# Wireless Network Deployment as Low Cost Building Management System Solution

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Abstract: This paper presents the design and implementation of a wireless monitoring and actuation network for residential and commercial buildings that was carried out as part of the ARTEMIS funded project ME3gas. The aim of this deployment is to demonstrate that low cost wireless sensor networks can be used in situations where a full building management system may not be suitable technically or commercially either in residential home applications or commercial enterprises. This work focuses not just on electricity consumption but also on gas consumption into the building. The current deployment consists of a number of wireless sensor motes retrofitted throughout a residential building converted for office use. The WSN nodes are based on the Tyndall modular mote platform running the Contiki operating system and communicating with a mesh network running IPV6 through 6LoWPAN over IEEE 802.15.4 at 2.4GHz. Each node is configured for a specific task within the framework of enabling energy efficiency and these tasks can be broadly described as, environmental sensing, metering (gas and electricity) and actuation. The motes are controlled through the LinkSmart middleware platform which is an open source hardware agnostic system for building energy management, which hides the underlying physical layer allowing ease of development for web based applications, which is also demonstrated as part of this work.

## 1 INTRODUCTION

Energy demand in residential and small commercial buildings is increasing dramatically and currently accounts for 65% of energy consumed on a national grid. European Union directives are targeting dramatic improvements in Energy efficiency of at least 20%, combined with a reduction of green house gases by 20% for the year 2020 (Directive of European Parliament, 2004/2006). Managing and reducing the energy demands from residential and small businesses will require a low cost and easily implementable strategy that can be easily adopted by non-technical users.

Building management systems (BMS) currently are not cost effective solutions for home or light commercial users. Cost estimates for wired systems can range from €1.60 per metre for a new construction up to €5.00 per metre for retrofit applications for wired BMS installations (Nan Li, 2010). This is a significant cost and does not take into account the cost of the BMS itself. Wireless systems can negate wiring cost with wireless motes ranging in costs from 20 -100 euro and the cost is continually dropping. Outside of potential cost savings wireless systems can also offer other advantages over traditional BMS solutions. These are (Nan Li, 2010; Jun Zhang et al., 2011)

- Ease of deployment
- Easily reconfigured
- Easily expanded and upgraded
- Low Maintenance
- Range of operational environments , they can be deployed in areas where wiring may not



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be practical
- Can be integrated into smart metering frameworks (Kaplantis, 2012)

There are a number of commercially available technologies primarily for home automation. Hardware such as EnOcean, Z-wave, and KNX that have been developed that can carry out energy monitoring and actuation commands. Currently these systems focus on the Home environment and while they could be adapted as light weight BMS solutions they are currently not optimised for such. These solutions also tend to focus primarily on electricity consumption of devices without offering cost effective methods of monitoring gas consumption (Anders, 2011). Industrial based wireless hardware and protocols exist on the other extreme such as WirelessHart. These systems again are not optimised for the intermediate BMS solution and are generally targeted towards very specific industrial applications. Additionally since these technologies tend towards proprietary technologies they do not offer a complete retrofit solution (they are not entirely future proof and if existing wireless infrastructure exists such as a smart meter, they may not be easily interoperable) A number of researchers have looked at physical architectures and deployments using Zigbee wireless networks (Yang, 2009; Jinsoo, 2009) for the areas of home automation. These papers have focused primarily on the design of the Zigbee mote and networks and do not discuss in any great details deployments or complete system requirements for a wireless BMS. Other authors have looked at using 6Lowpan enabled networks (Bernd and Thomas, 2011) and have focused on the advantages 6Lowpan, such as IPV6 compatibility and internet accessibility.

For a completely adaptable retrofit installation that can act as a BMS alternative the system should be broken into three distinct parts that are completely interchangeable. These are

1. Hardware infrastructure
2. Middleware platform
3. Application

The deployment presented here has successfully retrofitted a residence that is over one hundred years old with a light weight BMS solution, utilizing low cost wireless sensor nodes that are flexible and non-invasive in their design enabling them to easily integrate onto the existing utility framework at the pilot site.

The deployment looked at all the components required to create a lightweight BMS solution such as the sensor motes, a middleware platform and web based application that could interface through the middleware to the deployed hardware acting as the monitoring and intelligence of the BMS system.

