# THE RELIABILITY OF WIRELESS SENSORS IN BUILDING MANAGEMENT SYSTEMS

**Michael W. Bigrigg**[1]

## ABSTRACT

The greatest advance in building monitoring is through the use of wireless sensors, which can be pervasively deployed without requiring the installation of wiring. The biggest disadvantage to wireless sensors is the fragile nature of the communication system. Wireless sensor communication uses an ad hoc approach for communication, meaning that the sensors, in addition to being used for sensing, are used to help transfer data through the network. The configuration of the sensors placed in the building plays a critical role in the reliability of the sensor network. This paper identifies critical nodes that bear a greater responsibility in transferring data to the building management server by presenting an analytical study of the effects of building layout on the reliability of wireless sensor networks. The as-built model of a building is used as a case study to identify the critical sensors and the building configurations that will lead to a fragile sensor network.

## KEY WORDS

Wireless Sensors, Sensor Networks, Building Management, Reliability, Analytical Models.

## INTRODUCTION

With existing and emerging developments in sensor technology, sensors can now be pervasively placed in the environment to sense temperature, ambient light and other parameters required to monitor the building environment. The ability to continuously monitor the environment and to be able to store that information opens new opportunities in facilities resource planning, management and continuous commissioning. Wireless sensors collect data and return it to a central building management server. The reliability of the building management system is then directly related to the reliability of the sensor network.

The greatest advance in building monitoring is through the use of wireless sensors, which can be pervasively deployed without requiring the installation of wiring (Akyildiz 2002, Chong 2003, Culler 2004, Pottie 200, Tubaishat 2003). The biggest disadvantage to wireless sensors is the fragile nature of the communication system (Frye 2006). Wireless sensor communication uses an ad hoc approach for communication, meaning that the sensors, in addition to being used for sensing, are used to help transfer data through the network (Bao 2003, Chen 2001, Godfrey 2004, Hill 2004, Tubaishat 2003). Data is transferred to other sensors by moving the data closer and closer to the destination. The configuration of the sensors placed in the building plays a critical role in the reliability of the sensor network. We

[1] Project Scientist, Institute for Complex Engineered Systems, Carnegie Mellon University, Pittsburgh PA 15213, Phone +1 412/268-7668, bigrigg@cmu.edu

identify critical nodes that bear a greater responsibility in transferring data to the building management server.

We present an analytical study of the effects of building layout on the reliability of wireless sensor networks. We use the as-built models of the building as case studies to drive the development of our analysis technique. We identify the critical sensors and the building configurations that will lead to a fragile sensor network.

Sensor nodes can be considered critical when they play an important role in the transfer of data from the sensors to the building management server. Sensors that are used heavily may fail due to wear or the increased battery usage. There are sensors that due to their proximity to the building management server are important. Other sensors are critical as they are the only link between building sections.

## CASE STUDY

The built infrastructure of university buildings is used as a case study. They are a mix of structure (the building and office organization), mechanical (the heating, ventilation, and air conditioning systems), and computer (a deployed temperature sensor network) systems. This allows for the placement of sensor nodes to be based on the domain rather than a simple random distribution as is used to evaluate many wireless sensor algorithms.

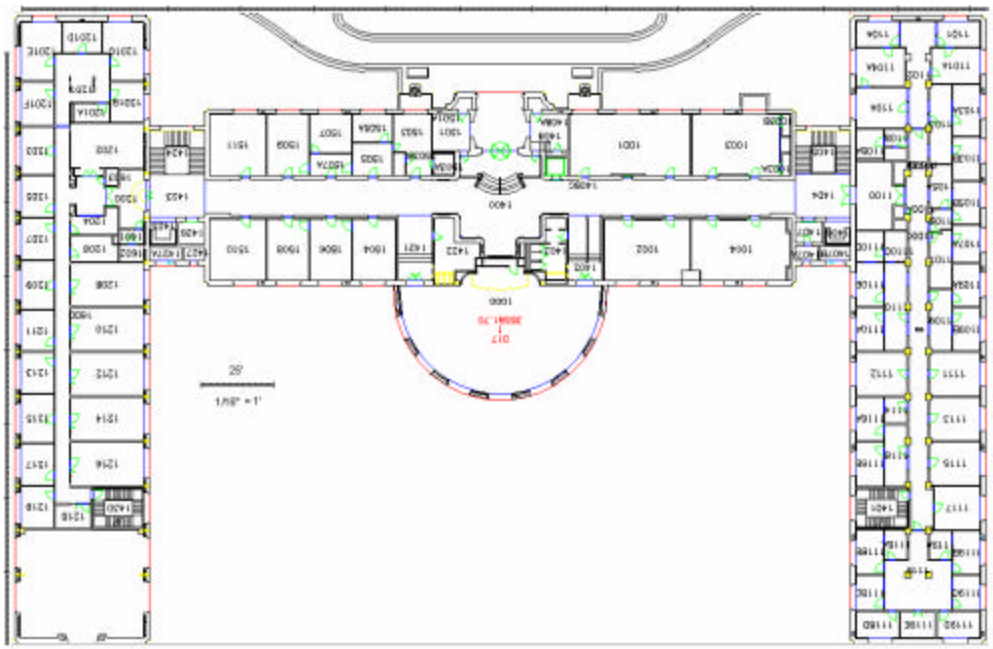

**Figure 1. Building Floor Layout**

Using real building, we built a simulated model of wireless sensor locations. An example of the data for this model is in Table 1. The light switch in many rooms has been replaced by occupancy sensors to control the lights when the room is not in use. A natural extension of this sensor configuration would link all the sensors together into a sensor network.

