Wireless Sensor Network for Data Center Environmental Monitoring

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Wireless Sensor Network for Data-Center Environmental Monitoring

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Abstract— *Data centers' energy consumption has attracted global attention because of the fast growth of the information technology (IT) industry. Up to 60% of the energy consumed in a data center is used for cooling in wasteful ways as a result of lack of environmental information and overcompensated cooling systems. In this project, a wireless sensor network for data-enter environmental monitoring was developed to improve energy efficiency and to optimize data-center performance. The sensor network consists of a suite of sensor nodes for data sensing, a router node to relay sensed data, and a coordinator node to establish a network, receive the data, and process the data. The prototype sensor network was built on Arduino open source hardware with a seamlessly integrated XBee RF module and configured to operate within the ZigBee mesh network standard. A 24-hour test run at Argonne's data center demonstrated that the wireless networked environmental monitoring solution is easy to integrate and manage with the existing IT infrastructure, while delivering better visibility into the data center's 3D temperature and humidity distribution and substantial improvements in energy efficiency.*

Keywords- wireless sensor network, data center, environmental monitoring, ZigBee, energy efficiency management.

I. INTRODUCTION

Data centers' energy consumption has attracted global attention because of the fast growth of the information technology (IT) industry. According to a U.S. Environmental Protection Agency (EPA) report, U.S. data centers consumed 61 billion kilowatt-hours (kWh), or 1.5 percent of total U.S. electricity consumption in 2006, and this amount could potentially double by 2011 [1]. This forecast indicates that unless energy efficiency is improved beyond current trends, the federal government's electricity cost for servers and data centers could be nearly $740 million annually by 2011. Around 60 percent of the energy consumed in a data center goes to cooling in wasteful ways as a result of lack of environmental information and overcompensated cooling systems [2].

Another trend at data centers is that the heat density of computing systems has increased at an accelerated rate. This increase in heat density is brought about by the increasing density of computing resources, which yields more computing power consumption. Such consumption is expected to increase to values upwards of 6 kW per square foot of equipment for compute servers and over 10 kW per square foot of communication equipment by 2014, based on EPA projections [3].

Cooling in data centers is a challenge that cannot be solved with regular air conditioning methods. It has therefore become customary to employ specialized air-conditioning units that supply the computer racks with cold air from a raised floor plenum. Vents are located on the tiles, which are perforated and placed directly next to the rack, such that air flow may travel through it. The rack rows are placed in what is known as a hot aisle/cold aisle arrangement, consisting of aisles where air flow alternates between the cold air coming out of the floor and hot air exhaust exiting the room through ceiling return vents. The objective of this approach is to prevent the mixing of the cold and hot air streams, which would reduce the efficiency of the cooling process.

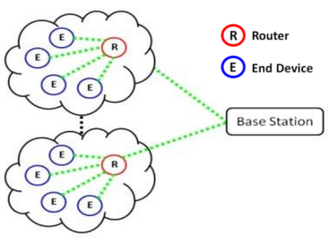
Much of the work performed for data-center efficiency improvement so far has focused on the development of analytical and numerical models to ensure that sufficient cooling is provided to all the facilities involved. This work includes case studies to model thermal maps after computer room air conditioning (CRAC) units become faulty [4]. Such analytical research is used to power tools that control and manage the cooling resources in computer machine rooms. Furthermore, studies have been made of the effect of the placement of the CRAC units on a data center's thermal map [5]. It has been established as well that the efficiency of data-center cooling processes can be increased by implementing automatic controls that respond to feedback from temperature sensors located at key locations throughout the data center [6]. The data collected from sensors, as well as knowledge of how environmental variables affect the conditions in the room, can be used to design control systems that can adjust the cooling resources, such as the fans and outlet temperatures, to maintain the room in its operating range. The Microsoft Research Group [7], for example, has changed wireless sensor networks for data centers using a string of sensors as workers to a transmitter. The workers were all wired to the master, which in turn polls the different sensors under it and broadcasts the readings to a base station.

Wireless sensor networks provide an optimal and integrated solution for distributed data collection, delivery and analysis in many applications including data-center environmental monitoring. In terms of a data-center application, the wireless sensor nodes are to be deployed in the preset locations, which include the computer racks and structural areas through the room (e.g., walls, tables, or other stationary locations) and at the air conditioner inlets and outlets. Also, mobile nodes may be placed for useful free-point data collection. These data collection points collect data according to which information is relevant in their specific location. For cooling purposes, temperature and humidity data will be collected, providing a real-time, high-resolution thermal map of the rack environment that could be used for dynamic controlling of the data center.

