DESIGN OF UNDERLYING NETWORK INFRASTRUCTURE OF SMART BUILDINGS

Alan Mc Gibney[1], Martin Klepal[1], James Thomas O'Donnell [2&3]

[1]Centre of Adaptive Wireless Systems, Cork Institute of Technology ,Cork, Ireland.
[1]alan.mcgibney@cit.ie, martin.klepal@cit.ie
[2]Department of Mechanical Engineering, National University of Ireland Galway, Ireland
[3]Department of Civil and [2]Environmental Engineering, University College Cork, Ireland. S97550272@ucc.ie

Keywords: Design, Optimisation, Wireless BMS.

Abstract

Wireless Building Management Systems (BMS) are an attractive option when it comes to building retrofitting due to the cost constraints introduced by wired systems. A crucial part of the wireless BMS is the initial planning stage, this process can be impossible for a designer to undertake, therefore highlighting the requirement for a software design tool to aid in this process.

1 Introduction

In order to implement more energy efficient management practices some retrofitting of existing Building Management Systems (BMS) are required. The majority of these systems are wired therefore the cost in retrofitting makes it an unattractive option. A proposed approach to overcome some of these shortcomings is the implementation of wireless sensor module platforms. The robustness and reliability of the wireless sensor/actuator network is crucial for a reliable and functional wireless building management system. However, the usual "try it and see" approach that is so often associated when deploying wireless sensor networks will not deliver a reliable wireless BMS. The performance of such a haphazard sensor network design can be significantly less than that achieved with a rational design approach. There are a number of factors a designer needs to consider when undertaking such a task, including environment configuration, technology used, site specific demands, signal coverage, latency and capacity. The sheer number of elements that need to be considered highlights the need for a software design tool to aid the designer when undertaking the difficult task of designing a robust, reliable and effective sensor network.

The paper will present initial research that has been undertaken towards the development of a design tool for wireless sensor networks and is structured as follows Section 2 will describe the problems faced by a designer and detail the initial requirements gathering. Section 3 will detailed required pre-processing and discuss the proposed agent based optimisation. Section 4 will conclude the paper.

2 Problem Specification

Before any optimisation can be carried out some problem specific requirements need to be gathered, this pre-processing involves the definition of environment constraints, including building geometry and measurement zones. Also sensor specific constraints are required. The following section suggests how these problem specific requirements should be obtained.

2.1 Environment Description

Building Information Models (BIM) are the most appropriate medium for storing building data across the entire life cycle of a project [1]. A sensor network design tool requires that certain pre-processes are performed before it can elicit the relevant information from an interoperable BIM environment. Building geometry must be instantiated in the BIM. A performance hierarchy that defines the sensor requirements in a building must also be instantiated and are in turn passed to the sensor network design tool. The environment description is used as an input for a propagation model that estimates the electromagnetic propagation throughout the environment, therefore walls with various materials that influence signal prediction need to be defined, to make it easier for the designer typical wall types can be defined and should be included as part of the BIM. Another important element that influences the design of a sensor network is the definition of "demand zones". A demand zone represents the areas within the building that are of interest to the BMS, and includes the type of monitoring required.

2.2 Sensor-Specific Requirements

The sensor is the most basic component in a wireless BMS and the accuracy required needs to be specified at design. General guidelines and considerations for correct sensor placement may be obtained from [2] and a comprehensive reference is available in ASHRAE Applications [3]. Table 1 includes a definition and an example of the required fields for a wireless temperature sensor. These fields contain information regarding the type of sensor, measurement resolution and placement constraints. The placement constraints are the most import fields for the sensor design tool.