**Table 1. Example Distance Room Model**

| Room | X Dist | Y Dist | Z Dist |
|---|---|---|---|
| **1200** | 33 | 55 | 15.375 |
| **1201** | 17 | 27 | 15.375 |
| **1202** | 22 | 52 | 15.375 |
| **1203** | 11 | 40.5 | 15.375 |
| **1204** | 16.5 | 67 | 15.375 |
| **1205** | 11 | 60 | 15.375 |
| **1206** | 16.5 | 75 | 15.375 |
| **1207** | 11 | 72.5 | 15.375 |
| **1208** | 16.5 | 93 | 15.375 |
| **1209** | 11 | 86 | 15.375 |
| **1210** | 16.5 | 108 | 15.375 |
| **1211** | 11 | 105 | 15.375 |
| **1212** | 16.5 | 123 | 15.375 |
| **1213** | 11 | 117.5 | 15.375 |
| **1214** | 16.5 | 138 | 15.375 |
| **1215** | 11 | 131 | 15.375 |
| **1216** | 16.5 | 153 | 15.375 |
| **1201A** | 24.5 | 27 | 15.375 |
| **1201B** | 31.5 | 27 | 15.375 |
| **1201C** | 31.5 | 10.5 | 15.375 |
| **1201D** | 18 | 10.5 | 15.375 |
| **1201E** | 11 | 10.5 | 15.375 |

An ad-hoc sensor network uses intermediate sensor nodes between the origin and destination to help aid in the transmission of the data. This is in contrast to the more familiar infrastructure based routing where there is a dedicated set of access points, routers, and hubs that are responsible for transmitting the data to its destination. In a wireless ad-hoc sensor network, the sensor nodes will transmit their data wirelessly using radio frequency (RF) communication. The effect of this is a broadcast of the data to any other sensor nodes within reception range of the originating sensor. One large factor that influences the range is the amount of power that is used to transmit the data. Power, given that the sensor is battery powered, is one of the scarcest resources on a wireless sensor node.

Taking the model of wireless sensor locations, we identified the reachability of each sensor based on a reasonable power level and accounting for walls and other building material that would interfere with transmission. We developed an analytical approach to understand under what conditions the sensor network would be unable to route messages. Most sensor network routing algorithms have been developed using a random distribution of sensor nodes. Rooms within buildings are not uniformly distributed. The result was that with even a small number of failed nodes, the network partitioned.

