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Design and deployment of a new wireless sensor node platform for building environmental monitoring and control

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Abstract

It is commonly agreed that a 15–40% reduction of building energy consumption is achievable by efficiently operated buildings when compared with typical practice. Existing research has identified that the level of information available to Building Managers with existing Building Management Systems and Environmental Monitoring Systems is insufficient to perform the required performance-based building assessment. The majority of today's buildings are insufficiently sensored to obtain an unambiguous understanding of performance. The cost of installing additional sensors and meters is extremely high, primarily due to the estimated cost of wiring and the needed labour. From these perspectives wireless sensors technology proves to have a greater cost-efficiency while maintaining high levels of functionality and reliability. In this paper, a wireless sensor network mote hardware design and implementation are introduced particularly for building deployment application. The core of the mote design is based on the 8-bit AVR microcontroller, Atmega1281 and 2.4 GHz wireless communication chip, CC2420. The sensors were selected carefully to meet both the building monitoring and design requirements. Beside the sensing capability, actuation and interfacing to external meters/sensors are provided to perform different management control and data recording tasks.

Keywords: building automation systems, sensors interfacing and motes deployment, wireless sensor network

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1. Introduction

A deeper understanding of system operation is possible if more detailed information is made available to Building Managers. This information must recognize the education and background of Building Managers if they are to fulfil their role with respect to organizational objectives and legislative compliance. Efficiency cannot be determined from displayed sensor readings without data access, storage and post-processing. Scheduling information must be displayed concurrently with Building Management System (BMS) data. All information used is dependent on accurate, robust and structured data.

Traditionally building automation systems are realized through wired communications. However, the wired automation systems require expensive communication cables to be installed and regularly maintained and thus they are not widely implemented in industrial plants because of their high cost [1, 2].

In recent years, wireless technologies have become very popular in both home and commercial networking applications. The use of wireless technologies offers distinctive advantages in the field of home and building automation [3–5]. First, installation costs are significantly reduced since no cabling is necessary. Neither conduits nor cable trays are required. Wireless technology also allows placing sensors where cabling is not appropriate for aesthetic, conservatory or safety reasons [4, 5]. With current

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wireless technology, a great challenge arises because of the level of expertise needed to fully make use of the sensors. The most sophisticated hardware often requires advanced knowledge of embedded programming to achieve the level of performance desired. A second issue is about the need for high active lifetime of the wireless installation which means the need for low-power design starts with the obligatory use of energy-efficient hardware (e.g. low supply voltages and sleep modes support in microcontrollers) [6].

Environmental monitoring and devices control of intelligent building based on Wireless Sensor Network (WSN) is considered as one of the most crucial applications. In the past, WSN has been used to measure number of signals within building environment like ambient light and temperature [7–11] to control and enhance the building energy performance. The initial target of the work in this paper is to deploy an efficient WSN capable of measuring wider range of vital signals inside the building and provide new methodologies for establishing reliable RF link and interactive user control.

In addition, this paper is focusing on the development of a miniaturized Wireless Sensor platform that is intended to be used for building sensing, meters interfacing and actuation. Next the deployment of large scale (around 60 nodes) of this platform is described in terms of network structure, topology and data presentation. The Environmental Research Institute (ERI) building, located at University College Cork (UCC), Ireland, was designed as a green flagship building and a low-energy research facility [12]. This building was chosen as the test bench for our large-scale deployment because it is the most densely measured building on the UCC campus.

The paper is structured as follows: Section 2 will be dealing with design aspects of the Wireless Sensor Node and the selection of the different sensors used for the target applications. The adopted WSN is described in Section 3. The data storage and representation techniques are given in Section 4. Number of Surveillance and Security concerns is discussed in Section 5. A newly developed tool for occupant interaction is presented in Section 6. Finally conclusions and future work plans are drawn in Section 7.

2. WSN node design

2.1. System architecture and functional units

The mote is designed in a modular three-layer mode. As Figure 1(a) shows, the overview system contains four main units, these are data processing unit, RF communication unit, sensors/meters and actuation (multi-sensor) unit and power supply management unit. The data processing unit can make valid control for other units. To have deeper look into the developed system, the block