Table 1: Sensor Specification Requirements from a Wireless Sensor Network Design Tool

Category	**Data**
Level	Zone Measurement
Sensor/Meter Name	Zone 1 Temperature
Measurement Description (Sensor Type)	Indoor Dry Bulb Temperature Sensor
Function (Unit)	°C
Measurement Interval	1 Minute
Measurement Resolution (also delta for communicating a change)	0.1 °C
Sensor/Meter Placement (Object)	North Wall
Placement Constraints	Not in direct Sunlight or within .5 meters of an artificial light
Power source (Battery or Wired)	Battery
Comment	None

3 Pre-Processing and Optimisation

The proposed sensor network architecture for the wireless BMS is shown in Figure 1, this architecture leads to the optimisation taking two distinct phases, firstly generation of candidate sensor/sink node positions followed by the optimisation of the communication network to support reliable data transmission to the BIM.

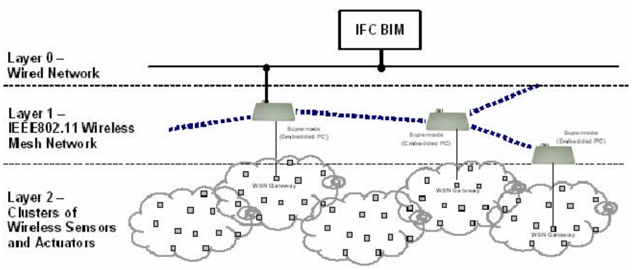

Figure 1 - Sensor Network Architecture

3.1 Positioning Pre-Processing

It is not feasible to expect the designer specify every possible position for sensor placement. Therefore an algorithm that can generate candidate sensor positions is required. It is proposed to adopt an algorithm based on a growing Neural-Gas (NG) network proposed by Bernd Fritzke [5]. In this approach a network topology is generated incrementally using Competitive Hebbian Learning (CHL) and a Neural Gas method [6].

This involves interfacing with the IFC BIM to retrieve site specific demand zones, encapsulating what types of sensors are required, for example temperature sensors with any additional constraints such as areas where they should be placed within the demand zone, such as on a north facing wall, position on a pipe. The design tool interprets these specifications and generates candidate zones, these zones are input into the NG algorithm, which results in the generation and distribution of candidate sensor nodes evenly in complex environments while maintaining desirable positions specified by sensing constraints. Once the candidate sensor positions have been obtained the next phase is to ensure reliable communication of sensed data. This involves positioning sink nodes that act as a gateway to the sensor nodes that transmit sensed data. In order to reduce the search space of the optimisation the design tool generates candidate sink positions, the sink nodes form the wired backbone and require high power therefore positions close to sockets and in range of a network point are desirable, this mesh is generated automatically using the NG algorithm as described above.

3.2 Communication Quality

In the current implementation of the design tool the IEEE 802.15.4 is considered as the radio standard used for sensor nodes each operating at 2.4 GHz frequency band. Each node of the candidate set not only has a position but it also has an associated coverage map. To generate this coverage map an accurate ray tracing based propagation model known as the Motif Model [7] was used. To evaluate the use of this model measurement was carried out. Figure 2 shows a sample measurement compared to predicted signal level within a typical office environment. The model is computationally fast and the results of measurement campaign indicate the propagation model is sufficiently accurate to estimate achievable coverage from the sensor node in complex indoor environments.

