of owning facilities.

Consequentially, the understanding and interpretation of efficient building operation is different, since it depends on the organisations' role. In order to balance the interests of the different parties formalised and transparent assessment criteria, such as performance evaluation metrics are required[3].

These clearly defined, holistic, life-cycle-oriented assessment criteria can finally be compared against the actual performance of the building. Therefore, the increased need for more precise data acquisition, multi-dimensional management and a long-term analysis of building performance data and the in-depth diagnostic of the buildings behaviour needs to be addressed.

1.2 Building performance and diagnostics

The term building performance and diagnostics was introduced as an independent research area in the 1980s[4,5]. Starting in the mid 1990s researchers have developed design tools to achieve improved human thermal comfort and integrated building operation[6]. Additionally, specific assessment criteria for the energy-efficient operation of buildings were developed and published[7].

1.3 Assessment criteria

Improved bioclimatic design and optimal human thermal comfort are important assessment criteria. Bioclimatic design aims to conserve resources by using place-based design, to benefit from renewable energies, such as sun, wind, or water. Human thermal comfort aims to optimize the climate in buildings. Both can be achieved with sustainable design strategies complemented by predictive building control systems[8].

Especially for the support of predictive building control systems extensive data about the building and its environment is required. This data is usually managed with integrated IT-platforms. Furthermore, the acquisition of building performance data can be substantially improved through the installation of wireless sensor networks in existing buildings. The reduced installation costs for wireless sensors support a denser, more precise monitoring of the building.

1.4 Requirements for integrated IT-solutions

In order to achieve wide spread adoption of the predictive control paradigm it is imperative to provide integrated, homogeneous IT-solutions for energy-efficient building operation.

Important requirements for those IT-solutions are:

- Easily deployable
  IT-solutions must be easily deployable by end users;
- Scalability
  IT-solutions must scale with needs of operators;
- Customisation
  The emphasis is on the development of a broad spectrum of interface options;
- Reliability
  Wireless sensor networks must survive in "harsh", complex RF environments;
- Multi-Purpose
  Wireless sensors must support both: zone control and central plant applications.

2 IT-Platform for Energy-Efficient Building Operation

Major components of an IT-Platform for Energy-Efficient Building Operation are:

(1) sensors,

(2) active network components and controllers, and

(3) software components.

Within the next chapter the major characteristics for each component are specified.

2.1 Wireless sensors

Wireless sensors must be available in multiple form factors. Additionally, wireless sensors must support multi-functional measuring for different variables, e.g. temperature, humidity, voltage, gas/water-flow, etc. A long battery life (3 to 8 years) for the wireless sensors is important to enable cost-efficient management and robust operation. It should be possible to operate wireless sensors in multiple modes (cf. section 3.2).

2.2 Wireless network

The topology of wireless sensor networks for integrated IT-platforms must address the need for frequent re-configuration of buildings which results from the changing business models in the Facilities Management sector (cf. section 1).

Active network components (e.g. repeaters/routers) are introduced to extend the range of wireless sensor networks. They provide alternate (wireless) communication paths thus improving the ability to cope with failures of network components or obstructed communication paths.

The preferred network topology is a mesh network as it provides multiple routes between peer nodes via multi-hop communication rather than simple one-hop star or single route tree topologies.

At a second level, individual sensor network zones are connected to gateways which also form mesh networks based on IEEE802.11 radio technology. By providing a second tier of mesh networking, scalability and reliability is improved and battery power consumption for embedded wireless sensor nodes is reduced. The gateways, using IEEE802.11 radio also allow external interfacing with the embedded network.

This flexibility is essential for our demonstrator, since we would like to support inspection and maintenance staff to connect to individual network elements using mobile devices with IEEE802.11 interfaces.

2.3 Software components

Multiple software components are part of the IT-platform, such as network management software (NMS), building management systems (BMS) or computer aided facilities management (CAFM) tools.