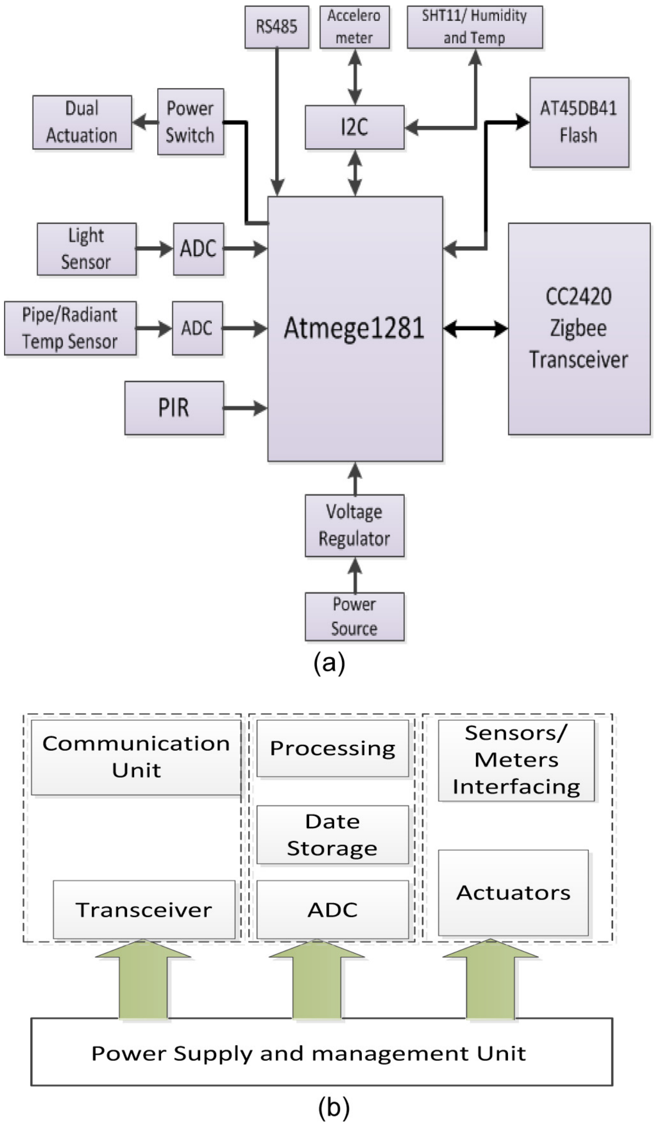

Figure 1. (a) System block diagram of the WSN mote and (b) block diagram of the mote functional units.

diagram of the mote functional units is shown in Figure1(b).

The multi-sensor layer was designed to interface with number of selected sensors as well as to incorporate additional capability for use within the building environment. This includes dual actuation capabilities for any AC/DC system using an external high-power relay-based system for devices that consume up to 280 V and 25 A (to turn on and off appliances) as well as an on-board low-power switch to enable the actuation facility. The type of on-board sensor is either digital communicating with the microcontroller through serial bus interface like I2C or analogue connected with any of the ADC channels.

The two external sensors/meters interfaces are dedicated to any meter using MODBUS protocol [13] and variable resistance temperature sensors. The MODBUS

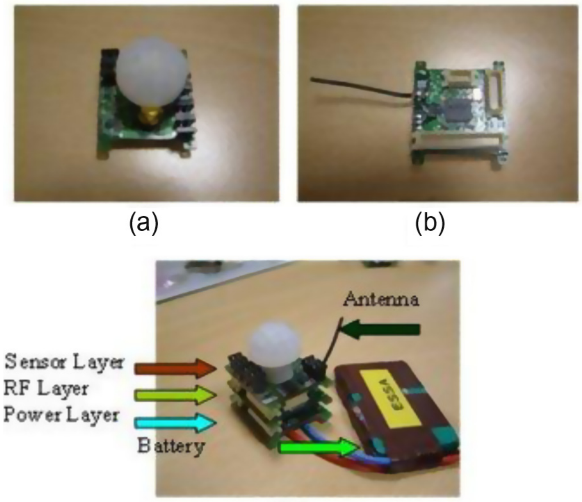

Figure 2. Photographs of the (a) sensor layer, (b) Zigbee and processor (RF) layer, and (c) 25 mm^2 mote.

meter exchanges data/commands through RS485 serial communications. This interface layer is also designed to incorporate external flash memory (Atmel AT45DB041). The layer features a 4-Mbit serial flash for storing data, measurements and remote re-programming. The photographs of both the RF and sensor layers are shown in Figure 2. The complete three-layer stackable 25 mm mote is also shown.

The processor and RF parts are located on the two sides of one layer called RF layer, while the third (power) layer contains the battery interfacing and voltage regulator.

2.2. Sensors selection

In this section, the different types of sensors and interface design options selected for the building monitoring application are illustrated.

Occupation sensor (passive infrared). Detecting the occupancy of the rooms inside the building was one of the essential requirements to be monitored, and there was need to find a suitable passive infrared (PIR) sensor module. The Panasonic AMN44122 [14] was selected for this purpose since it provides the required functionality in a module that is smaller, more convenient and of lower-energy consumption than the custom circuitry used in the prototype. Furthermore, the module provides a digital detection output that is used to trigger an interrupt on the processor when activity registers on the sensor. According to the datasheet of the PIR sensor, it has a detection distance of maximum 10 m (32.808 ft) and a detection range of 110° in horizontal and 93° in vertical. A simple laboratory test has been performed to verify the actual performance of the PIR sensor leading to results similar to those in the datasheet as in Table 1. However,

Table 1. The comparison of the AMN44122 PIR sensor with reference to datasheet.

Items		Data sheet	Laboratory test
Detection distance		10 m (32.808 ft)	9 m (29.528 ft)
Detection range	Horizontal	110°	90°
	Vertical	93°	90°

it was found that the actual detection region with high reliability is a little smaller than the detection region specified in the datasheet.

Humidity/temperature/light sensor. Relative humidity (RH) is an important indicator of air quality in buildings. Extremely low or high humidity levels (the comfort range is 30–70% RH) can cause discomfort to workers and can reduce building longevity. The temperature and humidity sensor SHT11 [15] shown in Figure 3 was used on the sensor board that integrates signal processing, tiny footprint and provides a fully calibrated digital output.

It uses I2C serial interface to communicate with the microcontroller and provide either the humidity or temperature data based on the received commands.

An ambient miniaturized photo diode with output current was used to measure the amount of light in LUX at room disc level.

Windows/doors status monitoring. The detection of the windows/doors status was one of the building parameters required to be monitored by the WSN node. Three-axis accelerometer was selected for this application since it can provide useful angle information which helps one to know how wide door/window is opened or closed. The LIS302DL is an ultra-compact low-power three-axis linear accelerometer that is integrated in the node design [16].