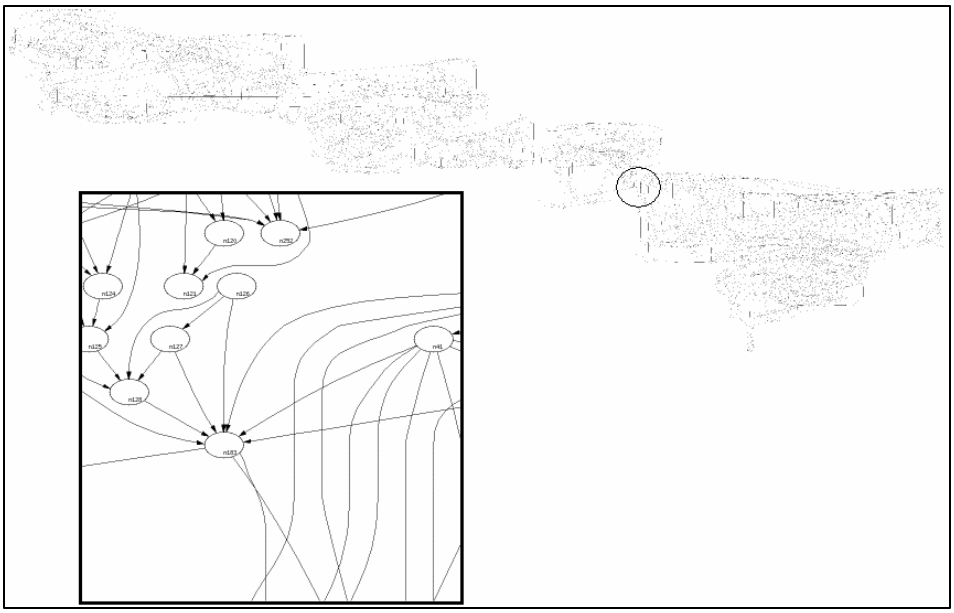

**Figure 2. Large Partitioning Single Gateway Node**

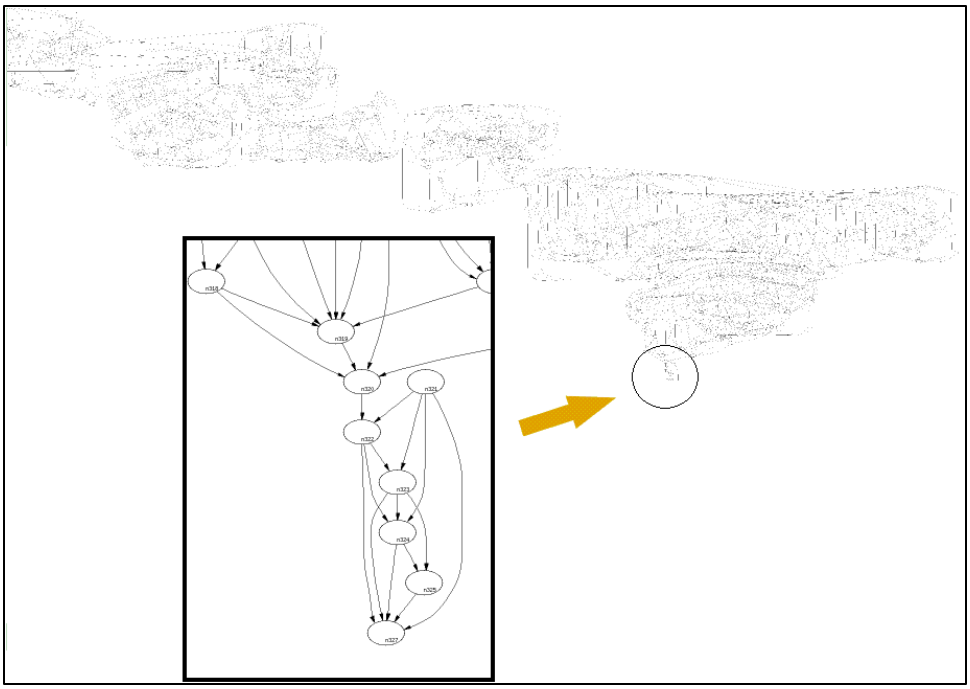

**Figure 3. Gateway with Potentially Isolated Nodes**

The sensor networks based on our building models were very fragile. Figure 2 and 3 each show a blow up section of the resulting sensor network connectivity graph. There were

many individual gateway nodes that would link one section of the network to another. Some were only gateways to smaller sub-networks such as in Figure 3. A few gateways link large sections of the network together.

## CONCLUSION

This paper presented a study of the effects of building layout on the reliability of wireless sensor networks. We used the as-built models of the building as case studies to drive the analysis technique. This study showed that a deployed wireless sensor network is likely to be very fragile. This use of wireless sensor network may not be feasible, as the reliability of the building management system is then directly related to the reliability of the sensor network.

## ACKNOWLEDGMENTS

This work is supported in part by the Pennsylvania Infrastructure Technology Alliance, a partnership of Carnegie Mellon, Lehigh University, and the Commonwealth of Pennsylvania's Department of Community and Economic Development (DCED). I would also like to thank Sean Salem and Joe Cahill for helping to create the building models.

## REFERENCES

I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "A survey of sensor networks", *IEEE Communications Magazine*, August 2002.

L. Bao and J. J. Garcia-Luna-Aceves, "Topology management in ad hoc networks", *ACM MobiHoc'*03, Annapolis, Maryland, June 1-3, 2003.

B. Chen, K. Jamieson, H. Balakrishnan, and R. Morris, "Span: an energy-efficient coordination algorithm for topology maintenance in ad hoc wireless networks", *Mobile Computing and Networking*, 2001.

C.-Y. Chong and S. P. Kumar, "Sensor networks: evolution, opportunities, and challenges", in *Proceedings of the IEEE*, Vol. 91, No. 8, August 2003.

D. Culler, D. Estrin and M. Srivastava, "Overview of sensor networks", *Computer*, August 2004.

L. Frye, L. Cheng, S. Du, and M. Bigrigg, "Topology Maintenance of Wireless Sensor Networks in Node Failure-prone Environments", *IEEE ICNSC'06*, Ft. Lauderdale, FL, April 23-25, 2006.

B. P. Godfrey and D. Ratajczak, "Naps: scalable, robust topology management in wireless ad hoc networks", *ACM ISPN* '04, Berkeley, CA, April 26-27 2004.

J. Hill, M. Horton, R. Kling and L. Krishnamurthy, "The platforms enabling wireless sensor networks", *Communications of the ACM*, Vol. 47, No. 6, June 2004.

G. J. Pottie and W. J. Kaiser, "Wireless integrated network sensors", *Communications of the ACM*, Vol. 43, No. 5, May 2000.

C. Schurgers, V. Tsiatsis, S. Ganeriwal and M. Srivastava, "Topology management for sensor networks: exploiting latency and density", *ACM MOBIHOC'*02, Lausanne, Switzerland, June 9-11 2002.

M. Tubaishat and S. Madria, "Sensor networks: an overview", *IEEE Potentials*, April/May 2003.