NMS consists of multiple modules, supporting the commissioning, operation and maintenance of the Sensor Network by providing the ability to manage a wireless network remotely from a central location.

Building performance data can be metered, monitored, and managed by data-rich system components, such as BMS, or CAFM.

BMS assist facility managers to provide the hard services to their clients (cf. section 1). BMS consist of a homogeneous IT-platform to monitor and control exclusively the building's mechanical and electrical systems. CAFM-tools complement BMS. They support the coordination of the physical workplace with the people (e.g. occupants, operators, inspectors, owners) and the core-activities of the organization by information technology. CAFM platforms support the provision of hard- and soft services to monitor, control and document all FM-activities.

2.4 Data communication protocols for Bbuilding automation and control networks

The existence of standardised, homogeneous data communication protocols for building performance data is essential for the complete and consistent exchange of building performance data using complex and inhomogeneous network structures. The following paragraph gives an overview about selected relevant standards.

Modbus is a serial communications protocol published by Modicon in 1979[9]. It has become a de facto standard communications protocol in industry. Modbus allows for communication between many devices connected to the same network.

BACnet is a data communication protocol for building automation and control networks. It supports six different underlying network technologies[10]. BACnet has been under development under the auspices of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) since June 1987. BACnet is an American National Standard (ANSI / ASHRAE Standard 135-2004), an established European standard, a world standard and a national standard in more than 30 countries[11].

LonWorks is a networking platform to support the operation of building control and building automation applications. Its core is a protocol created by Echelon Corporation. LON supports multiple media, such as Radio frequency (RF), twisted pair, fibre optics, or power lines.

LonTalk — the communication protocol and data link/physical layer of the BACnet-standard — is an accredited ANSI standard for control networking (ANSI/CEA-709.1-B). Recently, the protocol was made available for general purpose processors.

The availability of standard network variable types (SNVT) and standard configuration property types (SCPT) simplifies the network management and provides a standardized mechanism for data exchange.

Currently, LON specifies over 160 SNVTs supporting most of the data types and variables commonly used in control applications. New SNVTs are added on an annually basis as needed.

ZigBee is a wireless communication technology that provides a suite of high level communication protocols using small, low-power digital radios. ZigBee uses the

IEEE 802.15.4 standard for wireless personal area networks (WPANs). The technology is intended to be simpler and cheaper than other WPAN protocols (e.g. Bluetooth). ZigBee is targeted at RF-applications that require a low data rate, long battery life, and secure networking[12].

3 BuildWise Prototype

BuildWise is a technology transfer project funded by Enterprise Ireland from 2007 to 2010. BuildWise aims to specify, design, and validate a data management technology platform that will support integrated energy & environmental management in buildings.

The following paragraphs describe the wireless network components of the first buildwise demonstrator. Aspects of data and information management of sensed performance data are described in Ref. [13].

3.1 Tyndall mote—a hardware prototype

The Tyndall prototyping platform[14] has been developed based upon Tyndall's 25 mm modular wireless sensor node pictured in Fig. 1. The 25 mm wireless node has been used to develop a platform for low volume prototyping and research in the wireless sensor network domain. It has been developed for use as a platform for sensing and actuating, for use in scalable, reconfigurable distributed autonomous sensing networks.

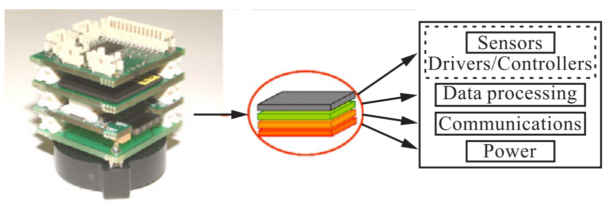

Fig. 1 Tyndall's 25 mm wireless sensor module

The modular nature of the Tyndall hardware lends itself to the development of numerous layers for use in various application scenarios. Layers can be combined in an innovative plug and play fashion and include communication, processing, sensing and power supply layers to create an application specific stack.