The main design challenge with using the accelerometer is that the microcontroller has to be continuously in active mode to record sensor data which means high current consumption and short battery lifetime. In order to overcome this problem, a mechanical vibration sensor with a very small package was used in this design to provide an external interrupt to the Atmel microcontroller when there is any kind of motion at any direction as

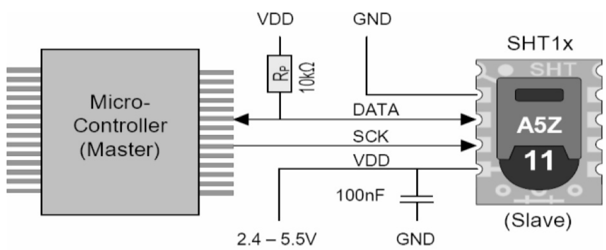

Figure 3. Typical application circuit of the SHT11.

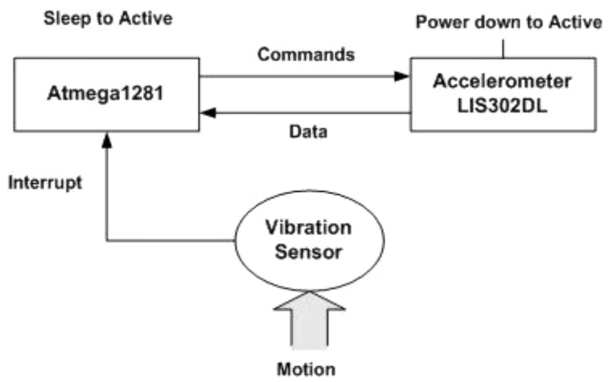

Figure 4. Functional block diagram of the motion sensor design.

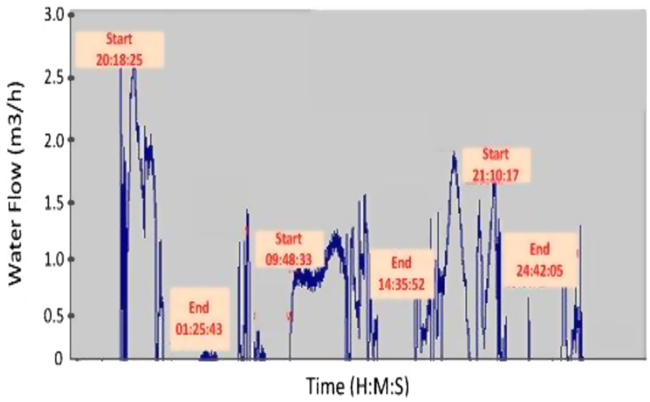

Figure 5. Water flow rate measurements.

presented by Figure 4. The selected accelerometer can be in power down mode with the lowest current consumption when there is no activity operating fully under the control of the microcontroller commands through serial bus interface. From the obtained power measurements for a fixed run time and duty cycle, a gain value of 3.5–4 was observed in the current consumption using the selected vibration switch.

Water flow/electricity meter interfacing using RS485 and MODBUS handshaking. It is required to get the flow rate measurements from different locations inside the building where pipes are made from different materials and have wide scale diameter size. The ultrasonic non-introductive unit was found to be the optimal solution for measuring the water flow rate of the water on building pipes since it is not disturbing the existing pipes installation and gives flexible testing option. Half-duplex RS485/RS232 IC was used to interface the water flow meter with the Universal Asynchronous Receiver Transmitter of microcontroller using the standard industrial MODBUS protocol [13].

The STUF-300EB flow meter from Shenitech [17] was used for this application. It provides excellent capabilities for accurate liquid flow measurement from outside of a pipe. The device is main powered and can be easily mounted on different pipe sizes.

To verify the performance of the meter interfacing, first the ultrasonic device was deployed in a chosen site inside the building. Figure 5 shows the water flow readings obtained from running the meter for almost 2 days.

The start and end times of each flow activity are marked. A MODBUS message is placed by the transmitting device into a frame with start and end headers. The receiver will be used to identify the beginning and end of the message using the two headers and will apply error checking using the Longitudinal Redundancy Checking algorithm.

The RS485 interface using MODBUS protocol will be used in later stage to interface both single-three-phase electricity meters and measure the lighting and zones energy consumptions.

Water pipe/radiant temperature sensor interfacing. The monitoring of the water temperature that is passing in the building pipes was needed as part of the wireless sensor system. Surface Mount Temperature Sensor from SIEMENS [18] was selected for this application as a non-introductive unit and can be mounted directly on a pipe inlet to sense the temperature of water passing through. The sensor performance was compared with those of the existing wired sensors read by the BMS as shown in Table 2.

It is very clear that the wireless sensor displays a comparative performance to the wired one and can provide useful data from number of pipe sites inside the building. It has to be mentioned that the temperature of the pipe surface is always higher than that of water by a few degrees. This will be taken into account in the calibration process by the mote to get accurate readings. The same interface was used to measure the room radiant temperature as the device manufactured using the same sensing material.

Actuation capability. The wireless control of switching on/off different types of AC loads in the building is meant to be the second application for the node beside the data monitoring. The base station presented by embedded PC and another node will be responsible for collecting and processing the different types of sensors data and send the commands to some of the designated

Table 2. Verifying the readings of the sensor with the existence of BMS.

Temp °C (BMS)	Temp °C (sensor)	Temp °C (calibrated sensor)
20.25	19.01	20.01
23.12	21.03	22.03
30.45	29.50	30.50
45.21	43.20	44.20
48.87	47.62	48.62

Figure 6. Wireless actuation for heat radiators.

nodes to perform actuation like switching on/off light, heat pumps, water valves or radiators. To achieve this goal on a miniaturized node, number of design options were taken into consideration with many aspects like the effect of AC high voltage on the low-power circuitry of the node and also the possible ways to interconnect with different types of single-/three-phase loads. The current design provides two options, first controlling small current, up to 2 Amps, AC loads like PCs using on-board PHOTOMOS relay which is an optoelectronic device that drives a power MOSFET [19]. The second option is providing the ability to connect an external relay that derives higher current loads through one of the on-board connectors.