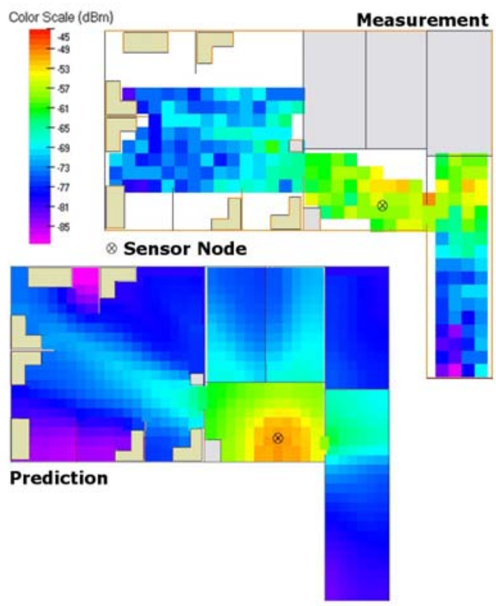

Figure 2 – Sample Measurement and Prediction of Sensor Node Signal Coverage

Signal coverage alone is not sufficient criteria to evaluate the viability of communication link; the network may have maximum coverage but may not be able to handle the capacity required by the sensing nodes. Therefore throughput prediction is required. Signal to noise ratio (SNR) is calculated using predicted signal level and associated noise from active nodes. Using a lookup of SNR versus throughput the maximum achievable throughput is estimated for single hop communication. There are a number of other elements that are considered including, maximum number of hops, and latency. The focus of the research presented in this paper is the design problem definition and optimisation method used therefore the qualitative parameters for multi-hop communication requires further attention in future work. The results presented in [8] offer a good starting point for estimation of throughput and latency for multi-hop communication. With all the criteria defined and pre-processed the next step is the incorporation of a scalable optimisation technique to optimise the sensor and communication nodes that maximise throughput with a minimum number.

3.3 Agent Based Optimisation

The most popular optimisation approaches applied in the area of wireless networks are direct search methods, mainly due to the fact that they are easy to implement, flexible and robust [9]. But scalability becomes an issue when the problem becomes large. A lot of attention has been drawn to the application of game theoretic techniques to problems in wireless sensor networks [10] (power control games, self organising networks); game theory is a set of tools that can be used to model interactions between agents with conflicting interests. Due to the large number of criteria and conflicting interests of nodes it is proposed to model the sensor network design optimisation problem as a game played by agents.

An Agent is an entity that can act, the features that distinguish an agent from a mere "program" include acting independently, having the ability to perceive its environment, persisting for a long period of time, adapting to change and being capable of taking on the goals of other agents [11]. A Rational Agent is one that acts to maximise its chances of success. When there is uncertainty then the best expected outcome must be achieved. For sensor network optimisation it is proposed to use a simple reflex, utility-based agent. The main components of an agent are environment percept, condition-action rules and utility function.

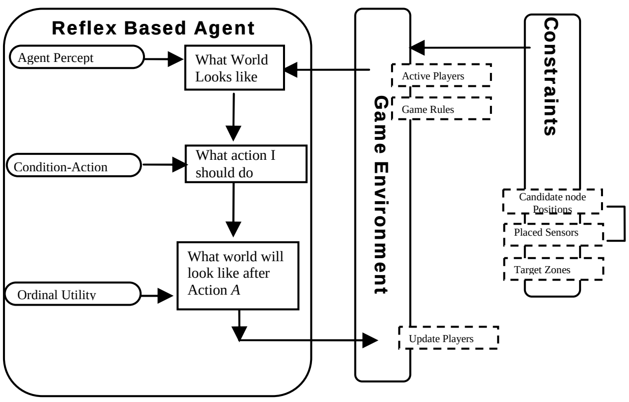

Figure 3 –Game Architecture for Sensor Network Design

Figure 3 shows the architecture of the optimisation environment. The constraints encapsulate all pre-processed information including candidate node positions, target zones, candidate sensor positions, as described in the previous section. The optimisation is modelled as an iterative game played by the agents competing to maximise their resources utilisation, for this problem the agent is comparable to a sink node attempting to maximise the number of associated sensor nodes. The game environment incorporates general rules pertaining to the game being played, such as agents should only move along edges of defined candidate node position mesh. The critical element of the game, shown in Figure 3, is the agent. The agent operates in a fully observable environment where it has sufficient facts about it; therefore a logical approach enables the agent to derive a plan that is guaranteed to work. Once the agent knows what the world looks like it can then use condition-action rules to establish a connection between agent percept and which action should be considered.