The rest of this paper describes the set-up, running and evaluation of a real world sensor network deployment demonstrating device interoperability and a non-invasive deployment that provides data to a communications agnostic middleware platform.

## 2 NETWORK OVERVIEW

The main objectives of the work carried out were to

- Retrofit an existing building with a wireless sensor enabled energy monitoring and management system
- Deploy wireless sensor motes in a real world “living-lab” environment
- Use a “self healing” mesh network to create a robust network infrastructure
- Utilize an IPV6 protocol for web interoperability
- Integrate with the LinkSmart middleware platform for network management
- Report to a web based application for data monitoring

### 2.1 Location

A suitable building was selected for deployment of the wireless sensor network. The building selected was the Crossleigh building located at University College Cork (UCC) Figure 1. It is an old residential building dating back to the middle of last century that was adapted for use as offices and computer laboratories for teaching staff and students in the School of Applied Social Studies. The building’s heating system is water based. There is a small boiler house where a gas driven boiler heats the water, which is then circulated in the building by a set of pumps, also located in the boiler house. A gas meter is located in a meter box in the front garden. In this application the deployed system will control the pump that serves the second floor, and use it to regulate the temperature on that floor. The building itself consists of three floors with the gas boiler located in a separate extension on the back of the house and the gas meter in a box out in front of the building. This building was considered an ideal test site as it represented both an old residential building and small commercial enterprise.

Figure 1: Crossleigh House.

## 2.2 Deployment Architecture

In order to retrofit an old building such as Crossleigh house with a light weight BMS solution three main architectural components are required. These are

- The physical hardware
- The middleware platform
- The BMS application

The system architecture is shown below in Figure 2. The physical hardware is the monitoring and control infrastructure for the building and is completely wireless. The middleware platform connects the application for monitoring and control with the deployed hardware. The middleware creates an agnostic environment for the application developer to work with, allowing applications to focus on higher level BMS and energy solutions rather than integrating with the lower physical layer. The middleware can be expanded to work with a range of protocols and devices creating a complete interoperable framework for retrofit deployments.

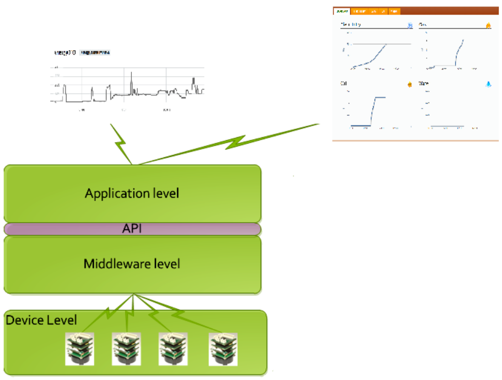


Figure 2: System Architecture.

### 2.2.1 The Wireless Hardware

The wireless sensor platform used for this deployment is the Tyndall 25mm platform known as the Tyndall Mote 0. The mote design is based on a modular layout which enables the user to integrate any combination of sensors, communications and power source. The flexible nature of the mote makes it ideal for an experimental wireless sensor deployment such as this.

The motes deployed here operate in the 2.4GHz ISM band using a Texas Instruments CC2420 as the transceiver. They are controlled by an MSP430F5437 microcontroller and their peripheral layer includes: - Temperature, Humidity, Light, RS-485 interface, UART interface, Modbus, SCADA, KNX, and DALI

The motes in this project all run the Contiki OS created by the Swedish Institute for Computer Science (SICS) (Dunkels et al., 2004).The node application layer sits on top of the Contiki operating system, and is capable of executing small C programs, such as programs for communicating over modbus to an electric meter or pulse counting on a gas meter. The Tyndall node is shown below in Figure 3 and the architecture in figure 4.

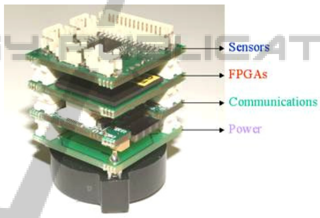


Figure 3: Hardware platform used.