To examine the actuation capability of the node, a small demonstration was set up inside one of the building rooms to control the operation of heat radiators as shown in Figure 6. Another node was deployed in the same room to monitor the room temperature/humidity and send the readings to the base station which will take an action and send the appropriate command to the actuator to either switch off or on the radiator.

Node power consumption. The power consumption of the node was critical issue for the design to make it reliable for long-term deployment. Primarily the mote will be powered from a 3.3 V lithium coin cell rechargeable battery with limited current capacity. In order to increase the operation lifetime of the mote, a number of SW/HW techniques were employed. At the HW level, the sensor layer has the ability to shut down the power from the unused sensors. Low current voltage regulator was integrated in the RF layer to provide stable voltage level. Also we focused on how to employ efficiently the different power-saving modes of both the microcontroller and transceiver units that are measured and presented by Figure 7.

From the previous figure number of power down options are available to reduce the overall node current consumption. The best scenario is to put both the microcontroller and transceiver in deep power down mode when there is no data transmission which brings down the total current to nearly 6 μA. Here the duty cycle has to be carefully considered for all the sensors to provide frequent useful data and at the same time guarantee low-power operation when there is no activity. In order to demonstrate such behaviour, the node has been programmed to send the sensors data every 15 s and go to power down after. The obtained current consumption measurements are given in Figure 8. Experimentally the lifetime of the different deployed nodes was found to be in the range of 4–10 weeks based on the type of the used sensors and desired duty cycle.

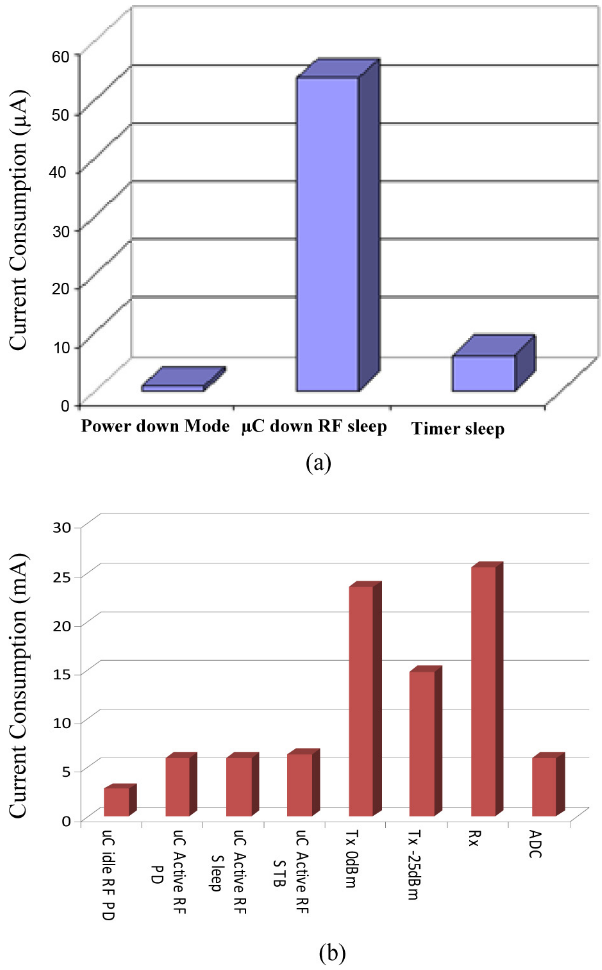

Figure 7. Current consumption at different power modes of both microcontroller (uC) and transceiver (RF) units. PD and STB refer to Power Down and Standby modes.

3. Adopted WSN

3.1. WSN system architecture

The adopted WSN architecture is based on recently released IETF IPv6 over low-power WPAN (6LoWPAN) (RFC 4944) open standard for IP communication over low-power radio devices—IEEE 802.15.4 represents one such link. WSN LoWPAN networks are connected

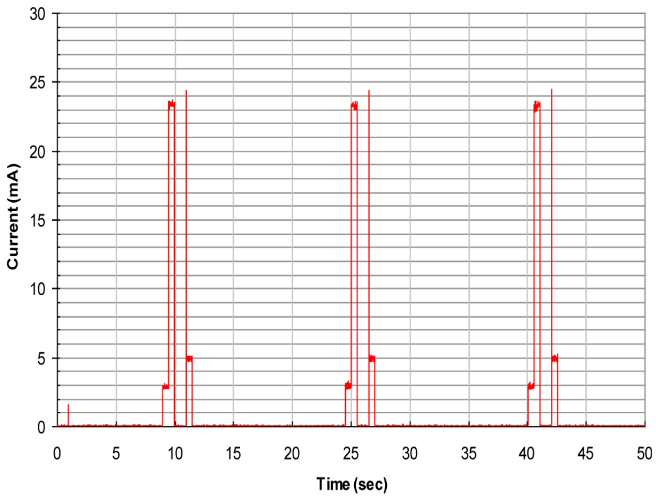

Figure 8. Node current consumption behaviour at fixed duty cycle.

to other IP networks through one or more border routers forwarding packets between different media including Ethernet, Wi-Fi or GPRS as shown in Figure 9 [20]. The IETF 6LoWPAN standard extends the same communication capabilities to low-power devices whose battery power must last for months or even years.

The 6LoWPAN utilizes a pay-only-for-what-you-use header-compression scheme. Through direct integration with IP routers, it can take advantage of advanced network security schemes rather than depending on those provided by *ad hoc* gateways.