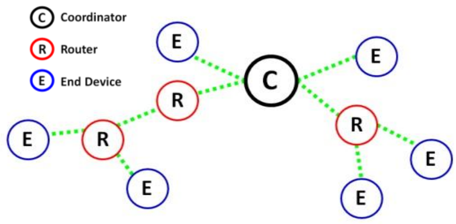
The objective of this research is to develop a wireless sensor network for data-center environmental monitoring in order to improve its energy efficiency and optimal data-center performance at Argonne National Laboratory. This real-time networked environmental monitoring solution should be easy to integrate and manage within existing IT infrastructure while delivering better visibility into the data center's thermal and power consumption profiles.

II. Network Architecture Design

A wireless sensor network consists of sensor nodes, interface circuit, power supply, and RF radio module. Compared with many short-range wireless communication protocols such as Bluetooth and WiFi, the ZigBee standard is more suitable for data-center environmental monitoring applications. In a data center, there are two areas of interest: the open area in the room and the rack inlet and outlet temperatures and humidity. The wireless sensor network in this study is designed having two different wireless network architectures, as shown in Figure 1. A multihop multipoint-to-point network design is to monitor the large area environmental profile inside the entire data center, and a multihop cluster network architecture is used to capture temperature and humidity information at a concentrated area of the rack. Each network is composed of a suite of sensor nodes to sense environmental information, a router node for relaying the sensed data, and a coordinator node to start the network, receive the data, and process the data. Software has been developed for managing the Arduino sensor interface, ZigBee wireless communication, and data management.



a. Multihop Cluster Network



b. Multihop Multipoint-to-Point Network

Fig.1 Architecture Diagram of Proposed Wireless Network.

III. Network Hardware Design

As the core of the wireless sensor network (WSN) hardware for data center environmental monitoring, the WSN node is usually composed of a series of basic sensing elements, sensor interface circuit, power supply, and a radio communication module.

A. Sensing Unit

The prototype wireless sensor network is used to monitor environmental data relevant to the cooling processes at a data center. For this purpose, Sensirion SHT15 temperature and humidity sensors are selected. This sensor employs a 2-wire interface and has a response time of less than 4 seconds and around 40 µW of power consumption.

B. Sensor Interface Unit

The Arduino Fio open source hardware is adopted as the sensor interface. This platform is based on AVR's ATMega 328P microcontroller, and the board houses 8 analog pins and 14 digital pins for input and output operations, supporting SPI and I2C communication on certain pins. The role of the microcontroller in the wireless sensor network is to poll the on-board sensor's data, arrange it using the developed packet protocol, and send it to the RF module to be transmitted to the route nodes. The data can be time stamped on board if necessary.

C. Wireless Communication Unit

The wireless sensor network is developed based on XBee 2.5 RF modules, which were engineered to operate within the IEEE 802.15.4/ZigBee protocol and support the needs of low-cost, low-power wireless sensor networks. ZigBee defines three device types. The coordinator is responsible for establishing the operating channel and personal area network (PAN) ID for an entire network. Once established, the coordinator can form a network by allowing routers and end devices to join to it. The router maintains network information and uses this information to determine the best route for a data packet. The end device always interacts with the parent nodes to receive or transmit data. The router can relay messages and allow the child node to connect to it. End nodes are intended to sleep periodically and therefore have no routing capacity.

XBee 2.5 RF modules support the use of the ZigBee standard, which provides a robust mesh networking architecture needed for the multihop multipoint-to-point network and multihop cluster hierarchy presented. This wireless module integrates seamlessly with the Arduino Fio board used as well. The RF module operates in the 2.4 GHz band with 16 direct sequence channels. Also, since the ZigBee standard is stacked on top of the IEEE 802.11.4 standard, it supports 16-bit and 64-bit addressing for each node. In total, each channel has 65,000 unique network addresses while supporting up to 250 kbps data rate. XBee modules consume 38-40 mA when transmitting and 35-40 mA when in receiving mode. Thus, the radio module is the most critical component of the wireless node from a power consumption viewpoint.