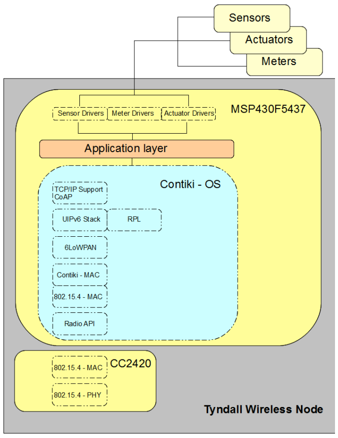


Figure 4: Wireless Hardware Architecture.

### 2.2.2 The Middleware

One of the key components of the deployment is to use an energy orientated middleware platform making it possible to network heterogeneous physical devices into a service-oriented architecture. The aim of the middleware is to hide the complexity of the underlying device and communications technologies, thus making it easier to develop applications. Developers can focus more on high rather than low level issues and functionality. This deployment utilizes the LinkSmart (formally Hydra) service orientated middleware software to achieve these aims (Eisenhaur et al., 2009). This middleware platform was developed by CNET, Fraunhofer Institute of Technology (FIT) and Telefonica and is an open source platform that can be adapted to any application domain (in this case energy efficiency).

A context manager (Frécon, 2012) was also part of the middleware platform which focuses specifically on energy awareness. The middleware platform communicates with a deployed wireless network over an RS232 connection to a PC. A border-router, communicates with the middleware via a SLIP protocol and acts as the interface between middleware and hardware. The middleware offers an API to higher level developers. A device that is incorporated through the LinkSmart platform is presented to the developer as software abstraction within the LinkSmart network, commands can be sent to the network and data taken from the devices without needing to know any of the underlying physical process. This device can then be made accessible via web services to the application layer.

### 2.2.3 The Application Layer

As mentioned one of the main advantages of using the LinkSmart middleware platform is it hides the complex physical layer from the higher level application developer. This enables shorter development times in creating custom applications for building monitoring. These applications can be interfaced with any hardware deployed that makes up the infrastructure of a light weight BMS as the middleware creates complete platform agnostic layer. Since the middleware presents physical devices services to the application layer as web services the applications can be entirely web based and accessible from any internet enabled device. Figure 5 below shows a sample of a developed

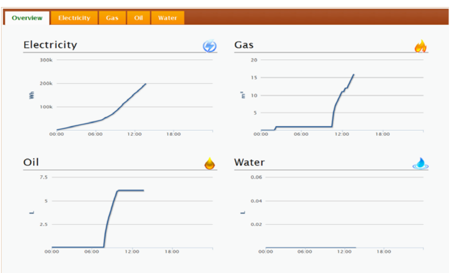


Figure 5: Graphical User Interface for Crossleigh house.

business GUI which was created specifically for Crossleigh house by the ME3gas partner ResourceKraft.

While the above GUI was developed specifically for Crossleigh house the web based nature of the middleware enables easy integration to open source applications again reducing costs if required. For example the data for this application has also been integrated with the online service COSM which is a free online sensor data monitoring service. A screenshot of it is illustrated in Figure 6 showing electricity data for the ground floor of Crossleigh house.

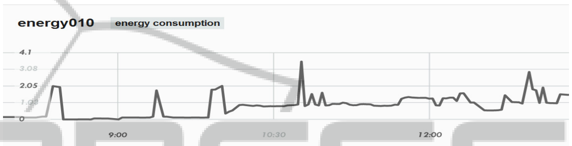


Figure 6: COSM Screenshot.

The first step in retrofitting this building with an intermediate BMS solution was to deploy the wireless hardware that would act as the sensing and control infrastructure for the building. Since wireless technology was chosen for the physical communications a radio survey was first carried out of the site in order to determine the effective range of individual wireless motes as well as to determine the number and placement of each individual mote in the network. The radio survey was a simple send receive test, where one node was configured to send a packet of data and another node configured to receive and display the data packet on a terminal program through a UART port. The motes were placed as shown in figure 7 below based on the radio survey carried out.

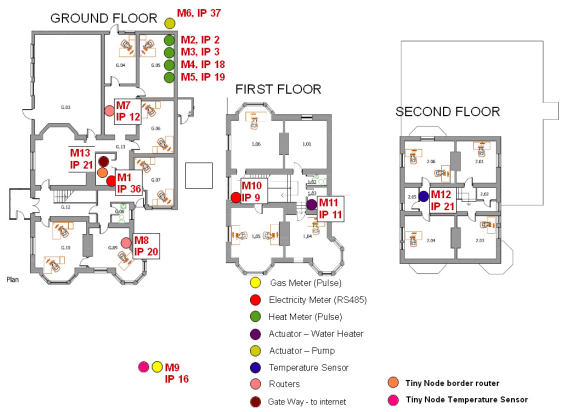


Figure 7: Placed wireless sensor motes.