The IP above offers widespread commercial adoption and broad interoperability due to its attributes such as openness, flexibility, scalability and manageability. Many industrial standards, including BACNet, LonTalk, CIP and SCADA, introduced an IP using either TCP/IP or UDP/IP over Ethernet [12]. The final topology of the

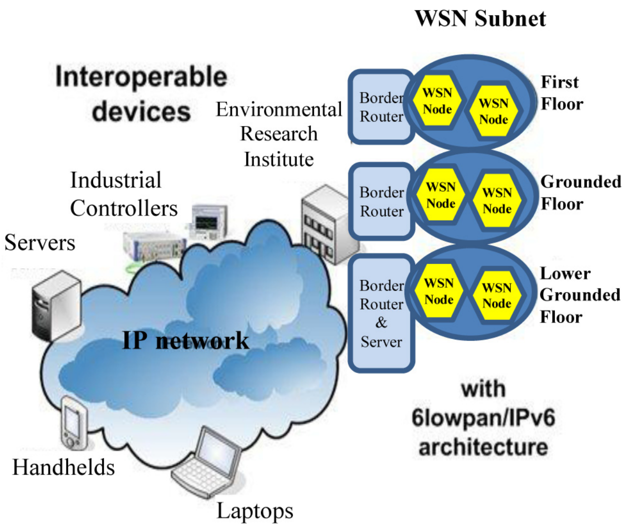

Figure 9. WSN in the broader view.

nodes deployed in the building is mesh network based on the 6LoWPAN protocol communication to meet the low-power and connectivity requirements of the used nodes platforms.

In this desired topology, the data nodes are deployed over three floors. The border router in Figure 9 at each floor is acting as a gateway to gather the data from the nodes in each floor and send them to the main server for further processing. In addition, a number of repeaters were used to deliver the data packets at the weak RF covered places between the adjacent sensor nodes.

3.2. ERI WSN topology design for reliable communications

While sensor positions were predefined within the ERI space to ensure appropriate sensed data are collected from the correct areas of the building, the positioning of gateways and repeaters to ensure a reliable communications network was supported through the design of the WSN topology using a dedicated WSN tool [21]. To assess the RF link quality for reliable communications, a temporary wireless sensor communications network was deployed in buildings spaces that were to be augmented with wireless sensing infrastructure. The RF link RSSI measurements were used for tuning the radio propagation model that is used by the design tool for infrastructure positioning. This propagation model is used to accurately predict the received signal strength between transmitters and receivers by considering the impact of the environment, such as wall type, on the signal level. Using this propagation model the design tool specifies the appropriate positions for gateway nodes, based on fixed sensor node positions, to provide a reliable communication backbone for all sensors. To develop an accurate propagation model, measurements are taken throughout the environment across all building floors focusing on the areas of interest.

The RF characterization is used to create a communications coverage map that is used for signal level prediction when assessing the suitability of candidate infrastructure position points during the topology design process.

The sequence of steps for the network topology design can be summarized as:

1. Floor plans of the building are input into a software site survey measurement tool. This allows the user to define the location of sensors and the measurement path. This tool stores the measurement data and visualizes the RF coverage map overlaid on the building layout.

2. Sensor nodes are deployed in areas of interest from a sensing point of view to establish a temporary broadcast-based communications network. The sensor nodes broadcast a dummy packet of data at set time intervals.

3. The measurement tool scans for sensors broadcasting and when it receives a packet it stores the received signal strength in a database for processing later.
4. Steps 2 and 3 are repeated in different areas of the building until a complete RF coverage map of the environment is built.
5. Based on the RF coverage map the Design tool suggests the number and positions of gateways and repeaters that are required for reliable communications.

Shown in Figure 10(a) are the measurements recorded with three nodes being used to establish a temporary communications network. These temporary nodes were deployed in the areas of interest on the ground floor of the ERI building.

The objectives of these measurements were to establish the position of gateways and repeaters to support reliable communications, the topology design decision was whether to place a gateway per floor or to use a single gateway to collect all data (with repeaters where necessary on each floor). Figure10(b) shows measurements recorded on the first floor of the ERI building from nodes deployed on ground floor (with the strongest signal being from node 0004). Signal level was received from node 0004, which is due to an open stair well, but the signal level is very low and cannot be relied upon for guaranteed communications. Consequently, the topology design decision is that it is not feasible to have nodes on the ground floor send data to a gateway positioned on or near the first floor; the material type on the floor is extra heavily poured concrete that attenuates the signal greatly.

Again to establish reliable communications on the first floor, measurements were recorded with temporary nodes being deployed in the areas of interest across this floor, as shown in Figure 10(c). The design decision for the position of the gateway on this floor is restricted to placing the gateway in the stairwell because of the availability of power sockets and also the gateway must interface with the *ad hoc* WiFi backbone back to the BMS server. To have reliable communications between the nodes on this floor and the gateway, a repeater node must be positioned in the corridor marked with X in Figure 10(c) map below to ensure connectivity.