The following is a basic environment configuration used to demonstrate the approach. A game iteration begins with a single agent (triangle) randomly positioned within the candidate node positions. From this position the agent is aware of its communication range (based on propagation model as described in Section 3.2) and the sensors that are covered by this cell, the agent can evaluate the quality of the communication to these sensor nodes. Figure 4 shows the initial configuration with the agent, and sensor nodes coverage. As the agent is aware of the nodes that it can not successfully act as a gateway for, it can make a decision to add intermediate nodes to aid in the communication, creating a multi-hop mesh network. Figure 5 shows the addition of such nodes. At this position the agent can evaluate its utility function.

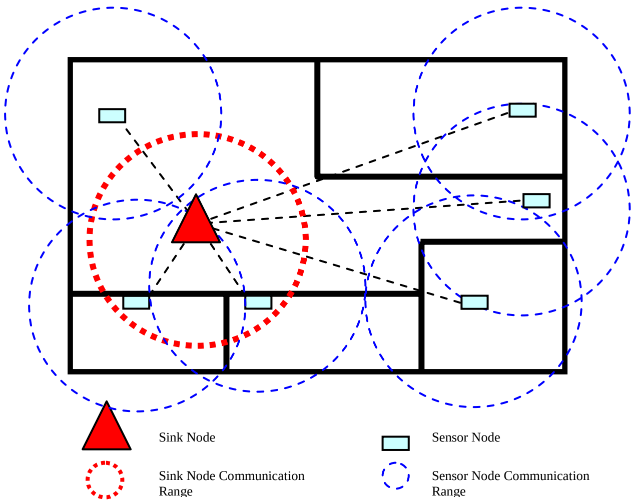

Figure 4 - Initial Configuration

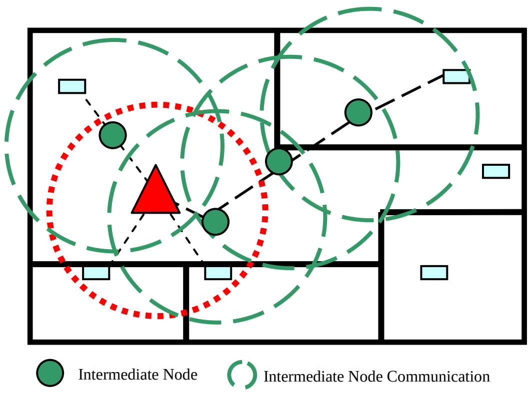

Figure 5 - Addition of Intermediary Nodes

3.4 Utility Function

The utility function is a mathematical representation of preferred outcomes, to show the degree of success of selected action. The goal of the agent is to maximise its utility, this makes agents rational – the only rational choice is an action which increases the agent's utility. The complex process of designing utility function that governs the success of achieving an optimal solution requires careful investigation, this is currently been undertaken, it is suggested at a minimum include the number of intermediate nodes, the number of hops and the quality of the communication. From the current position the choice of actions that are available to the agent are move to a neighbouring position from within the candidate access point grid or to split into two; enlisting another agent into the game to help achieve its goal.

Figure 6 demonstrates the outcome of a number of iterations. Due to the agent not being able to improve its utility by moving to the neighbouring position and the number of hops has exceeded the user defined maximum it made the rational choice of adding another agent to the game. After a number of move actions to improve utility two sink nodes should be deployed with a number of intermediate nodes to ensure reliable communication.