The system has the capability to implement a variety of ISM band transceiver protocols including the 2.4 GHz ZigBee (802.1.5.4) standard transceiver, which provides a very powerful customisable wireless sensing system which can be quickly and easily deployed and tested in a particular application.

The stackable configuration enables ease of connectivity between layers depending on the system level requirements and deployment scenarios and can incorporate sensor layers, DSP/FPGA system layers and energy harvesting layers as required by the particular deployment scenario.

3.2 Wireless network

The BuildWise-demonstrator is implemented in the building of UCC's Environmental Research Institute[15]. The Building has 3 floors. The northern part of the building is equipped with laboratories and the southern part is equipped with offices. All rooms will be equipped with 4 wireless sensors (temperature, humidity, and light).

Figure 2 depicts the ground floor of the ERI-Building, the proposed sensor locations and their types as well as the locations of the proposed gateways.

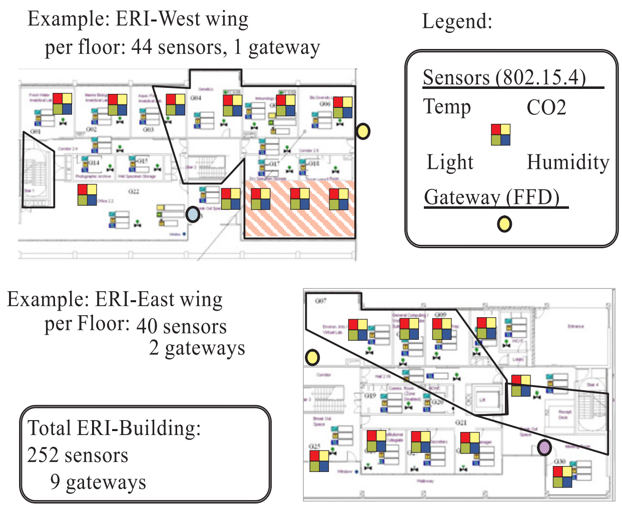

Fig. 2 Proposed sensor locations and signal distribution

Furthermore, Fig. 2 depicts the "uncovered areas" for each gateway-node (grey areas).

In the final demonstrator (version 2, to be completed in 2010) 252 wireless sensors will be installed. These sensors will be co-ordinated by 9 gateways.

3.3 Proposed network topology

For the implementation of our first demonstrator (version 0) we have decided to implement a hybrid, hierarchical network topology. The communication between the sensor nodes and the zone controller will be implemented using a modified IEEE802.15.4/ZigBee protocol[16]. The zone controller will coordinate the communication between sensors, collect sensor data from the sensors and "feed" the data into the existing wireless LAN using the 802.11 protocol.

Usually sensors are so called reduced function devices (RFD). In our demonstrator all sensors can be configured as RFD or Full Functional Devices.

Zone controllers can also act as gateways. Gateways are full function devices (FFD) with the following characteristics:

- PAN coordinator, co-ordinator, end device;
- FFD can talk to other nodes;
- PAN coordinator starts up a network;
- PAN coordinator vs. coordinator.

3.4 Data management

The network topology described above will allow us to compile the data sets from all sensors on one single machine. This "BMS"-machine is the physical interface to the data warehouse system. The data warehouse system is the data management and data analysis module of the overall building information model. We envisage to use the LON SNVT's as open standard for the data communication. A first specification of the data warehouse functionality is given in Ref. [13].

3.5 Data aggregation and representation

The Data Warehouse component will allow us to consolidate, group, aggregate, and analyse building performance data in different performance profiles. These profiles will expand the functionality of CAFM tools.

The building owner profile will present an aggregated view on energy consumption data for the overall building as well as its maintenance and operation costs.

The building operator profile will aggregate sensor information about the energy consumption per "zone" (e.g. "tenant zone").

The tenant profile will aggregate sensor information about both, the human thermal comfort and the energy consumption in the tenant's work zone(s).

Finally, the tenant organisation profile will aggregate sensor information about both, the human thermal comfort and the energy consumption for all zones used by the organisation.

