Technical Design for Holistic Wireless Communication in Smart Buildings

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Abstract: This paper presents the design of a wireless building monitoring network implemented at the University of Nottingham's Creative Energy Homes test site. The network is installed in seven smart buildings with the aim of holistically collecting energy data. Data will be used to inform a central control algorithm to optimise the energy flows between buildings, in turn promoting the smart cities concept. Sensors and meters measuring temperature, humidity, CO_2, heat energy, power, and stratified tank temperature are described. Furthermore, the communication protocols utilised are also discussed, which include wireless MBus and EnOcean. This paper also covers the methods used for ensuring the reliability of data signals and the system controls.

Key words: smart cities; smart buildings; communication network; building monitoring

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0 Introduction

Understanding how buildings operate through data collection is vital to improve comfort levels and energy efficiency. As a result, recently there has been increased focus on smart buildings and how they can integrate with energy networks to support the concept of interconnected smart cities [1]. Smart buildings improve building operation by incorporating systems on a common network. This integration allows for the sharing of information and functionality.

Improving building systems integration is important to reduce energy consumption and greenhouse-gas emissions in line with the 2050 climate obligations for decarbonisation under the Kyoto Protocol [2] and more recently the UN-led Paris Agreement[3]. Furthermore, the European 20-20-20 strategy for improving energy efficiency and reducing fossil-fuel consumption is also a key driver for building improvements.

Smart buildings are only enabled with adequate controls. However, sophisticated software and computing cannot compensate for poor-quality or incomplete data. Therefore, a holistic data monitoring architecture is required.

As some of the most important technologies of the 21st century, networked wireless sensors are crucial for future data collection. Wireless sensors facilitate flexibility in industrial automation, electronic equipment, medical care, and in the case of this paper, smart buildings and building management systems. In addition, the onset of sensors with built-in energy harvesting has resulted in low-cost and low-power consumption. Overall, when using wireless equipment, there is an ease of installation and the ability to redesign or develop when compared with traditional wired systems.

This paper introduces the hardware and software architecture implemented at the University of Nottingham's Creative Energy Homes test site to enable wireless monitoring and control of several smart buildings. The research is unique as

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the first to connect smart buildings to an integrated heat and power network.

1 Methodology

The design of building instrumentation, data collection and processing is based on the work by Bolchini et al., which is focussed on developing methodologies for smart building monitoring [4]. As there is no defacto standard approach to design building monitoring systems, Fig. 1 is used to outline the design methodology.

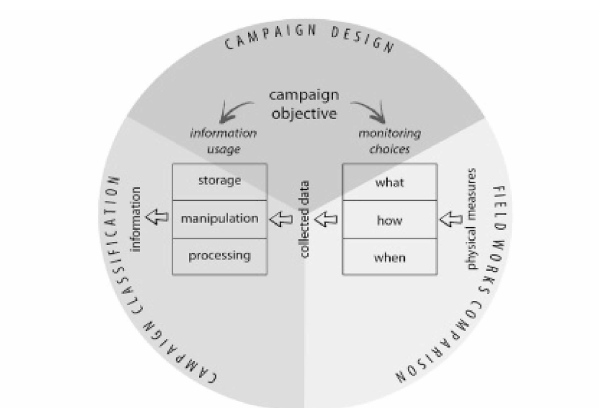

Fig. 1 The conceptual methodological framework for smart building monitoring and data analysis[4]

1.1 Monitoring campaign objective

We intend to implement a holistic, wireless building monitoring system, in which the sensor and meters should be energy harvesting to allow for cost and energy consumption reductions, as well as installation flexibility. Data must be accurate and precise as it will inform building controls for improved comfort levels and energy efficiency. Furthermore, the data will be used to enable buildings to connect to a smart heat and power energy network.

1.2 Monitoring choices

Sensors and meters using wireless meter-bus (MBus) and EnOcean communication are used to collect data on the following parameters: temperature, humidity, CO_2, stratified hot water tank temperature, electrical import, export, consumption and generation, heat generation and consumption, and gas consumption.