4. ERI data storage and representation

To provide sensed data to the end user (or other software components) for the purpose of Building Performance Monitoring (BPM), there are a number of conceptual and practical challenges that need to be overcome. The conceptual challenges can be the definition of BPM to different stakeholders of a building [22]. Practical challenges include data quality, availability and consistency, and benchmarking. A Data Warehouse (DW) implementation was created to store large data sets provided by the data streams of the WSN in ERI [23, 24]. In Figure 10, the staging area was designed to support data from multiple sensor, meter and actuator types. These data are processed to form data cubes that support the presentation of relevant building performance measures to stakeholders. To extract the environment information from the WSN deployment in the ERI, a Service-Orientated Architecture (SOA) was used [25]. The different building blocks of this SOA were developed and validated by our research team. The Service Orchestration ensures that separate and independent services interact in a way that a larger application's goals are met. As an architectural concept SOA abstracts from any particular operating system and any implementation details. It does not matter which

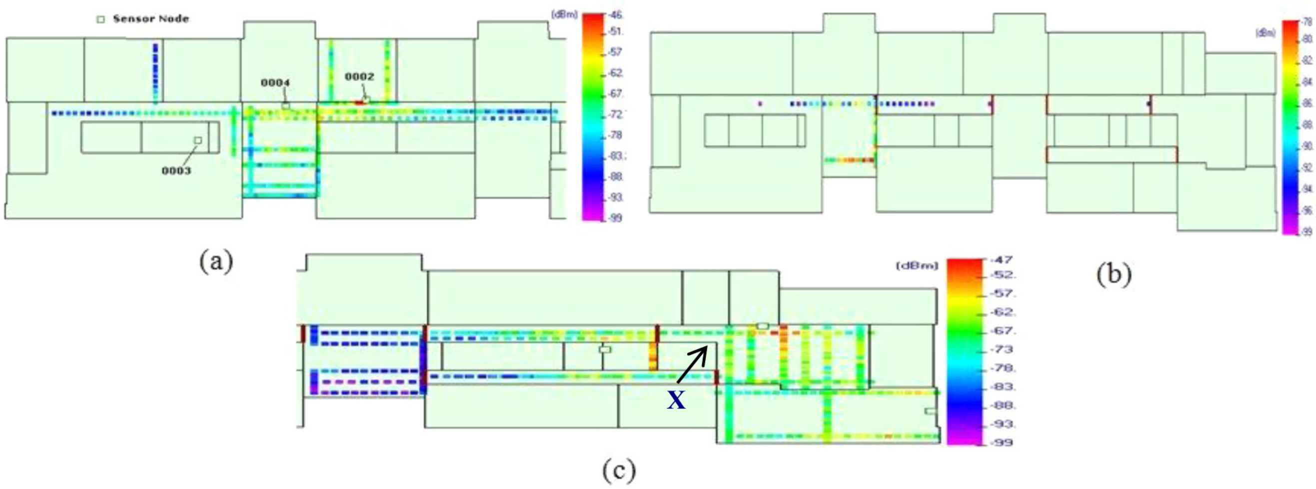

Figure 10. (a) Measurement data path recorded in the ERI ground floor, (b) first floor measurements from nodes deployed on ground floor and (C) first floor measurements.

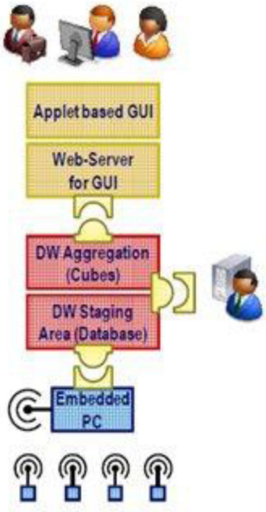

Figure 11. SOA for WSN to DW and DW to GUI.

platform and which language are used to implement some service. The functionality of a service is entirely defined by the service interface.

For the ERI deployment, the data are gathered from the first and ground floors and sent through the wireless backbone to the embedded PC (gateway) in the basement of the building. From embedded PC, a SOA connection is maintained to a DW. Figure 11 shows the architecture used to gather data from the sensors and present data through a Graphical User Interface (GUI) to the end user.

A sample of the obtained results using a building operator GUI is displayed in Figure 12 showing 1 day data from light (Immunology Lab), radiant (Immunology Lab), occupancy (Seminar Room) and door status (the Lobby). Figure 13 shows samples of the selected deployment sites.

In total (60) nodes were deployed in the selected three main zones within the ERI building to perform various functions of sensing and monitoring. Although each node has the same sensor layer, the types/number of sensors/meters interfaces used with each are different depending on the required parameters to be measured and their desired physical locations.

These building performance data will be used to support decision making for facility manager and building operators to optimize maintenance activities [21] and assist in fault detection and diagnosis.

5. Surveillance, security and climate change matters

With the development of novel BMS, the border between environmental monitoring and surveillance of an individual may need to be examined more closely. From a technical standpoint sensing technology to monitor the environment [26, 27] is similar to sensing technology to evaluate individuals' performance at various tasks [28]. Ubiquitous wireless sensors are a relatively recent technology and when we work/live in environments with novel sensors, acknowledgement of people's concerns about surveillance, privacy and autonomy is a must.