4 Experimental Challenges

The proposed topology will support two experimentation scenarios: (1) wireless data collection and (2) network operation with meshed topology.

4.1 Data collection with hierarchical networks

This scenario will explore the reliability of the data collection tools under different loads (from 30 s interval up to 10 minutes interval). Additionally, we will test different complexities of the "logical network set-up".

The focus will be on the "virtual" allocation of sensors to "SpatialStructures" used by a specific "Organisation", i.e. to allocate sensors in the Building Information Model (BIM) to an "operator zone" or a "tenant zone". These zones must relate to the representation profiles. This should be achieved by using the "dimensional data structures" (dimension "Spatialstructure") as described in Ref. [13] and depicted in Fig. 3.

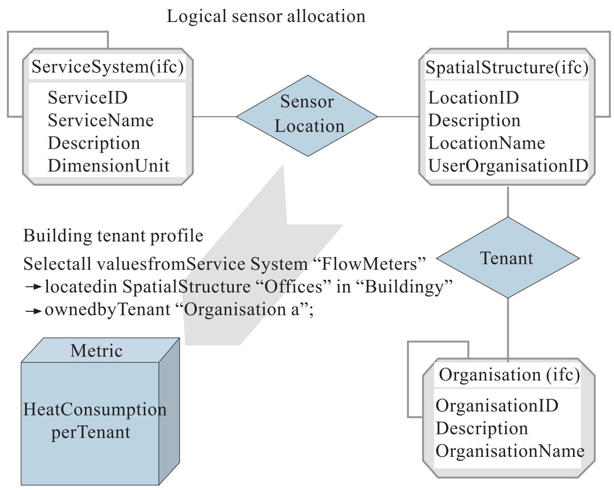

Fig. 3 Logical sensor allocation through relations

4.2 Network operation with meshed topology

This scenario will test the reliability of the mesh-network management. The proposed network topology depicted in Fig. 4 will allow us to "disable" individual gateways (e.g. gateway No. 2).

In case node 2 is not available the sensor nodes marked with "(2)" in Fig. 4 must then establish a connection to other network nodes (either node (1) or node (3)). In parallel we envisage to perform network simulations and to compare field test results with simulation results.

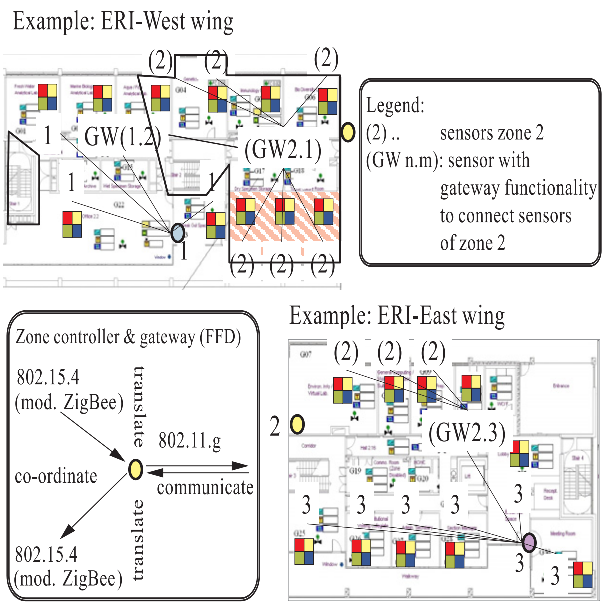

Fig. 4 Proposed hybrid network topology

5 Conclusions

This paper describes the current development status of the so called “Prototype 0” of the “BuildWise” project. This prototype focuses on a feasibility study for a hybrid network integrating wireless sensors into an existing wired BMS. In a following demonstrator we envisage to test gateways to other data communication protocols (e.g. EIB/KNX), more complex network structures, and to increase the “load” of the network by adding substantially more sensors and decreasing the measurement interval.

Acknowledgements

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