Data will be collected in 1-10 min time steps depending on control requirements.

1.3 Information usage

Data is collected using EnOceanPi and MBus transceivers, which are connected to RaspberryPi microcomputers and an MBus master, respectively. These devices manipulate data and send it to a central Linux computer running on an Ubuntu 16.04 LTS operating system where it is manipulated to inform building controls. Data is stored on hard disk and backed up using HP Data Protector installed on the central computer managed by the University of Nottingham's Data Centre remotely.

2 Communication Network Architecture

A communication network is composed of a physical medium for transporting signals such as a wire, optical fibre, or radio link; and a protocol which is the common language between devices.

Within this project, radio link and wire are the physical mediums used, whereas EnOcean and wireless MBus protocols facilitate holistic data collection. Due to the variety of measurements taken within buildings, several sensors and meters are required (see Table 1). Fig. 2 highlights the complex network of devices and communication signals, whereas Table 2 describes the physical medium and protocols used. The following list explains the logic behind some of the less obvious points in the network architecture and the numbering corresponds to the component numbers given in Fig. 2 and Table 1.

(1) Heat meters (No. 1) transmit wireless MBus signals to a receiver (No. 2) within each building. Heat meters measure flow rate, pipe inlet and outlet temperature and calculate heat energy. The MBus receiver is then wired back to an MBus master (No. 3) where data is collected and stored to be released in packets to a RaspberryPi via email.

(2) kWh meters (No. 4) used to measure electrical generation, import and export have a pulsed signal output of 1 imp per Wh. These nee-

Table 1　Component selection - sensors and meters

No.		Equipment	Measurement	Protocol
Env. conditions	7	Temperature and humidity sensor	Temperature & humidity	EnOcean
	8	Ambient CO_2 sensor 0/200 ppm	CO_2	EnOcean
Heating	Not shown	Self-powered wireless temperature sensor	Immersion temperature	EnOcean
	9	PT1000	Tank surface contact temperature	EnOcean
	1	Heat meter	Inlet and outlet temperature, flow rate, energy	MBus
	10	3-channel temperature data transmitter	Tank surface contact temperature signals	EnOcean
Electricity	6	Wireless single-phase energy meter transmitter module	Active power	EnOcean
	4	Single phase kWh pulsed energy meter transmitter module	Electrical PV generation; grid import and export	Pulsed output
	5	SR-MI pulse meter	S0 pulsed signal outputs from kWh energy meters	EnOcean
Gas	Not shown	SR-MI pulse meter	S0 pulsed signal outputs from gas meters	EnOcean
Monitoring network infrastructure	11 & 13	RaspberryPi 3 Model B microcomputer	All EnOcean signals	EnOcean
	2	MBus receiver module	Wireless and wired MBus signals	MBus
	3	MBus master data logger	MBus signals	MBus
	11	EnOceanPi 868MHz radio frequency transceiver module	868MHz radio frequency signals	EnOcean
	12	Network switch		