The Motes are segmented by task into three main categories. These are 1. Metering and sensing 2. Routing and 3.Actuation The metering part of this application is split into three areas which are Electricity, Gas and Heat Metering. Two electricity meter motes were installed, one mote for the ground floor of the building (M13) and the other for the 2nd and 3rd floors (M10) A mote was connected to the pulse output of the gas meter in Crossleigh at M9 (Figure 8) and four meters were connected to pulse output heat meters M2-M5 Each heat meter corresponds to one heating zone within Crossleigh house. The four zones are (i) Ground floor, (ii) Computer lab (attached to ground floor) , (iii) Floor 2 and (iv) Floor 3.

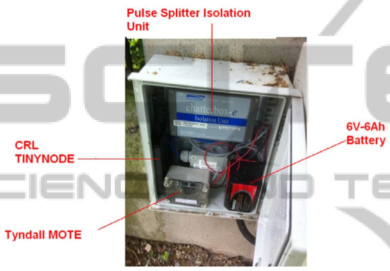


Figure 8: Gas meter mote.

Based on the radio survey carried out at the start of this work two motes were placed purely for routing purposes at M8 and M7.

Actuation is carried out via M6 which controls the heating for the third floor of the building. M11 is an under sink heater and this also controlled by the network.

### 2.2.4 Network Topology

The wireless network is mesh configured. It operates UDP for sending data and a TCP-IP for configuration with an IPV6 header over 802.15.4 utilizing 6LOWPAN for the sensor network itself. It was envisioned that the network would run on only TCP. One advantage of using TCP was that any "normal" tools can be used to monitor and debug the network and this was proven to work very well for configuration with a REST Client plug-in for Firefox. Data is transferred through the motes using JSON expressions. Problems occurred when trying to deliver data packets over TCP. Since another advantage of TCP is the reliability that is offered from a handshaking protocol, call-backs occur which raises the network overhead and could cause the network to "freeze" resulting in situations where no data was able to get through. As a result TCP was used for configuration and actuation commands while UDP was used for sending data packets. This worked to improve the network stability as non-critical data packets could be sent via UDP (which were the majority of data packets). Critical data packets such as actuation commands were still sent offer TCP to guarantee delivery.

## 3 RESULTS

In order to justify the cost of any building management system savings on utility costs need to be demonstrated. While actuation was implemented in this deployment, due to contractual agreements with the users of the building, no advanced control strategies were implemented in order to avoid impact to the quality of their utility services. All actuation carried out was in-line with existing building constraints. So for example the actuator controlling the under sink heater the original system switched on the heating at 7:00 and off at 18:00 and?? this system did the same. Despite these restraints based on the monitoring alone and the integrated application it was possible to show where further cost savings could be made. Using the deployed system it was possible to monitor the electrical consumption of the building broken into two zones (a) Ground floor which also houses a computer lab used by students and (b) combined second and third floors). The electrical consumption is shown in Figure 9. This graph shows the consumption per zone as well as the total peak consumptions. Figure 10 shows the total amount of gas being consumed in Crossleigh house.

This data is presented as kWhrs for electricity and gas. For most people the main consideration is cost. Through the business GUI this data can easily be converted to monetary value if the pricing is known. This allows the user to quickly check various plans and costings on offer from utility companies and determine the savings that can be made directly to them. For example, based on the data available and looking at various plans available within Ireland (Residential price plans used, company names not used as this is only a snapshot of what's available and not indicative of the whole market) where this deployment is situated, comparisons can be made as shown in Table1 for the week.

Total Gas Consumption = 1750kWhr
Total Electricity Consumption = 700kWhr

Table 1: Prices applied to gathered data.

| | Gas (c/kWhr) | Electricity (c/kWhr) | Total Gas € | Total Electric € |
|---|---|---|---|---|
| Utility 1 | 5.540 | 17.161 | 94.5 | 120 |
| Utility 2 | 5.628 | 16.93 | 98.49 | 118.51 |
| Utility 3 | 5.894 | 17.93 | 103.145 | 125.51 |

The data in Table 1shows how using this data can provide estimates of where to make initial savings and this is before advanced control techniques are employed.