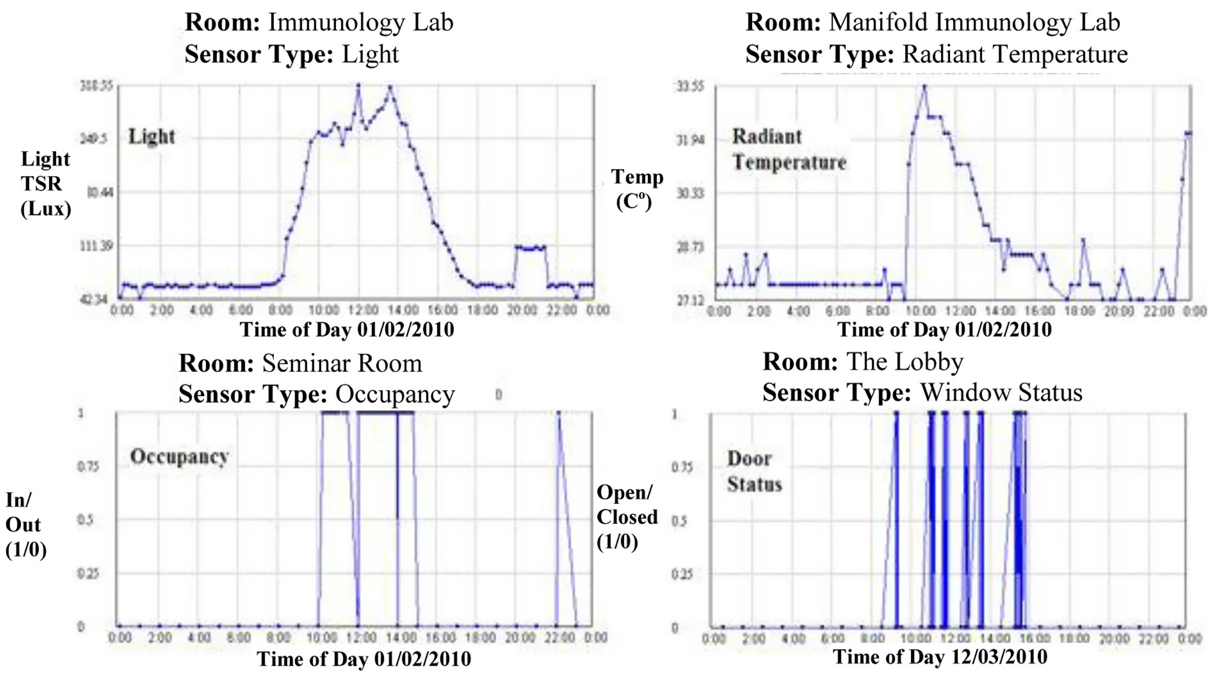

Figure 12. GUI 1-day recorded data of (a) light, (b) radiant temperature, (C) occupancy and (D) door status.

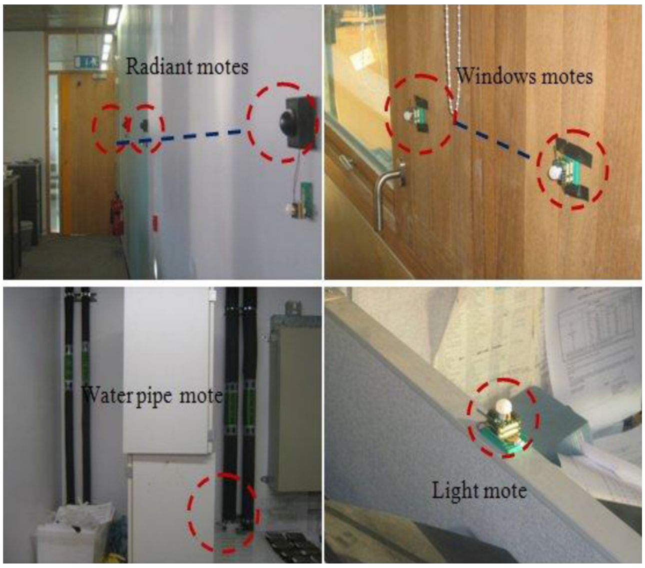

Figure 13. Number of deployment sites for (window, radiant, light and water pipe) sensors.

Clearly new sensing technology, where the boundaries between environmental monitoring and person monitoring are fuzzy, has the potential to turn work/home life into life of surveillance, where the system administrator can omnisciently monitor the activity of tenants.

Considering the apparent or real threats to privacy and autonomy there is a need to establish ethical guidelines for the appropriate deployment of BMS.

The field of Human–Computer Interaction (HCI) has established guidelines on how to evaluate the working systems that operate via the keyboard, mouse, and VDU, or even the mobile technologies of the 2000s. One set of guidelines, heuristic evaluation [29], emphasizes that the system status should be visible to the user and keep the user informed about what is going on.

The technical advance of wireless environmental monitoring [26, 27] is rapid, so rapid that appropriate design guidelines acknowledging the autonomy and privacy of the individual have yet to be established. Contemporary design guidelines from HCI are informative. However, these guidelines are based on the idea of a user actively controlling the user interface and so still fall short of addressing issues specific to environmental monitoring, such as threats to autonomy and privacy via the surveillance of real-world activities [30]. The need for appropriate design guidelines that respects individuals' rights is made even more acute by the inevitable convergence of environmental monitoring with other fields such as, for example, applied biometrics, i.e. user authentication via image recognition or biological signals [31]. Issues of network security are also important when designing novel sensing technologies. The lesson learned from the internet infrastructure, where there are daily security concerns/breaches, is that incorporating security into the system from the start is critical. The consequence of a breach in security with a BMS could mean that the water and electricity supply is controlled by a remote attacker, or that a remote attacker could learn private information. It is imperative to protect the infrastructure from synthetic, or natural, attacks. The next section will be addressing a newly developed user interface tool to monitor and interact with the building performance data recorded by the deployed wireless sensor nodes.

6. Mobile tool for occupant interaction

Access from mobile devices and desktop applications enables the stakeholders to interact with the system. Figure 14 is a prototypical view to provide a Building Operator view of building performance data. The view is divided into logical sections for graphically visualizing the data, locations or zones in the site they maintain the sensors and actuators in that zone and date selection. The data presented in the graph represent the gas boiler curve on 1 May 2009. The Maintenance and Monitoring Tools access the DW Web services and the data received are displayed in a cognitive format to the end user.

Figure 15 is a view of a Monitoring Tool to interact with the tenant in a building. The objective is to collect user's preferences through feedback on their current environmental conditions. Based on analysis of the user responses, actuation commands can be initiated. For example, if the user is extremely cold and the system finds that the room heating conditions are below normal, then the service in the WSN is called to turn on the heater in the user's room.