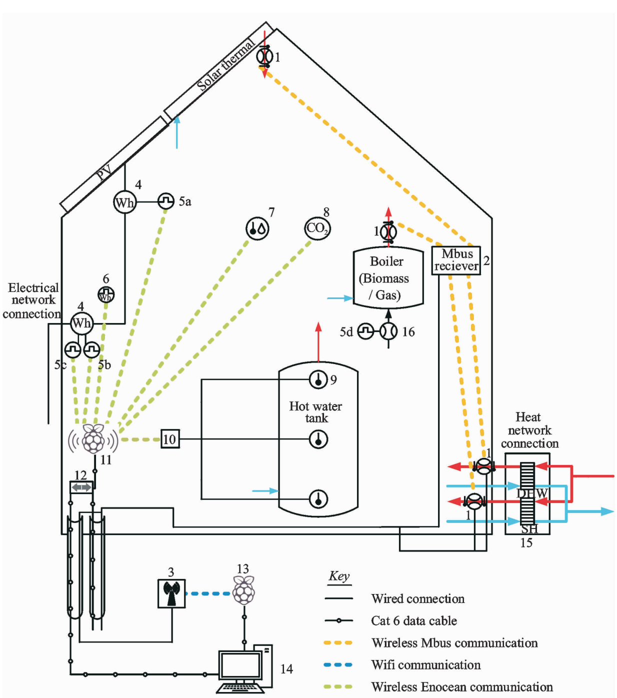

Fig. 2　Installed communication network architecture schematic

Table 2　Physical medium and communication protocols

Measurement	Physical medium	Protocol
Temperature & humidity	Radio link (868.3 MHz)	EnOcean
CO_2	Radio link (868.3 MHz)	EnOcean
Heat energy, flow rate, inlet & outlet temperature	Radio link (868 - 870 MHz) and wire	Wireless MBus
Electrical (kWh) import, export & generation	Radio link (868.3 MHz) and wire	EnOcean
Tank surface temperature	Radio link (868.3 MHz) and wire	EnOcean
Electrical circuit consumption	Radio link (868.3 MHz)	EnOcean

ded to be retrofitted with an SR-MI pulse meter (Nos. (5a, 5b, 5c)) which is an input module for implementing S0 signals in EnOcean telegrams. Essentially, the kWh meter is allowed to send data via the EnOcean communication platform.

(3) Pt1000 contact temperature sensors (No. 9) for hot water tank stratification temperatures measurements were hard-wired into a 3 channel temperature data transmitter (No. 10), again to enable communication on the EnOcean platform.

(4) Data signals from all EnOcean enabled sensors and meter are read by an En Ocean Pi transceiver connected to a Raspberry Pi microcomputer. The Raspberry Pis (No. 11) within each of the 7 homes are then hard-wired by daisy chained CAT6 ethernet cable to a central computer (No. 14).

(5) At the central computer, data is stored and processed to inform the control algorithm written for each building management system.

3 Component Selection

Within this section, the rationale behind the system component selection is presented. Table II gives a comprehensive summary of the equipment along with their function. Sensors, EnOcean communication protocols, and MBus communication protocols describe the reasoning for selecting sensors and communication protocols.

3.1 Sensors

Selecting the correct sensor is vital to achieve the best performance of any monitoring and control system. Ineffective sensors will lead to control malfunction and high maintenance costs. As a result, to avoid the common problem of drift or early failure, only sensors with proven reliability were chosen. Where possible miniaturised energy harvesting and ultra-low power radio equipment was used to reduce the possibility of power supply failure. These sensors are also maintenance, wire and battery free resulting in flexibility, time saving, energy efficiency, and reduced capital and operational costs.

3.2 EnOcean communication protocol

EnOcean protocols are deemed most suitable as they are wireless with a radio signal range of 30m inside buildings [5]. Devices based on EnOcean systems contain micro-energy converters, ultra-low power electronics, and wireless communications to enable sensors, switches, controllers and gateways to be battery and maintenance free. Communication is via 14 byte radio signal data packets, with radio frequency energy transmitted for 1 binary data resulting in lower power requirement [5]. To tackle packet collision, three packets are sent at pseudo-random intervals. Furthermore, 868.3 MHz transmission frequency is used.

Within this network, a RaspberryPi microcomputer with EnOceanPi transceiver allows up to 20 sensors and actuators to communicate (see Fig. 3). Additionally, this kit enables remote sensing and control of smart buildings via PC or phone through a smart home server. Effectively, the EnOceanPi is a mountable radio transmitter module that acts as a gateway controller to the EnOcean radio frequency (Fig. 3).