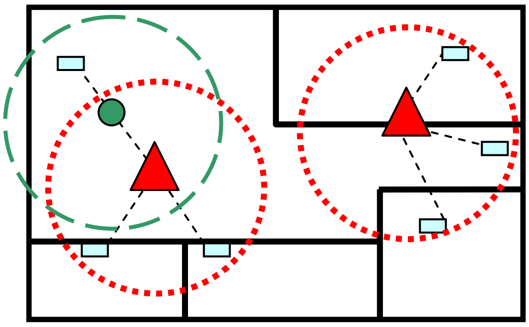

Figure 6 - Addition of another sink node

Initial implementation of the proposed optimisation technique only considers signal coverage and estimated throughput (designer defines throughput requirements throughout the building),

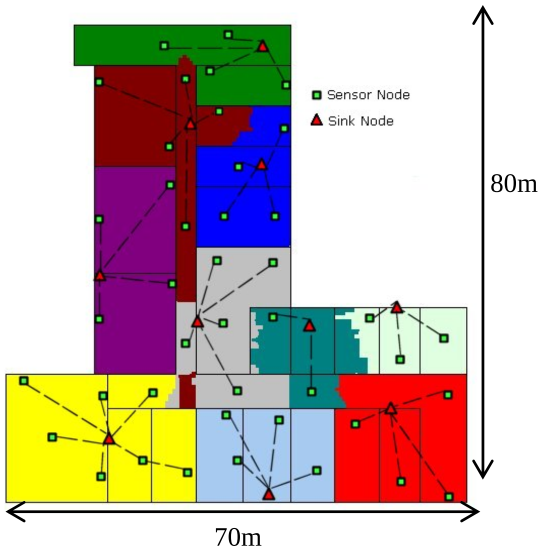

Figure 7 - Throughput optimisation of sink nodes

Figure 7 shows the suggested positions and coverage cells of sink nodes, where sensor nodes were randomly dispersed, no intermediate nodes were considered as part of the optimisation, based on the required throughput a sink node is assigned.

4 Conclusions

Presented here was initial research undertaken to develop of a design tool to aid a designer when deploying a wireless sensor network particularly for application to the development of a more cost effective, reliable and efficient wireless BMS. There is a lot of scope in this area that requires much attention particularly the definition of utility function for evaluation of a particular solution.

Acknowledgements

The authors wish to acknowledge the support of Enterprise Ireland under the Proof of Concept PC/2004/402 and Commercialisation Fund Technology Development TD/2006/330 projects in funding work reported in this paper.

References

[1] Morrissey, E. (2006a), Building Effectiveness Communication Ratios (BECs): An Integrated 'Life-Cycle' Methodology for Mitigating Energy-use in Buildings, Phd, University College Cork.

[2] Klaassen, C. J. (2001a), 'Installing bas sensors properly', HPAC Engineering August, 53–55.

[3] ASHRAE (2003b), Applications, ASRAE Publications, ASHRAE.

[4] Klaassen, C. J. (2001b), 'Selecting and specifying building automation system sensors', HPAC Engineering July, 64–66.

[5] Bernd Fritzke, "A Growing Neural Gas Network Learns Topologies". Advances in Neural Infoarmation Processing Systems 7, MIT Press, Cambridge MA, 1995

[6] T. M. Martinetz, K. J. Schulten, "*A "Neural-Gas" Network Learns Topologies*", In T. Kohonen, K. Mäkisara, O. Simula, and J. Kangas, (eds.), Artificial Neural Networks, pages 397-402. North-Holland, Amsterdam, 1991

[7] M. Klepal, P. Pechac, "Prediction of Wide-Band Parameters of Mobile Propagation Channel", XXVIIth URSI General Assembly the International Union of Radio Science, Maastricht, August 2002

[8] F. Osterlin and A. Dunkels, "Approaching the Maximum 802.15.4 Multi-hop Throughput", SICS Technical Report, May 2008

[9] R. M. Lewis, V. Torczon and M. W. Trosset, "Direct Search Methods: Then and Now" Journal of Computational and Applied Mathematics, Volume. 124, 2000

[10] A. B. MacKenzie, S. B. Wicker ,"Game Theory in Communications: Motivation, Explanation, and Application to Power Control" Global Telecommunications Conference, 2001

[11] Stuart Russell, Peter Norvig, "Artificial Intelligence, A Modern Approach", Second Edition, Prentice Hall, 2003