Through our Web services implementation, a middleware was created to integrate various components to improve the provision of building information to end users and with improved data analysis techniques, it supports more accessible and easier understood information to support stakeholders' decision-making processes.

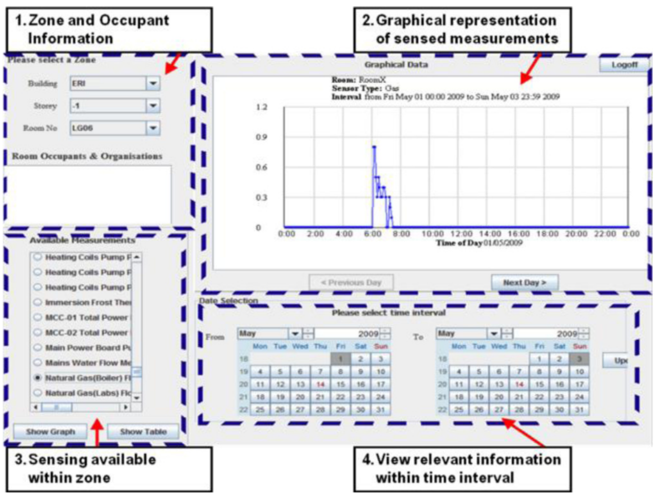

Figure 14. Graphical user interface for building operator.

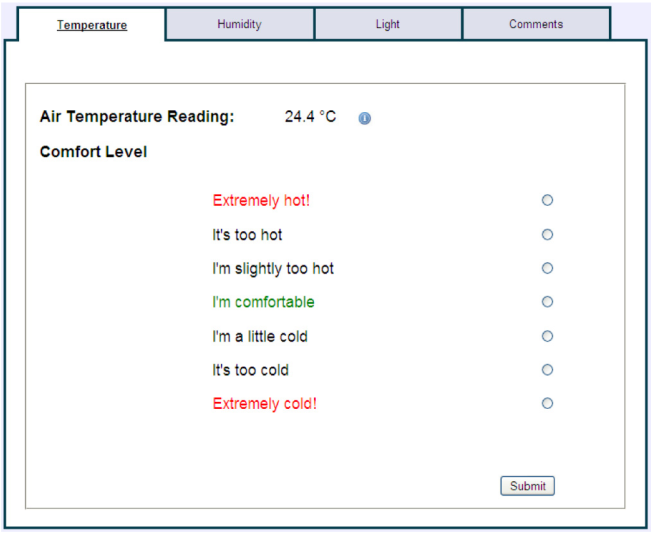

Figure 15. Thermal comfort feedback from tenant.

7. Conclusions and future work

This paper presents the design, development and deployment of a miniaturized WSN mote based on Zigbee technology for building monitoring, exploring its system control management and technology characters. The stackable technique was adopted in this work to manufacture efficiently the mote layers within small cubic size. The node can implement wide scale of stable sensors/meters data acquisition to provide the needed functions. In addition to the building monitoring, it has the capability to act as an actuator using on-board or interfaced external relay. As an advance step before installing the WSN, an RF characterization study of the building was implemented to establish the position of gateways and repeaters to support reliable communications. An efficient BPM was developed to maintain the data streams from all wireless sensors to the DW and at the same time provide the end user with useful information.

As novel sensor technologies become ubiquitous the convergence of environmental monitoring with individual monitoring becomes a source of worry for building tenants. There is a need to establish ground rules about how building tenants can access the data gathered by the BMS. How to design a system that is safe from outside attack is also imperative.

In the future, a number of ideas can be considered for implementation to tackle the issues of keeping the network secure from any unauthorized parties. One of these standard approaches for keeping sensitive data secret is to encrypt the data with a secret key that only intended receivers possess, hence achieving confidentiality. Data authenticity will be considered as well in the future so that the receiver needs to make sure that the data used in any decision-making process or HCI originate from the correct source. Data authentication prevents unauthorized parties from participating in the network and legitimate nodes should be able to detect messages from unauthorized nodes and reject them. In the two-party communication case, data authentication can be achieved through a purely symmetric mechanism: the sender and the receiver share a secret key to compute a Message Authentication Code (MAC) of all communicated data. When a message with a correct MAC arrives, the receiver knows that it must have been sent by the sender. However, authentication for broadcast messages requires stronger trust assumptions on the network nodes.

Data integrity and freshness are two issues that can be dealt with within the scope of the above.

On the plus side and despite the security risks associated with deploying ubiquitous sensors, the more efficient use of natural resources brought about by environmental monitoring mitigates the effects of climate change. Therefore, the more efficient use of energy and water resources through the wide-scale deployment of smart building sensors is a proactive step in lessening the risks associated with climate change. Even in residential homes, sensors can identify ways for the occupant to use heating and lighting more ecologically thus saving the homeowner money.

The experiments in this paper demonstrate the capabilities and reliability of the proposed mote platform and adopted WSN topology to perform the desired tasks and extend the current BMS sensing parameters.

A number of plans are adapted for future work improvement. This includes extending the number of deployed nodes to cover other zones inside the ERI building. A flat version of the current stackable miniaturized nodes is under development to have more enhanced features like multi-antenna tuning, better external interfacing and USB programming capability. It is planned to use another type of rechargeable batteries like AA that have a bigger capacity with version to significantly increase the node lifetime.

The energy harvesting techniques will be investigated through a number of solutions available in building environment like light, heat and surface vibration to provide efficient alternate power sources for the embedded systems.

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