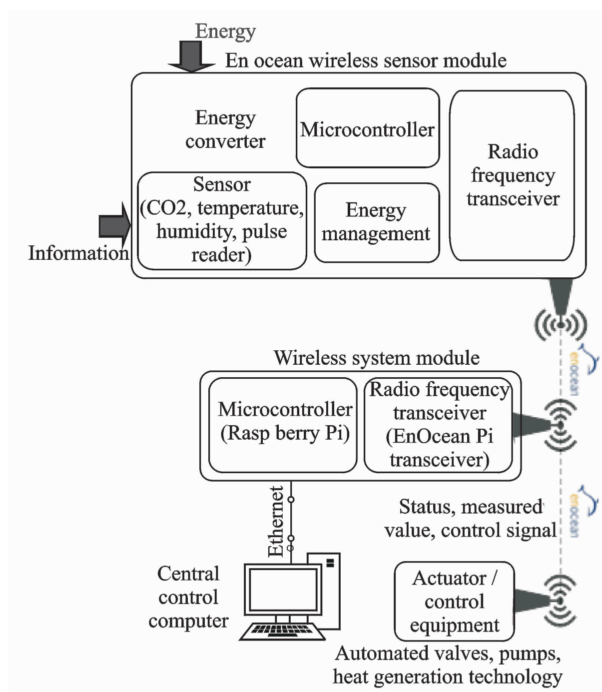

Fig. 3 EnOcean communication protocol overview

3.3 MBus communication protocol

MBus is a European standard for remote electronic heat meter reading. Benefits of this protocol include individual addressability of units, fail-safe characteristics, minimum cost and power consumption, good transmission speed, and ease of network expansion[5]..

Despite the benefits of using the EnOcean protocol listed in the previous section, one limitation is that there aren't EnOcean enabled heat meters. That is to say, a standard heat meter with pulsed signal output and a retrofitted EnOcean-pulse sender could be used to integrate heat into the monitoring network. However, as pulse senders only transmit one data type, kWh heat. As a result, a parallel MBus communication network was set up. Using MBus means data is collecting on inlet and outlet temperature, and flow rate, and kWh heat make the dataset more robust.

4 Radio Signal Transmission in Buildings

When installing the monitoring equipment, considering radio signal transmission through the building fabric is imperative to ensure data to be read by receivers. As radio signals are electromagnetic waves, their signals weakens with the distance from transmitter device. As a rule of thumb, a 30 m range is expected based on ideal conditions. However. There are a number of factors that influence transmission range, including

(1) Antenna and orientation

Good design and orientation of the antenna will give a range >20 m, yet this can be reduced to >10 m if conditions are not favourable. The angle at which an antenna points through a wall can affect the thickness the signal passing through. The EnOceanPi comes with a flexible external antenna and where possible antennas pointed directly through walls to prevent signal loss.

(2) Link path obstruction and terrain

Depending on the direction of propagation and the materials that signals encounter, dampening can occur when compared to line of site signal strength (see Table 3 and Fig. 4).

Table 3 Range reduction through materials [7]

Material	Range reduction vs line of site/%
Wood, plaster, glass uncoated, without metal	5—10
Brick, press board	10—30
Ferro concrete	20—90

The variability in building fabric at our test site meant that the location of transceivers needed considerable consideration based on the information in Table 3. Penetration is limited to 5 dry walls, 2 brick walls, or 2 aero concrete walls which reduce the positioning options for transceiver equipment.

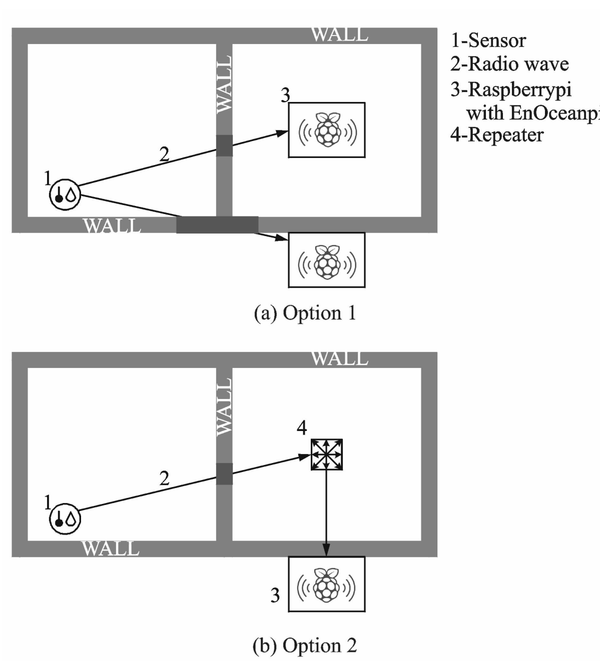

Fig. 4 Sensor signal schematic[7]

(3) Interference

EnOcean transceivers were separated from emitters of high-frequency signals, such as computers, by at least 3 meters.