D. Power Supply

The prototype sensor node is powered by a 2000 mAh, 3.7V lithium polymer battery. This battery was selected because of its long battery life when taking into account the application and the fact that the Arduino Fio includes a lithium polymer battery port. Also, lithium polymer batteries are rechargeable, which is of interest for continued deployment in the data center.

IV. NETWORK SOFTWARE DESIGN

Three software products were developed for this wireless sensor network in order to establish the sensor interface, configure mesh network, and manage the sensed data for receiving, storing and displaying data.

A. Sensor Interface Software Design

The Arduino Fio open-source software reads temperature and humidity strings from the sensors, converts these strings into numerical values with specific data format, manages sensor ID, and develops a data packet to be sent to the RF module. Then, Arduino Fio is programmed by the Arduino Integrated Development Environment with FTDI USB cable. The Arduino open source software provides sensor interface programming to facilitate application development.

B. Zigbee RF Module Configuration

In order to realize the designed network architectures, XBee modules were configured to behave as coordinators, routers, and end devices depending of the circumstances. The XBee Series 2 is designed to add mesh networking to the underlying 802.15.4 radio. The mesh network consists of a coordinator node that receives data from its surrounding router/end nodes. The coordinator has the function of forming a network and is responsible for establishing the operating channel and PAN ID. Once established, the coordinator can form a network by allowing end devices to join to it. Since all XBee modules come with a default PAN ID, a unique PAN ID was assigned to each XBee module in order to avoid having a communication problem with other sensor networks in the same area. After choosing the correct function set by X-CTU, which is the XBee configuration software provided by the Digi website, the new configuration will be downloaded into the RF modules.

C. Data Management System Software Design

Three data management programs were developed by using the MATLAB programming language. The first program reads real-time data strings from coordinator nodes, converts them to numerical values, detects types of information (temperature or humidity), puts time stamps on each received sensor data, and saves the data into the database file. The second program organizes the database into separate temperature and humidity data files. The third program visualizes the sensed data. This is an easy-to-use graphic interface with a drop-down menu for selecting sensor nodes, and temperature or humidity files, and the program has a button to refresh the screen in order to show all the data in the same screen.

V. RESULTS AND DISCUSSIONS

Figure 2 shows 10 prototype networked wireless nodes with temperature and humidity sensors.

A. Key Features of the Developed Wireless Sensor Network

1) High Performance
   - Up to 100 m/indoor and 1.6 km/outdoor
   - RF data rate: 250 kbps
2) Low Power
   - Tx current: 295 mA @ 3.3 V
   - Rx current: 45 mA @ 3.3 V
   - Power down current (Idle mode): < 1 µA @25 ºC
3) *Advanced Networking Capability*
   - 16 channels
   - 65,000 unique network address
   - Self-routing, self-healing, fault-tolerant mesh network.
   - 16-bit unique physical address for each sensor node
4) Sleep Mode
   - Both pin sleep and cyclic sleep, allowing the RF module to enter states of low power consumption when not in use.

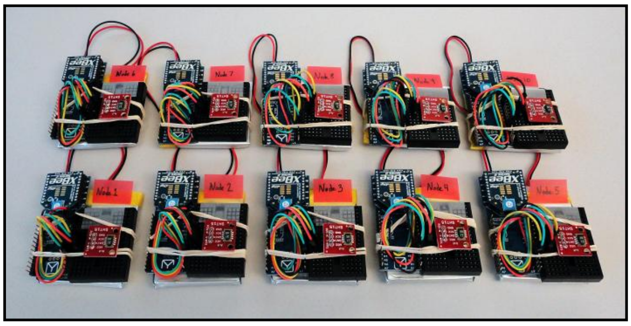


Fig. 2 Networked Wireless Nodes with Temperature and Humidity Sensors.

B. System Operation Verification

The data-center metal case environment, humidity conditions and arrangement of electronic equipment could affect the radio wave propagation of the developed wireless sensor network. To validate the reliable communication performance and packet loss rate, we conducted two 24-hour measurements. Figure 3 shows the deployment of the multihop multipoint-to-point sensor network at the data center and Figure 4 illustrates the multihop cluster network wireless sensor node deployed on one rack.