As can be seen from the table above switching providers based on the monitored data and real values of up to 9% on gas bills and 5% on electricity can be made. For the week shown this works to an actual saving of nearly €15. This a very basic analysis based on basic price plans and one weeks data but the potential for ensuring cost savings and return on investment has been demonstrated.

There is only one gas meter within Crossleigh but the gas is only used to feed the heating supply within the building. The heating within Crossleigh is split into 4 separate zones. These are the ground floor, the student's computer laboratory, the second floor and the third floor. As already mentioned there are heat meters attached to the heating pipe outlets for each zone and each meter has a wireless mote attached to it. Thus a breakdown of gas consumption in Crossleigh could be derived and is shown in Figure 11. The largest area is the ground floor and not surprisingly this consumed the most in terms of gas. The second largest area is the second floor and this was not surprisingly the second largest consumer of gas. The computer lab was third largest area but this consumed the least gas due to the fact that heat generating equipment is located here and less heating was needed. From this breakdown it is easy to see what each area of the buildings is consuming in terms of heating.

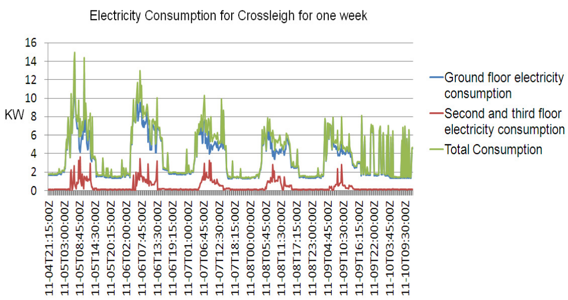


Figure 9: Electricity Consumption 1 week.

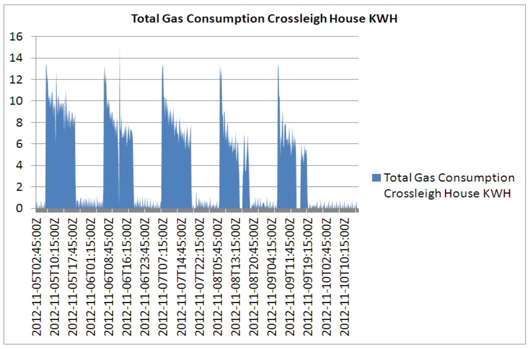


Figure 10: Gas Consumption of Crossleigh 1 week.

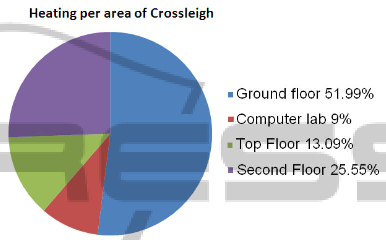


Figure 11: Gas use per zone in Crossleigh.

## 4 CONCLUSIONS

Presented here is a real world application of a wireless network for energy metering and management that has successfully been retrofitted into an existing 100+ year old building. This deployment demonstrated a clear alternative for building management that bypasses the more expensive & invasive building energy management system with

- a deployment of all components that would be required for a wireless BMS deployment
- A 6lowpan network for wireless sensing and actuation in a real world environment
- A middleware platform to act as an intermediary between application layer & physical layer
- A business application for monitoring of the deployed network

The installation did not require the addition of any capital equipment such as new boilers or gas meters and for the most part existing equipment already in the building was adapted with "add-on" wireless sensor motes in the form of the Tyndall mote. Trouble free wireless mote deployment in this scenario was resultant from the radio survey of the site carried out early on in the development. Although relatively simple it still proved a valuable and effective tool in deploying the sensors in suitable locations. This helped in avoiding problems as the network was expanded. Another observation related to the issues with TCP mentioned above. HTTP over IPV6 is believed by many to be the future of wireless sensor networks due to the ability to access sensors directly over the web. This deployment has shown that there can be issues with this method of communications, future work on this project is investigating the use of other strategies such as the use of websockets reduce header overhead when transmitting sensing and actuation data over TCP. Other future work is to deploy this type of set-up on a larger scale in countries such as Sweden & Spain.

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