(4) Signal reflection

Steel structural beams, metal plant, and foil heat insulation were responsible for radio shadow resulting in a loss of around 30% coverage. To avoid this transmitter position testing was carried out, in which necessary repeaters were used.

Range testing was carried out to ensure the aforementioned conditions within acceptable limits, where appropriate signal repeaters are used to extend signal range (see Fig. 5).

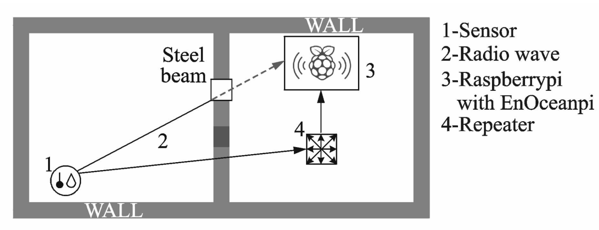

Fig. 5 Sensor signal schematic highlighting signal reflection and repeater solution[7]

5 MBus Transmission

When interrogated, wireless MBus meters give collected data to a central MBus receiver which periodically takes readings. Frequencies of 868 and 870 MHz are used in mode S1 which sends messages at regular intervals from the meter to the receiver. Again, wireless communications allows for installation flexibility and reduced hardware requirements. Each receiver is hardwired back to a common master which can communicate with up to 32 heat meters. Receivers must be hard wired to a master as the data collection site is too large for wireless range transmission.

6 System Controls

Ultimately, the smart building data collection described will provide a better understanding of building operation. In turn, the data will inform the control of an integrated heat and power network.

A central computer will run control algorithms to optimise the generation, distribution, and storage of energy onsite. By controlling domestic energy networks and utilising energy storage, it is possible to enable sustainable energy generation and the sharing of energy within communities. The advantages include reduced carbon emissions and associated environmental benefits. As well as the enablement of the prosumer concept, home owners can be both buyers and sellers of energy, in turn saving money.

Within our system, each property will have multi-vector energy generation, which includes: various evacuated solar thermal tube arrays, various flat plate solar thermal arrays, 20 kW Ökofen biomass boiler, worcester GreenstarRi 24 kW condensing gas boiler, main Eco Elite 24 kW System ErP gas boiler, and howden 12 kW immersion heater.

In both hydraulic and electrical networks, the equipment controlled by the algorithms include automatic valves, pumps, immersion heater relay, solar thermal flow stations (including pumps and valves), and Boiler on/off scheduling.

In summary, the data collected through the communication and monitoring architecture described in this paper will inform the wider control of a novel system heat and power network linking 7 smart buildings.

7 Conclusions

Smart buildings and cities that are responsive to needs have recently received a lot of attention in Refs. [8-10]. The core of all smart buildings and cities is the monitoring systems that provide centralised data collection and processing. Overall, benefits such as improved energy efficiency, enhanced operational effectiveness, and increased occupant satisfaction, can be achieved through implementing the smart philosophy in building control.

Within this paper the technical design of a smart building monitoring system installed at the University of Nottingham's Creative Energy Homes test site has been described. Data collected by this flexible, wireless communication network is used to inform control algorithms that optimise the generation, distribution and storage of energy in a novel heat and power network. Linking buildings in both heat and power networks is key to achieving interconnected smart cities where energy flows can be distributed to improve efficiencies.

The communication network architecture uses a combination of EnOcean and wireless MBus communication protocols to link sensors and meters to central transceivers. These transceivers then distribute data to a central computer for storage and processing.

In future, the equipment set-up designed in this paper will be integrated with a holistic control system, which can be used in test scenarios of heat generation in low temperature district heating, and power distribution and storage in microgrids.

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