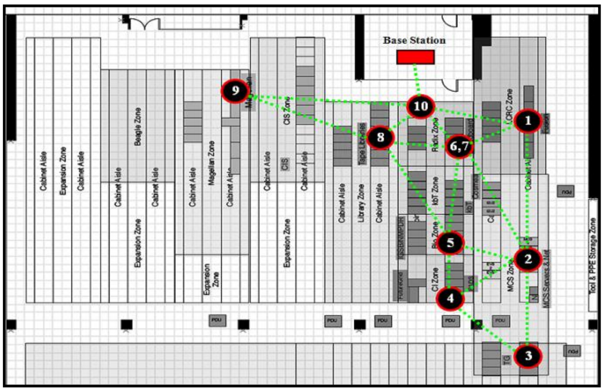
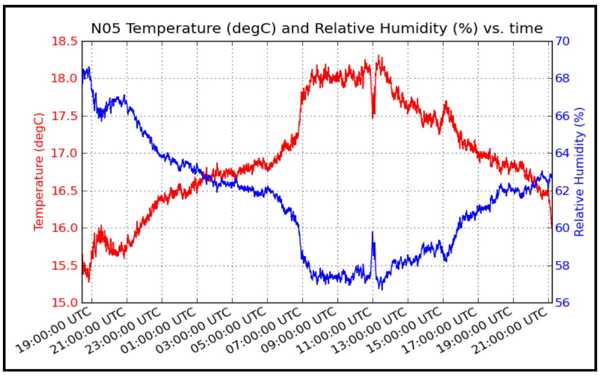
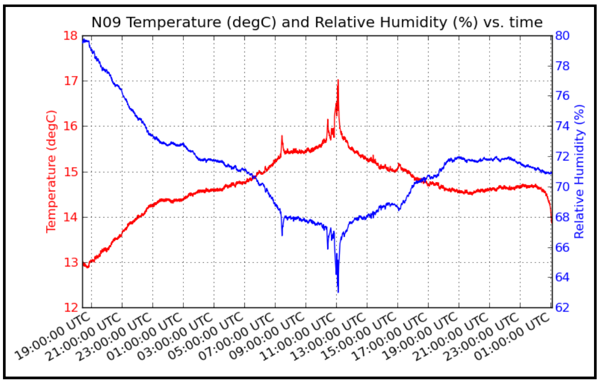


Fig.3 Deployment of Multihop Multipoint-to-Point Sensor Network at the Argonne Data Center.

Fig. 4 Wireless Sensor Nodes Deployed at the Argonne Data Center.



(a)



(b)

Fig. 5 Examples of Temperatures (Red Line) and Humidity (Blue Line) Readings from Node 5 (a) and Node 9 (b).

Examples of preliminary temperature and humidity monitoring results from node 5 and node 9 are given in Figure 5. The maximum data-center registered temperatures varied from 15°C to 32°C, and humidity values fluctuated from 28% to 72%.

This study demonstrates that wireless sensor networks can be an effective tool for environment monitoring in a data center. Such a network offers the advantage of easy deployment throughout the computer racks because there is no need of wiring for power and data transmission. This network also offer freedom in deployment, as the sensor modules can be placed in locations where wired sensors would be unfeasible for technical or safety reasons.

The performance of the wireless sensor network prototype inside a rack during the 24-hour run, from a data collection point of view, was shown to be effective. No data packets were lost during transmission.

Although this particular test lasted for about 24 hours, it was noticed that the temperature and humidity variations occurred between the zones. The results show that some areas of the data center are being chilled too much, while in others the cooling is not enough. Significant changes in humidity and temperature can cause timing, corrosion, and hygroscopic dust failures, and electrostatic discharge in data center equipment.

VI. Conclusions

A prototype wireless sensor network for data-center environmental monitoring has been developed. A 24-hour test run at Argonne's data center has demonstrated that the wireless networked environmental monitoring solution is easy to integrate and manage with the existing IT infrastructure, while delivering better visibility into the data center's 3D temperature and humidity distribution. Any type of analog or digital sensors can be added to this sensor network.

Collecting data to understand temperature and humidity distribution is a first step toward improving a data-center's energy efficiency. The ultimate goal of this project is to close the loop between large-scale sensing and distributed actuation, in order to dynamically change the environmental conditions and energy resource allocation in data centers. The developed wireless sensor network could also be used as a diagnostic tool to readily identify current data-center energy efficiency problems and help mitigate the cooling challenges of the data center.

ACKNOWLEDGMENT

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